Evaluation of a cocopeat-based hydroponic system for production of roses, *Rosa hybrida* in Naivasha, Kenya

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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To my parents and siblings for their continual support and love.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABBREVIATIONS AND ACRONYMS

GDP	Gross domestic product
KFC	Kenya Flower Council
KNBS	Kenya National Bureau of Statistics
HCDA	Horticultural Crops Development Authority
RH	Relative humidity
EC	Electrical conductivity
pH	Potential of hydrogen
CEC	Cation exchange capacity
GA_3	Gibberellic acid 3
SA	Salicylic acid
CCC	Cycocel Chlormequat Chloride

ABSTRACT

The cut flower industry is a key sub sector in the Kenyan economy due to its contribution to the national foreign exchange earnings. Rose flower is Kenya's leading cut flower in terms of production and export. Much of the production of this flower occurs around Lake Naivasha which is a major source of water for production. This lake has experienced declines in the water level and water quality in the recent past due to abstraction of large volumes of water and pollution by agrochemicals from the horticultural farms situated around it. Economic and social benefits derived from the lake can therefore only be sustained if there is sustainable utilization of the lake taking the declining levels of water into consideration. Mitigation measures may include recycling of water through hydroponics cultivation system. A study was carried out from January to December 2013 at a commercial rose farm in Naivasha called Van den Berg Roses, Kenya, to evaluate the potential of a cocopeat-based system, which additionally enables re-use of the drain water in a soil-based system. Vegetative growth in both systems was assessed in terms of leaf expansion, number of leaves, stem length, chlorophyll content (represented by the measured SPAD value) and flower head expansion. The number of stems produced, weight of stems, the proportion of stem classes, rejected stems and the vase life were used to assess the production quantity and quality. The water used throughout the year in both soil and cocopeat systems was also measured. Water volume drained from the cocopeat system, the nutrients contained in the water and its quality were also assessed. Finally, the economic benefit of rose production in cocopeat substrate was calculated. Leaf expansion was characterized by an initial slow expansion rate followed by a fast expansion rate before levelling off. Maximum leaf length reached was 63 mm in the cocopeat system, while it was 60 mm in soil system; however, the difference was not significant. The number of leaves produced did not differ between the soil and cocopeat systems. The maximum number of leaves per stem was 20 for both systems. There was no significant difference in stem length of plants in cocopeat system (650 mm) and in soil system (630 mm). Measured SPAD value on plants grown in the cocopeat system were significantly higher than for plants grown in soil ($P<0.01$). Flower head length and width showed no significant difference between the two systems ($P>0.01$). Net water use for the cocopeat system

was lower than for the soil system, with a difference of 1197 l m^{-2} or 58%, due to the re-use of water from the cocopeat system. There was a significant substrate effect on the number of stems per unit area (m^{-2}) and measured SPAD value, which could have resulted from the differences in leaf chlorophyll and nitrogen content in the plants. It is suggested that the optimized fertigation regime in cocopeat system led to higher growth rates and enabled higher stem production. Other growth and quality parameters such as unmarketable stems and vase life were not significantly affected by the substrate type under the same greenhouse climatic conditions. Cocopeat system performed better in terms of number, weight, and length of stems than soil system. It also resulted in a higher turnover in terms of water and fertilizers used due to the drainage water collected from the system being re-used in an adjacent soil system.

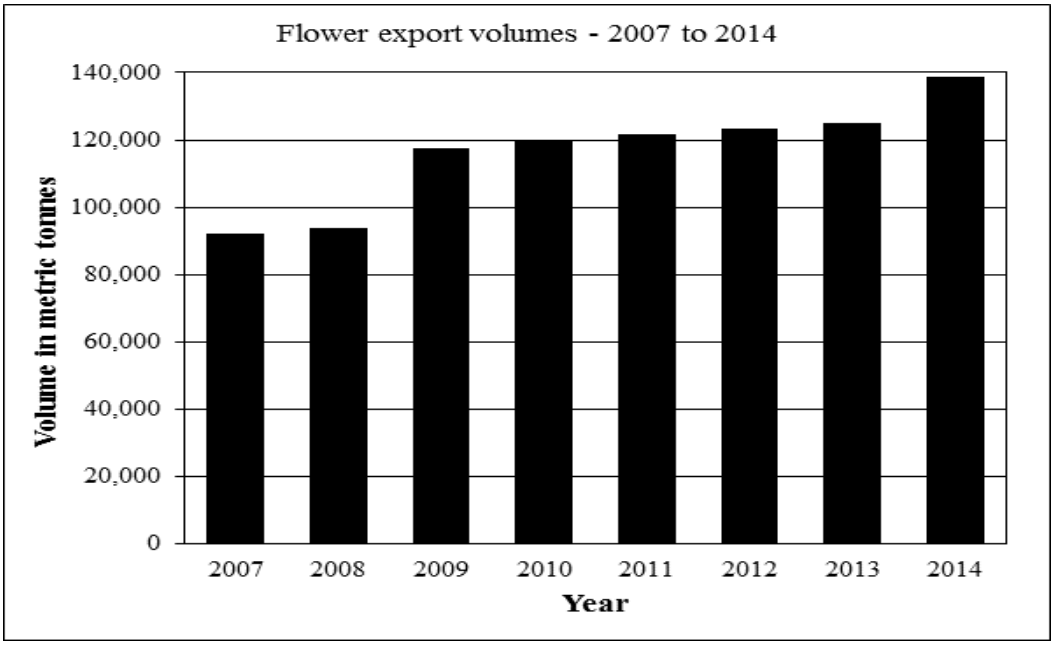
CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

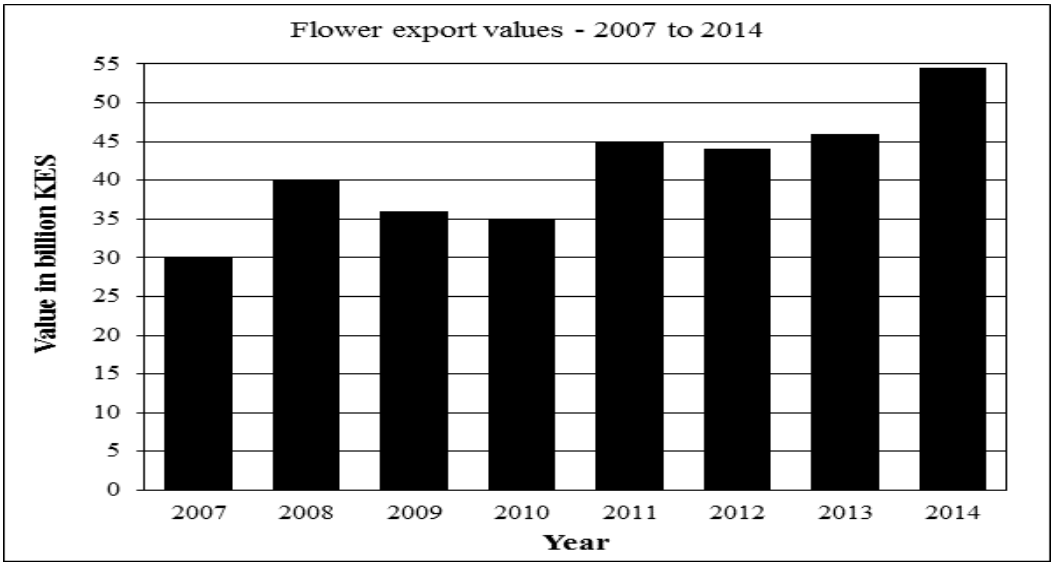
Agriculture is a key sector in Kenya's economy due to its contribution to the national foreign exchange earnings. For, example in 2014, it contributed 25.3% of the national Gross Domestic Product (GDP). In the same year, the horticulture sub-sector contributed 2.63% of the national GDP of which 1.29% was from the floriculture industry (KFC, 2015).

There has been a tremendous growth in volume and value of exported flowers in the floriculture industry over the years. For instance, 10,946 tons were exported in 1988 compared to 86,480 tons in 2006. According to Kenya Flower Council (KFC, 2015), exports weighed 117,713 tons, 120,220 tons, 121,891 tons, 123,511 tons and 124,858 tons in 2009, 2010, 2011, 2012 and 2013 respectively (Figure 1.1).



Source: KFC website, May 14, 2015 (http://kenyaflowercouncil.org)

Figure 1.1: Kenya flower export volume for the period 2007 to 2014



Source: KFC website, May 14, 2015 (http://kenyaflowercouncil.org)

Figure 1.2: Kenya flower export values for the period 2007 to 2014

According to the Kenya National Bureau of Statistics report of 2014 (KNBS, 2015), the floriculture industry exported 136, 601 tons valued at Kshs 54.6 billion (Figure 1.2) which was an increase of 9% from 2013 by volume.

In 2012, flowers from the cut flower industry, as shown in Table 1.1, fetched US$ 764 million in 2012 (HCDA, 2013). Rose is considered the most famous and popular cut flower in global floriculture trade and Kenya is one of its major producers and exporters. In 2012, roses contributed US$ 464 million representing 61% of the value of flowers exported from Kenya (HCDA, 2013).

Table 1.1: Export volumes and values of horticultural commodities from Kenya in 2012.

Commodity	Volumes (kg)	Value (US$)
Roses	88,000,000	464,000,000
Flowers	108,000,000	764,000,000
Vegetables	66,000,000	238,000,000
Fruits	31,000,000	55,000,000
Total	**293,000,000**	**1,521,000,000**

Source: HCDA Export Statistics, 2012 (http://www.hcda.or.ke)

The majority of cut-flower production for the period of 1996-2005, occurred around Lake Naivasha according to Becht (2007) and accounted for about 95% of total area under production (Becht, 2007). Recently, there have risen more areas under production such as Athi River, Kiambu and outskirts of Nairobi (Justus & Yu, 2014). Cut rose flowers are used extensively in expressing love and in interior decoration as well as during various occasions like marriage ceremonies, arrival and departure of different dignitaries, gifts on birthdays and Valentine's Day among others.

Use of soilless media has been shown by various researchers to be effective in terms of production quantity and quality of flowers and edible crops (Ghehsareh *et al.*, 2011; Ahmad *et al.*, 2012). A study to investigate the comparative effect of different potting media on vegetative and reproductive growth of *Antirrhinum majus* L. was undertaken in Faisalabad Pakistan. Results showed that plants grown using peat moss containing silt and top soil in the ratio of 1:1:1 showed positive results for vegetative and reproductive growth compared to the control which was silt and top soil (Mehmood *et al.*, 2013).

Water is the most important compound in an active plant and constitutes 80-90% of the fresh weight of most herbaceous plants (Kramer & Boyer, 1995). It is primarily needed for transpiration and the growth of plant organs, which largely consist of water. In general, a rose plant consists of about 75% of water. The rest is dry matter content which varies with variety and plant part (stem, leaf) (Van der Maden *et al.*, 2011). The largest part of the dry matter consists of organic compounds such as sugars, starch and cellulose, which are synthesized by the plant during photosynthesis (Van der Maden *et al.*, 2011).

Water is a scarce resource and is perhaps one of the most limiting factors for crop production. A good root environment should contain sufficient water with optimal nutrient concentrations but should be well-aerated to stimulate root growth. Deficient aeration of soil not only reduces root growth but also reduces the absorption of water and minerals (Kramer & Boyer, 1995). To meet the water requirements of plants, substrates with a low water retaining capacity require more frequent water supply. However, this will result in greater nutrient losses through leaching which would lead to nutrient deficiencies.

Water enters the plant from the soil via the root hairs, which provide a large surface area for absorption. Once inside the plant, it moves via the conducting elements of the xylem along a water potential gradient from soil to root, root to stem, stem to leaf, and leaf to air forming a continuum of water movement (Kirkham, 2011). The trend is for water to move from the region of higher water potential to the region of lower water potential, which is how water moves from soil to the air.

Lake Naivasha is a fresh lake among the Kenyan series of lakes within the Rift Valley which are lakes Turkana, Baringo, Bogoria, Nakuru, Elementeita, Naivasha and Magadi, running from the North to the South of the valley (Mavuti & Harper, 2006). The lake water remains fresh because of significant outflow of ground water and receives drainage from two perennial rivers. The rivers are Malewa, draining the Nyandarua (Aberdare) Mountains, and Gilgil, draining the Rift Valley escarpment ridges from the North (Harper *et al.*, 2011). The region around this lake has over three decades grown to be the major site of Kenya's horticulture, majorly cut flower production. Flower farms began expanding in acreage at a rapid rate in the late 1990s (Becht *et al*., 2005). Besides cut flowers, vegetables and fruits are produced for export and local markets with about 50% of all vegetable production exported and the remainder used locally.

There has been decline in the water level and water quality in Lake Naivasha. Large scale horticultural farms are seen as a threat to the lake (Kargbo *et al.*, 2010) due to abstraction of large volumes of water (Musota, 2008) and pollution by agrochemicals. Irrigated area increased steadily from 714 Ha in 1975 to 4467 Ha in 2006 and irrigation has been shown to take up 72% of total water abstracted from the lake (Musota, 2008). There were outcries from both local and international organizations keen to ensure sustainability of the lake leading to a management plan in 1996 and the creation of the Lake Naivasha Management Implementation Committee. With the onset of water reforms and subsequent enactment of water Act in 2002 (National Council for Law Reporting, 2012), there were radical changes to the water legal framework regarding its management (Mumma, 2005). The legal

framework included measures of managing the water resource in a more sustainable way and recognition of water as an economic good.

Modelling the lake Naivasha system was done in a research where crop water requirement and applied irrigation were compared. The results showed that the plants were supplied with more water than they needed (over irrigation), by approximately 120% for greenhouse flowers, 108% for open flowers and over 600% for open field vegetables (Musota, 2008). Therefore, while there is scope for water saving from greenhouse production, targeting vegetable production could result in greater benefits.

Water quality is affected by pollution from sources such as sewage discharge from the Municipal Council and agrochemicals from horticultural farms. The pollution of the lake water has been attributed to horticultural farms (Kargbo *et al.*, 2010). There is also application of fertilizers to vegetable farms hence mineral nutrition could be a pollution source as well. Mineral nutrition deteriorates water quality in a number of ways, namely: run off and erosion of nutrient loads resulting in eutrophication of surface water; leaching of fertilizers resulting in nitrate pollution of ground water; and pollution by trace elements which can cause heavy contamination of surface and ground water. Sewage effluents pollute the lake water through high levels of fecal material and organic matter which also accelerate the level of eutrophication of the surface water (Tang, 1999).

Crop yields can be increased through irrigation in areas where rain is insufficient like Naivasha, Kenya. Irrigation allows growers to apply water at the most beneficial times for the crop, instead of dependence on erratic rainfall. However, water for irrigation is becoming both scarce and expensive hence the necessity for its efficient utilization. Water saving irrigation practices could play a critical role in alleviating the problem of water shortage. This study sought to demonstrate the potential savings from a recycling system compared to a soil based non recycling system.

1.2 Statement of the problem

There is a worldwide need to conserve water in crop production and reduce the high cost of production. Kenya is recognized as a water scarce country by the National Development Plans (2002-2008, 2008-2012) whereby demand for water exceeds renewable fresh water sources (NDP 10, 2009). It is estimated that Kenya's per capita availability is at 647 m^3 and is further projected to fall to 245 m^3 per capita by the year 2025. This is far too below 1000 m^3 which is the recommended minimum (Muchapondwa, 2014).

Lake Naivasha has experienced fluctuations in its water level with a notable decline during some periods which has caused serious concerns to stakeholders. In addition, there has been decline in water quality of the lake. Though a fluctuating lake level is a natural phenomenon and essential for functioning of the lake ecosystem, the decline in the lake levels was attributed to the commencement and rapid expansion of the horticulture crops in the area (Becht & Harper, 2002; Becht *et al.*, 2005). It has been shown by Becht and Harper (2002) that in the late 1998, Lake Naivasha was lower by 3.5 m than it would have been had it followed the hydrological records. Modelling has shown that the lake levels were 0.7 cm lower in the high bed leakance model (leaky lakebed) and 7.5 cm lower in the low leakance model (sealed lakebed) in 2014 (Hogeboom *et al.*, 2015). Previous modelling by Van Oel *et al.* (2013) showed that lake levels were lowered by about 1 m in 2013 due to groundwater abstractions. The decline in water quality may be due to the inflow of nutrients from both the commercial farms and farm activities from the upper catchment and municipal sewage via surface run off. There is a danger that the lake may not withstand a continued increase in demand for irrigation water hence the need to devise measures to ensure sustainable use of the lake. Nutrients and contaminants reaching the lake lead to eutrophication and other negative effects to the lake. Economic and social benefits derived from the lake can therefore be sustained only if there is sustainable utilization of the lake which take the declining levels of water in the lake into consideration (Becht & Harper, 2002; Becht *et al.*, 2005). Mitigation measures may include recycling of water resources through a hydroponics cultivation system. A study was therefore initiated to introduce cocopeat based recycling hydroponic system for rose production.

The abstraction of water from the lake by farms lead to water footprint resulting from the cut flowers for export. This has been quantified as a virtual water export as 16 Mm^3 yr^{-1} during the period 1996-2005 (22% green water; 45% blue water, 33% grey water) (Mekonnen *et al.*, 2012).

1.3 Justification

Horticulture is one of the key sub sectors of the Kenyan economy and therefore strategies need to be explored to sustain and improve production. Determining the benefits of a soilless culture as an alternative to soil-based production in Kenya, an area which has not been adequately documented or researched widely, could help to enhance rose production in Naivasha due to higher output than presently possible through soil production. Horticulture profitability is driven by high output which translates to higher returns hence the need to shore up production and reduce costs. This can be achieved by research to provide scientific proof of the benefits realized from hydroponics-based production specifically in Naivasha area so that decisions can be made between the alternatives which will be economically viable and sustainable.

Efficient and sustainable water utilization is critical if the thriving floriculture or horticulture sub-sector is to be sustained. This study sought to determine the potential for recycling fertigation solution for production of roses. In particular, it sought to collect and provide information on the performance of the recycling hydroponic system for rose production in terms of growth, production and quality and benefit analysis. It was hoped that the results of the study would contribute to the understanding of rose production using recycling hydroponic systems. In the long term the study will contribute to the problem of water shortage and declining water quality in Lake Naivasha. The findings may be applied to other production situations.

Of specific interest of this study was to demonstrate that through the implementation of proper technology and management, water and nutrient use in protected cultivation systems can be reduced and production quantity and quality can be increased at the same time. Through water recycling, the system sought to reduce the water losses from the production

system. However, the use of the system requires evaluation to ascertain its operation and benefits accruing from water savings. It is also necessary to determine the costs and benefits aspects of the system. The quality of the drainage water also needs to be confirmed before reusing it to avoid any possible negative impacts. The main aim of this study was therefore to determine the possibility of using a soil-less culture comprised of cocopeat media while re-using the drainage collected from the system for rose production in Naivasha.

1.4 Hypotheses

The null hypotheses are:

1. There is no difference in growth, production and quality of roses grown in a water re-use system with cocopeat substrate compared with those grown in a soil-based cultivation system.
2. Large amounts of drainage water of good quality can be obtained from a water re-use system with cocopeat substrate in production of roses.
3. Drainage water obtained from a water re-use system with cocopeat substrate contain large amounts of nutrients.
4. Use of cocopeat substrate in rose production is more beneficial than use of soil as a media.

1.5 Objectives

1.5.1 Overall Objective

To assess the potential of a water re-use system with cocopeat substrate for rose production in Naivasha.

1.5.2 Specific objectives

1. To assess the growth, production and quality of roses in a water re-use system with cocopeat substrate in comparison with a soil-based cultivation system
2. To determine the quantity and quality of drainage water from a water re-use system with cocopeat substrate in rose production

3. To determine the amount of nutrients in drainage water from the water re-use system with cocopeat substrate
4. To determine the benefits of rose production in a water re-use system with cocopeat substrate in comparison with a soil-based cultivation system

CHAPTER TWO

2.0 REVIEW OF LITERATURE

2.1 Lake Naivasha Ecosystem

Lake Naivasha is a shallow fresh water lake situated approximately 80 km North-West of Nairobi in the Rift Valley of Kenya (0º 45′S, 36º 20′E) as shown in Figure 2.1. It receives an average rainfall of 600 mm year^{-1}. This lake is fed by two rivers namely Malewa and Gilgil which receive their waters from the highlands of Nyandarua Range and Bahati Escarpment (Musota, 2008).

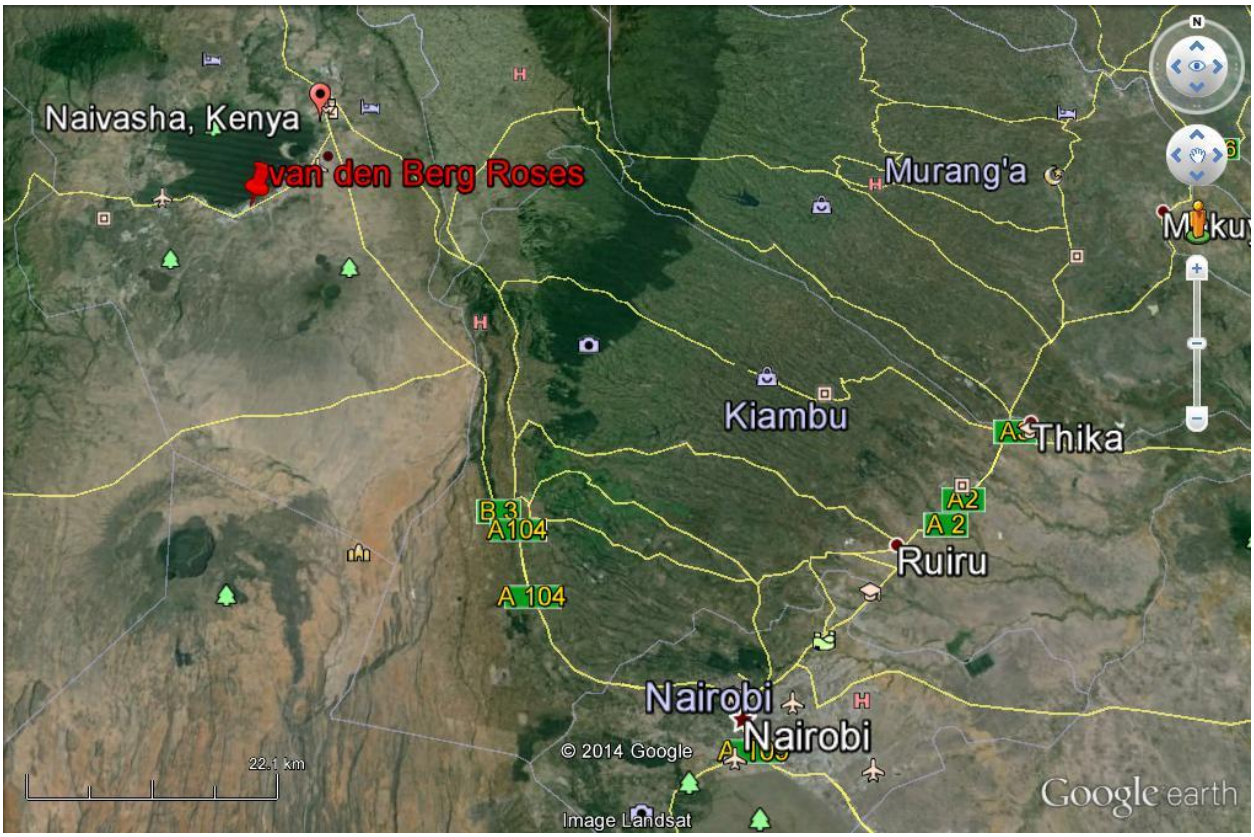
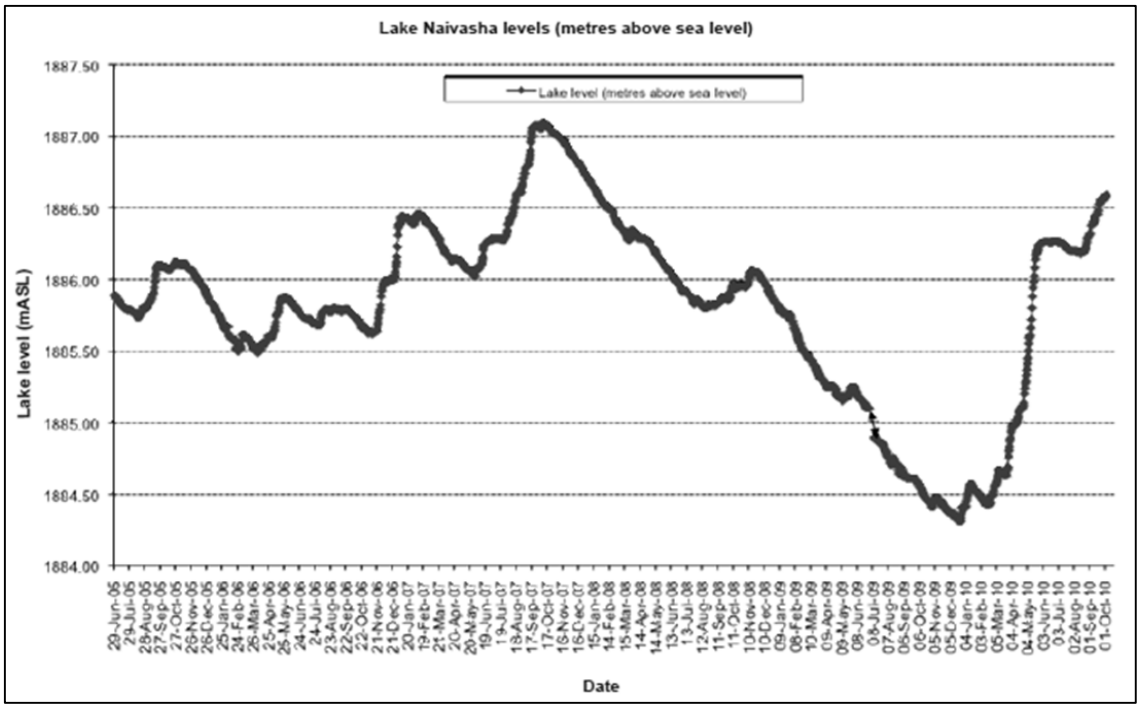


Figure 2.1: Naivasha, Kenya from Google Earth (https://earth.google.com)

Figure 2.2: Van den Berg Roses farm from Google Earth (https://earth.google.com)

Over the last century, the natural variation of the lake water level has been in excess of 12 meters (Mavuti & Harper, 2006). However, in the recent past the lake has recovered its level following high rainfall received in 2007 (Awange *et al.*, 2013). A study by Harper *et al.* (2011), conducted for the period June 2006 to October 2010, showed fluctuation of the lake level (Figure 2.3) due to over exploitation of the lake water for irrigation, geothermal power exploration and water abstraction for domestic supplies outside the catchment.



Source: Harper *et al.* (2011)

Figure 2.3: Lake level changes in Lake Naivasha between June 2006 and October 2010

Harper *et al.* (2011) continues to say that a prolonged drought in 2009-2010 further caused the lake level to recede to the lowest level since the late 1940s and this brought the concern to global attention.

The ecosystem of Lake Naivasha is characterized by a vibrant horticultural economy fully dependent on the water resources of the lake (Mekonnen *et al.*, 2012). The lake has been exploited for irrigation from the 1980s when the first farm was started from the South Western side of the lake and the success of this flower business resulted in upsurge of the horticultural activities in the area and the present occupation of the South Western shores of the lake with flower farms. The area under irrigation is estimated at 4,467 ha which includes 42.8% cut flowers, 40.8% vegetables, fodder at 14.9% and trees at 1.5% (Mekonnen *et al.*, 2012; Musota, 2008).

Over the past few years the lake has become eutrophic as shown by nutrient concentrations (Kitaka *et al.*, 2002a). Nutrient enrichment of the lake can be explained by inflow of

sediments and nutrients from the catchment due to increased small scale agriculture in the catchment area as population surges (Kitaka *et al.*, 2002a; Kitaka *et al.*, 2002b). Van den Berg Roses farm is situated on the shores of Southern part of the lake and therefore, is within its catchment (Figure 2.2). Subsistence cultivation on steep slopes of Nyandarua Range, Kinangop Plateau, Mau Escarpment and Bahati Escarpment, which initially had vegetation that could control soil erosion, can be linked to eutrophication of the lake. However, this does not absolve some horticultural companies that have destroyed buffer vegetation especially papyrus in lake basin area and those that cultivate right to the lake edge as well as using chemical sprays from blame (Becht & Harper, 2002; Becht *et al.*, 2005).

It is therefore important to devise ways of addressing the problem of horticultural production around Lake Naivasha to ensure sustainability. Previous studies recommended a water recycling system to alleviate pollution impact from farm to lake and reduce water consumption thereby saving the water resource (Tang, 1999).

2.2 Rose production

The cut-flower industry is a key sub sector in Kenya due to its contribution to the national earnings that averaged US$ 141 million (Kshs 10.1 billion) per year between 1996 and 2005 and about US$ 352 million (Kshs 26.7 billion) in 2005 alone (Mekonnen *et al.*, 2012). In 2014, the contribution of the cut-flower industry was Kshs 54.6 billion (KNBS, 2015).

Horticulture is currently Kenya's third most vital source of foreign exchange besides tea and tourism (KNBS, 2015). Rose is among the leading cut flowers whose international market share was estimated to increase at the rate of 5% annually (Chimonidou *et al.*, 2007). Other statistics estimated roses to contribute to over 70% of the export volume (Kargbo *et al.*, 2010; HCDA, 2007). In Israel, roses make up 15% of the exported ornamental production (Nirit *et al.*, 2006).

In Kenya, the major production zones of cut roses include Lake Naivasha, Kiambu, Limuru, Thika and Kericho (Kargbo *et al.*, 2010), with Lake Naivasha accounting for the

lion share of the produce and having about 95% of cultivated area (Mekonnen *et al*., 2012). Around Lake Naivasha, in the year 2006, irrigated rose production either alone or combined with hypericum or carnations covered 1779 Ha which represented 39.83% of total Lake Naivasha area under irrigation. The other percentage of 60.17% represented the area under irrigation of other crops such as vegetables, fodder, macadamia and eucalyptus (Musota, 2008; Mekonnen *et al.*, 2012). The floriculture industry comprises of the major flower varieties grown being roses, carnations, *Alstroemeria*, lisianthus, statice and cut foliage according to Mekonnen *et al.* (2012).

Rose belongs to family Rosaceae and genus Rosa, which contains 200 species and more than 18,000 cultivars (Gudin, 2000). Rose flower is considered one of the most intensively cultivated plant/ornamental per surface unit and water volume in the world (Chimonidou *et al.*, 2007).

Flower size and stem length are two important factors that dictate the value of cut-flower roses (Shin *et al.*, 2001). It is therefore important to understand how they are influenced by growing conditions. Stem length influences the economic value of the crop. Flowers are generally graded by length in 10 cm increments and an increase in the stem length could move a portion of the produce into the next higher grade (Ahmad, 2009). It has been shown that high temperature results in smaller flowers with fewer and smaller petals (Moe & Kristoffersen, 1969). It has also been shown that carbohydrate export rate of expanded leaves to the flowering shoot could be reduced by 80% under high temperature (Jiao & Grodzinski, 1998).

2.2.1 Hydroponic production systems

Hydroponics is a way of producing crops without the use of soil. Consideration of hydroponics as a means of commercial production of crops is due to the capability for growth of special high priced crops especially in greenhouses where there are poor soils or where production in soil conditions is highly expensive (Cuervo *et al.*, 2012). Infestation of soil beds by diseases in greenhouses or accumulation of toxic substances make soilless production a safer alternative. Other advantages include the possibility of controlling

nutrition levels hence lowering nutrition costs as well as stability and high yields coupled with reduction of nutrition pollution to the environment (Chimonidou *et al.*, 2007) since it is possible to apply nutrients based on the needs of the crop. The system also provides roots with a better growth environment.

2.2.2 Environmental conditions

Rose flower growth, production and quality are affected by climatic factors including light, temperature and relative humidity. According to Zieslin and Mor (1990), rose is a light intensive crop whose production is favored by an extended growing season with more sunny days. Low light intensity and duration reduce production and quality of roses and may lead to blind shoots (Zieslin & Mor, 1990). A high greenhouse relative humidity increases leaf size but it should be maintained at less than 75% (Zieslin & Mor, 1990). Roses are sensitive to pH and are susceptible to pH-induced chlorosis (De Kreij, 1995). They prefer a pH ranging from 5.5 to 7.

Air humidity can be expressed as absolute humidity (g/m^3), specific humidity (g water/kg air) or relative humidity (RH) which is the ratio between the mass of water vapour in the air and the mass it can hold at the saturation point. Vapour pressure deficit is the difference between the fully saturated atmosphere inside the leaf (100% RH) and the water vapour content outside the leaf. It is measured by comparisons of wet and dry bulb thermometers (Monteith & Unsworth, 2013). Vapour pressure deficit (VPD) provides a method of combining both relative humidity and temperature into a single number.

The ideal temperature for rose production is 20-25°C during the day and 13-16°C at night (Shin *et al.*, 2001). If average daily temperatures are below 15°C, stems become longer, bull heads are produced, and the period between flushes increases. Poor quality flowers with less number of petals are produced above 30°C (Lerner, *et al.*, 2003). Literature shows that an increase in temperature increases the rate of leaf initiation but decreases number of leaves and number of leaf primordia (Ahmad, 2009). In one study, it was reported that the number of days from bud to flowering increased from 21.6 to 63.0 days as temperature decreased from 30 to 15^{o}C in *Rosa hybrida* cv. Kardinal (Shin *et al.*, 2001). In addition leaf

area, stem length, chlorophyll contents and stem diameter generally increased with decreasing temperature, but the best quality stem was observed at 18ºC. Maximum flower yield, stem length and flower quality has been reported in plants grown at 23.9ºC day temperature (Holocomb & Tsinaraki, 1987).

For the same relative humidity, the VPD is higher at a higher temperature which increases transpiration. Nutrient uptake and photosynthesis are optimal at 4-8 mbar vapour pressure deficit. Transpiration is reduced when VPD is too low (very high humidity), and leaves may appear thicker and larger (Peet, 2005). Stems are also thick, but root systems may be weak and plants are more susceptible to diseases (Peet, 2005). Very high VPD (low humidity) results in stomatal closure due to excessive transpiration, stressing the plant (Peet, 2005). Though VPD cannot be completely controlled in greenhouses, increasing temperature, closing and opening the vents and air movement will generally increase VPD, while increasing irrigation water, misting and fogging will generally decrease VPD (Peet, 2005).

2.2.3 Substrates and rose production

The chemical condition of a growing substrate including pH, electrical conductivity (EC) and concentration of ions which influences plant growth are affected by the growing substrate (Cuervo *et al.,* 2012). In a study to determine nutrient uptake, growth and yield of cucumber cultivated on different growing substrates using closed and open hydroponic systems, the height, fresh weight and dry weight of plants grown in a closed system were higher than those cultivated in an open system except for cocopeat substrate (Choi *et al.*, 2001). The researchers also found that in cocopeat, the pH decrease was a little more than that in other substrates during the reproductive stage, from 5.8 at the beginning to 4.8 before harvest. In rockwool granulate, pH in the open system increased continuously from 5.8 at first stage to 6.7. The EC and pH were higher in the open system than in the closed system respectively.

In a closed hydroponic system with *Rosa hybrida,* the number of shoots harvested increased with increased irrigation frequency, with an average of 20.7 and 16.2 per

greenhouse m^{-2} for high and low irrigation frequencies, respectively (Katsoulas *et al.*, 2006). Irrigation frequency influenced cut flower fresh and dry weight. Substrate did not influence cumulative production of rose plants but productivity significantly differed among flower stem classes (Samartzidisa *et al.*, 2005). Rose flower is sensitive to salinity and salinity levels greater than 2.5 dS m^{-1} have been found to reduce growth, yield and quality of stems and flowers (Ahmad, 2009).

Mixed results have been obtained on performance of recirculating system for rose production. Raviv *et al.* (1998) found no differences in rose production or quality when comparing an open system with each of three different recirculating techniques. On the other hand Tsujita and Roberts (1995) reported that roses were less vigorous when grown in recirculation as compared to those in open system, the effect becoming more pronounced with the passage of time. The reduction in vigour in the recirculating system was attributed to potential changes in mineral balance or concentration which could influence the plants. It was also speculated that pH could have an effect. Change of 1 unit in pH can alter the availability and uptake of several essential nutrients (Mengel & Kirkby, 1987), particularly for plants such as roses which are susceptible to pH-induced chlorosis (De Kreij, 1995).

A study found that growing media affected yield and quality of roses (Fascella & Zizzo, 2005). It also affected water consumption and mineral nutrient availability. In the study perlite/coir dust mixed in the ratio of 1:1 had the highest amount of flowers (17.7 stems $plant^{-1}$) and the longest stems (65 cm) compared to pure perlite. Water consumption was 0.78 and 0.62 L/plant/day for plants in perlite and in perlite/coir, respectively. The superiority of the substrate mixture was attributed to higher water holding capacity and cation exchange capacity (CEC) of coconut dust. In carnations, polyurethane ether sponge produced taller plants and higher yield than rockwool substrate while differences in flower stem length was not significant (Lévai *et al.*, 2010).

Rose plant is categorized as a salt sensitive species, with yield and quality reductions reported when the EC of the saturated soil paste is ≥ 3 dS m^{-1} (Ahmad *et al.*, 2013). With nutrient solution used for irrigation being within $1 - 2$ dS m^{-1} range it is easy to reach and

surpass the above limit resulting in reduced growth, production and quality of roses. Flower yield and vase life were affected by EC in *Rosa hybrida* cv. Sonia grown in soilless conditions (Ahmad *et al.*, 2013). Shoot elongation in *Rosa hybrida* cv. 'Lambada' was negatively correlated with sodium concentration (Lorenzo *et al.*, 2000). Reduction in growth, yield and quality of roses by high EC was attributed to blockage of vascular system that restricted water uptake. This could result in water stress which would cause loss of cell turgor and reduction in leaf expansion rates (Jones, 1992). Consequently, reduction in leaf area available for photosynthesis could cause a loss of yield and quality (Kool & Lenssen, 1997).

A study was carried out in Faisalabad Pakistan to determine the substrate salinity effects on growth, yield and quality on *Rosa hybrida*. Results showed that the number of leaves branch^{-1}, leaf area, leaf total chlorophyll contents, bud diameter, flower diameter and flower quality were greater when plants were grown at 0.4 dS m^{-1} salinity compared to 2.5 dS m^{-1}, 5.0 dS m^{-1}, 7.5 dS m^{-1} and 10.0 dS m^{-1}, while plant height, number of flowers plant^{-1} flush^{-1}, fresh and dry weight of a flower, flower stem length and diameter were higher with 2.5 dS m^{-1} substrate salinity compared to 0.4 dS m^{-1}, 5.0 dS m^{-1}, 7.5 dS m^{-1} and 10.0 dS m^{-1} (Ahmad *et al.*, 2013). From the study it was concluded that roses should be grown below 2.5 dS m^{-1}.

2.3 Cocopeat substrate

Also referred to as coir dust (Verhagen, 1999), coco peat is a spongy like by-product of fibre processing from coconut (Abad *et al.*, 2005; Cresswell, 2007). It consists of short fibres and cork like particles. Coco peat is produced from various countries including Sri Lanka, Costa Rica, India, Ivory Coast, the Philippines, Indonesia, Malaysia, New Guinea, Fiji, Samoa and Thailand (Abad *et al.*, 2005; Cresswell, 2007). It is used as an alternative to peat. It strongly absorbs liquids and gases as a result of honey comb structure that gives it a high surface area per unit volume. It easily wets even when dry and has strong capillarity which ensures easy spread of water within its matrix. It is stable when moist and does not collapse when wetted nor shrink when dried. Cocopeat has been shown to wet

within 7 min compared to 19 min for peat (Abad *et al.*, 2005). However, cocopeat has been shown to have variable physical properties (water supply and availability, aeration and relative hydraulic conductivity) depending on the country of origin due to the differences in the particle density distribution caused by differences in processing methods (Abad *et al.*, 2005). Chemically, cocopeat has high CEC which can lead to nutrient imbalance within the root zone and affect availability of nutrients (Verhagen, 1999).

Cocopeat has been widely used as a substrate in horticultural production. In Iran, cocopeat (70%) combined with perlite (30%) was used to grow roses for studying the effect of levels of GA_3 (Gibberellic acid 3), SA (Salicylic acid) and CCC (Cycocel Chlormequat Chloride) on the quality and yield performance of rose cv. 'Poison' (Hashemabadi & Mohammad, 2010). In another study in Iran, cocopeat alone or in combination with perlite performed better than other media types for rose production (Rezaee *et al.*, 2013). On the other hand use of cocopeat either alone or combined with peat did not perform better than loam soil in terms of shoot dry weight of oriental lily in California, USA (Merhaut and Newman, 2005). However, leaching of NO_3^- in pure cocopeat was less compared to loam soil and cocopeat mixed with peat. In Brazil, cocopeat is used as a premium substrate for trays and plugs with several gerbera growers substituting soil with cocopeat (Mathias, 2006). In a study in India, cocopeat either alone or combined with perlite did not perform as well as peat or perlite alone or combined for gerbera production (Khalaj *et al.*, 2011). Cocopeat mixed with perlite performed better than perlite alone for rose production in Italy (Fascella and Zizzo, 2005).

Various studies have been carried out in Kenya by utilizing cocopeat media as substrate (Ketter *et al.*, 2013; Kipngeno *et al.*, 2015 and Gechemba *et al.*, 2015) to achieve the best results. This media is organic and can stimulate root growth and provide high water holding capacity which provide a buffer in high temperatures and crop load demand without compromising supply of air (Galukucocopeat, 2011). Cocopeat is available in Kenya though in small quantities by various companies, for example Kocos Kenya Ltd that sells coir fibre at US$ 135 per metric tonne (Danda *et al.*, 2006).

2.4 Recycling of resources in hydroponic systems

Large amounts of resources used in horticultural production can be collected and reused in the production system. In the Netherlands, it was found that 40-80% of nutrients applied to crop production was leached beyond the root zone causing the Dutch government to impose a policy that required growers to adopt recirculation systems (Heinen & de Willingen, 1999). Re-use of substrate can contribute to savings and sustainability of production. Studies showed that it was possible to reuse rock wool after steam pasteurization in hydroponics for rose production without decline in yield and quality (Jeong and Hwang, 2001). In the same study, higher amounts of pinewood chips lowered yields. In a simulation study, it was observed that sodium did not affect the CEC of the substrate significantly in recirculation system using rock wool (Heinen & de Willingen, 1999).

2.5 Hydroponics system and diseases

One reason that justifies the change from soil culture to substrate cultivation is the proliferation of diseases (Cuervo *et al.*, 2012). Soil as a substrate has been shown to harbor pathogens which make it necessary to use alternative substrates. For instance, soils were found to harbor viruses that infect rose (Sweet, 1975). In the Netherlands change from soil to substrate production was done to overcome soil borne pathogens such as *Gnomonia radicola* and *Phytophthora* species (Amsing, 1995). However, it has been shown that *Gnomonia radicola* and *phytophthora* fungi can be dispersed by drain water in rockwool hydroponic system (Amsing, 1995) indicating the need to treat drainage water from the production system before usage. Nematodes have also been reported to occur in soilless production systems (Hallmann *et al.*, 2005).

2.6 Water productivity (WP)

Water productivity (WP) is the ratio between the output of a crop and the amount of water consumed expressed as crop production per unit volume of water (Perry *et al.*, 2009; Ali & Talukder, 2008). The growing competition for water among several sectors from domestic to industrial, calls for efficient water management approaches. This can be

achieved by growers by increasing crop WP so as to achieve efficient and effective use of water (Ali & Talukder, 2008).

2.7 Vase life of rose cut flower

Literature available on the vase life of roses shows that it is affected by relative humidity and photoperiod. In a study done with roses from Punjab in Pakistan vase life reduced from 8 to 2 days with slight increase in air humidity while increasing the photoperiod from 16-24 h day $^{-1}$ at 65% relative humidity reduced the vase life from 13 to 8 days (Ahmad, 2009). In a different study, vapour pressure deficit (VPD) and potassium to calcium ratio (K: Ca) also affected vase life (Mortensen *et al.*, 2001). Vase life was reduced by 3 days when VPD decreased from 720 Pa to 220 Pa. The vase life was increased by 9 days when the K:Ca ratio was decreased from highest to lowest (Mortensen *et al.*, 2001). Plants grown at high relative humidity accumulated less Ca in leaves and flowers than moderate relative humidity plants (Ahmad, 2009). Roses grown at moderate relative humidity had a longer vase life than high relative humidity roses, irrespective of the K/Ca ratio of the nutrient solution (Ahmad, 2009).

In regard to other factors that affect vase life of rose, variety 'Poison' was not significantly affected by different growth regulators but it varied between 8.5 days and 12.7 days (Hashemabadi & Mohammad, 2010). Vase life of roses grown with treated waste water in Israel did not vary significantly among different substrates including coco peat and it ranged from 9 to 15 days (Nirit *et al.*, 2006).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Site

The study was carried out in a commercial rose farm in Naivasha, Kenya called Van den Berg Roses which lies at the shores of the southern part of Lake Naivasha. Lake Naivasha (00º40′S – 00º53′S, 36º15′E – 36º30′E) is situated in the Eastern African Rift Valley at an altitude of 1890 m above sea level. It lies approximately 80 km northwest of the Kenyan capital city, Nairobi. Its basin lies within the semi-arid belt of Kenya with mean annual rainfall varying from about 600 mm at the Naivasha township to some 1700 mm along the slopes of the Nyandarua mountains (Awange *et al*., 2013), with open water evaporation estimated to be approximately 172 cm/year (Becht *et al.*, 2005).

3.2 Experimental site

Rosa hybrida cv. Upperclass was planted in a greenhouse between weeks 29 and 34, with 19th August 2012 as average date at Van den Berg Roses. The greenhouse was a gutter connect type of metal framework and completely covered with a glazing material of polyethylene. The sides of the greenhouse were covered with insect nets from inside and polyethylene from the outside. They were retractable allowing for manual opening of side vents for natural ventilation when greenhouse temperatures and relative humidity increased. Roof vents were installed for further ventilation and were opened and closed automatically.

Drip lines supplied irrigation water via drip system of 20 cm spacing at the plant root base. Irrigation water was mixed with fertilizers using a Fertilizer mixer and the solution pumped into large tanks called silos that were placed inside the greenhouse. Other technology such as heating the greenhouse and the plant beds, forced ventilation by fans and modification of greenhouse environment by screens were not used in the experiment.

The greenhouses were fitted with data sensors that collected weather information such as radiation, relative humidity, wind speed, wind direction and temperature (Day and night temperature). The weather sensors (Hoogendoorn Growth Management, Vlaardingen, the Netherlands), placed inside an Aspirator box and raised at the centre of the greenhouse at 10 cm above the plants, transmitted weather data to a central computer. The sensors also measured the EC and pH of irrigation water and drainage water and sent to the central computer. All the data was stored in an iSii process computer (Hoogendoorn Growth Management, Vlaardingen, the Netherlands) with version 4.0 software, retrieved weekly and used in analysis.

3.3 Experimental design

There were two treatments, soil system and cocopeat system. The area of 1.6 ha of cocopeat substrate and 1.6 ha of soil was planted. Rose plants in the soil were grown on raised beds on the ground while those on the cocopeat in slabs raised 30 cm above the ground. There were a total of 224 rows of 100 m long for each treatment. Between and within-row plant spacing was 40 cm and 20 cm, respectively, in both systems resulting in a plant density of 7.3 plants m^{-2} in each treatment.

A completely randomized design was used where three sample areas measuring 121 m^2 each per treatment were randomly selected and demarcated for crop measurements. Each sample area consisted of 900 plants.

3.4 Data collection

3.4.1 Determination of weather data

Temperature (^oC), daily radiation (J cm^{-2}) and relative air humidity (%) were assessed. These were recorded at 5 min interval by data sensors (Hoogendoorn Growth Management, Vlaardingen, the Netherlands) in an aspirator box. Daily values of minimum, average and maximum temperature and relative air humidity as well as monthly values were calculated for the experimental period. Daily and monthly minimum, maximum, average and radiation sum were computed from the daily measurements of radiation.

Vapour pressure deficit (VPD) was calculated from relative humidity and temperature by following FAO guidelines (Allen *et al.*, 1998) as follows:

$$VPD = Es - Ea \qquad \text{Equation 1}$$

$$E_a = 0.6107 * e^{(17.4*T_{air}/T_{air}+239)} \qquad \text{Equation 2}$$

$$Ea = RH/100 * Es \qquad \text{Equation 3}$$

VPD = vapour pressure deficit (kPa)

RH = relative air humidity (%)

Es = saturated vapour pressure at ambient air temperature (kPa)

Ea = actual vapour pressure at ambient air temperature (kPa)

T_{air} = actual air temperature (^oC)

3.4.2 Determination of plant growth, yield and quality

Crop measurements were taken in the three randomly selected sampling areas. Plant growth was assessed in terms of leaf length, stem length and number of leaves. For leaf length, leaves of approximately equal size were sampled and tagged. The length of each leaf was taken daily until the leaves reached maximum length when no more increase in length was recorded. Several leaf samples were taken to represent the different growth periods during the year. Stem length and number of leaves were determined on tagged shoots of approximately same initial height. In addition, flower buds were tagged and their diameter measured using Vernier calipers daily for assessment of their expansion. Chlorophyll content was measured using a SPAD meter (SPAD-502Plus, KONICA MINOLTA, Sensing Europe). Production was determined in terms of fresh stem weight (kg m^{-2}) and number of stems per m^2.

Stem quality was determined in terms of weight per stem and stem length. Mature flower stems were harvested daily and taken to the pack-house where they were sorted in length classes of 30 cm, 40 cm, 50 cm, 60 cm, 70 cm and 80 cm. The stems were counted and

weighed separately per length class. Daily values were accumulated over the experimental period. In addition, the weight per stem was measured.

Stems were rejected in the postharvest section if they did not meet the standards for export. The quantity of these stems was daily recorded which included rejected stems from both the greenhouse and the grading hall. The cause of rejection was divided into four: diseases, pests, morphological causes and mechanical damage.

The vase life was determined using a protocol that was developed by Van den Berg (commercial farm where the project was undertaken) and the VBN (the Dutch Flower Auctions Association, website www.vbn.nl) as follows:

1. The stems were harvested from the field, sorted by stem length and 30 stems of 40cm selected for each treatment.
2. The stems were placed in the receiving cold store (4.5^{o}C) for 3 hours then bunched per treatment and cut approximately 2 cm at the stem base (to let the stems be on the same level).
3. The stems were packed in the box and placed in the packing cold store (2^{o}C) for 2 days (dry packing) to mimic the road and the air transport conditions (transport simulation).
4. The stems were then cut 2 cm at the base (to minimize embolism and occlusion) and placed in a bucket with Chrysal RVB^{TM} vase life storage solution containing aluminium sulphate, paltine and bovine in the receiving cold store (4.5^{o}C) for 2 days for depot simulation.
5. The stems were then sleeved and placed into buckets with water and pre-treatment (Chrysal RVB^{TM}) in a cold store (2^{o}C) and left for 4 days to simulate transport to the retailer (transport simulation).
6. The stems were placed in the vase life room (19^{o}C) in the buckets with water and a Chrysal RVB T-bag (a slow release food with some anti-bacterial properties) and left to stand there for 2 days to mimic the retail shop (retail simulation).
7. The stems in the vase life room (19^{o}C) were put in vases containing Chrysal RVB^{TM} for customer simulation.

8. In the vase life room, the stems were left to open normally as at the customer's premises. The number of days taken before senescence was recorded and inferences made.

9. Steps 1 to 8 were repeated three times.

Vase life of individual flowers was considered to have ended when either (1) flower opening was halted; (2) the flower had a bent neck (an angle of 90º or more); (3) one or more petals fell; (4) the flower showed one or more brown (necrotic) spots due to *Botrytis cinerea* infection or downy mildew; or (5) when fading signs became visible on most of petals (Pompodakis, 2003;Van der Sman *et al.*, 1996).

3.4.3 Fertigation

A fertigation system was used to apply nutrient solution through a drip irrigation in both soil and cocopeat systems. Irrigation water was obtained from an 80 m deep well nearby that was purified by use of multimedia filtration and reverse osmosis. After mixing water with nutrients in a fertigation unit, the nutrient solution was fed to the crop in the cocopeat system. The drain water was collected in a drainage pit and added to the volume of water going to the soil system (Figure 3.1). Soil fertigation had a mixture of borehole water purified by reverse osmosis, fertilizers and drain water from the cocopeat system.

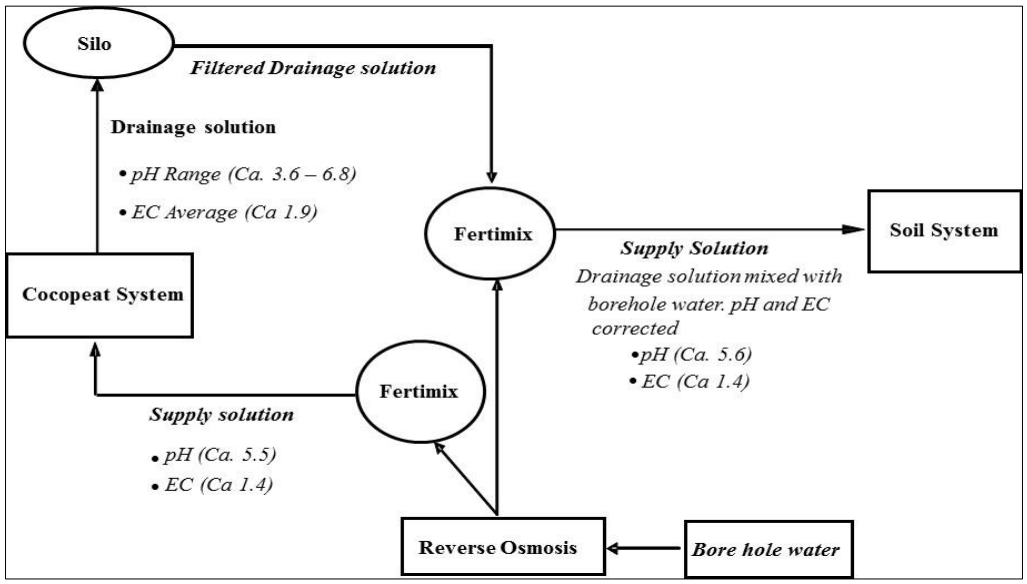


Figure 3.1: Schematic representation of the water flow in the experimental setup

3.4.4 Determination of water use and savings

The flow of water in the system began at the borehole where water was pumped into the reverse osmosis plant for purification by multimedia filtration and reverse osmosis. Water was then mixed with fertilizers in the mixing tanks and pumped to tanks in the greenhouse for day storage. This mixture was then applied to rose crop in cocopeat system via drip irrigation. The drain water collected was purified by multimedia filtration and added to the volume of water going to soil system. This volume was therefore a mixture of borehole water purified by reverse osmosis, fertilizers and drain water from the cocopeat system (Figure 3.1).

The cocopeat and soil systems had the same component, water, which came into each system by water application and went out through four means: crop transpiration, fresh growth, soil evaporation and drainage (Figure 3.2). The rose plants in cocopeat system lost water by evaporation (albeit very small quantities as the substrate was covered by plastic), transpiration and fresh growth while those in soil lost by evaporation, transpiration, fresh growth and drainage.

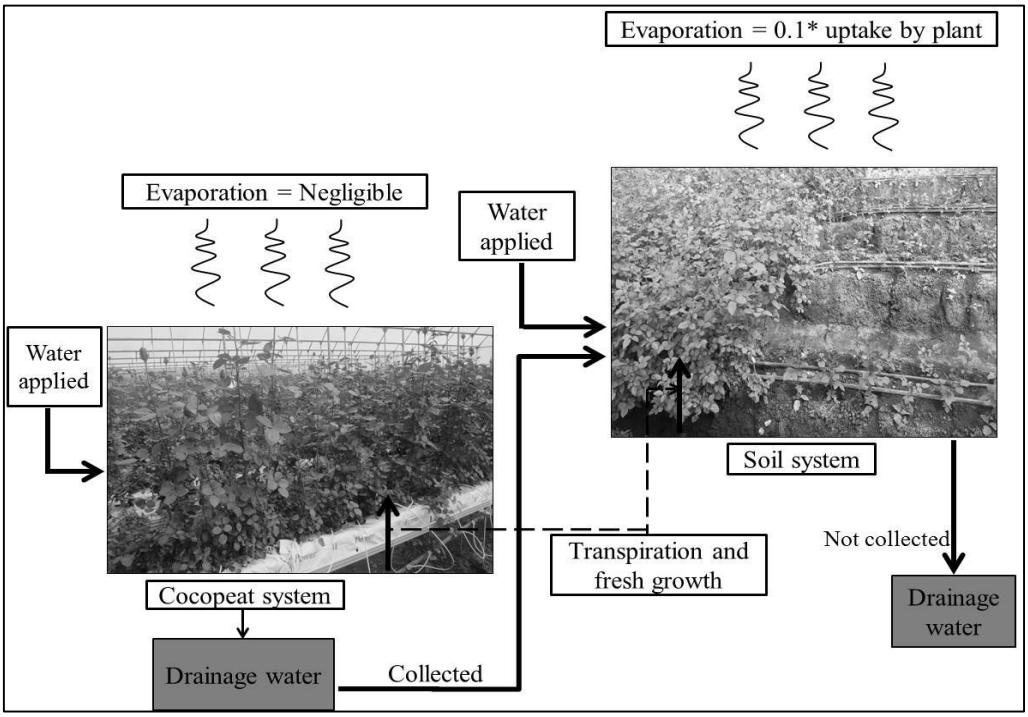


Figure 3.2: Graphical representation of water movement in the system

Evaporation from the cocopeat system was considered negligible because the growth media was enclosed in a grow bag except the point where the stem emerged from. Drainage water was collected from the cocopeat system but not from the soil system. Water drained from the soil system was estimated using formulas that were developed according to Equations 4a and 4b.

$$W_{na,h} = W_{ga,h} - W_{d,h} \qquad \text{Equation 4a}$$

$$W_{u,h} = W_{na,h} \qquad \text{Equation 4b}$$

Where:

$W_{u,h} = Water\ uptake\ by\ crop, hydroponics$

$W_{ga,h} = Water\ gross\ application, hydroponics$

$W_{na,h} = Water\ net\ application, hydroponics$

$W_{d,h} = Water\ drained, hydroponics$

A step used in calculation of water in soil and cocopeat systems was summarized as in table 3.1 below:

Table 3.1: Steps of calculation of water in the system

Water flow	**Cocopeat**	**Soil**
Application (supply)	**Step 1**: Observation	**Step 5**: Observation
Drain	**Step 2**: Observation	**Step 8**: Application – Evaporation - Uptake
Evaporation	**Step 3**: = 0	**Step 7**: = 0.1 * (Uptake by plant)
Uptake by the plant = (Transpiration + Fresh growth)	**Step 4**: = Application – Drain - Evaporation	**Step 6**: =0.9* (Supply-Drain) in cocopeat

Settings were made in the computer on a daily basis for number of cycles of irrigation per day and amount of water per cycle, in l m^{-2} based on amount of radiation received. The cycles refer to the number of times of irrigation per day and they varied from 10 cycles to 18 cycles in cocopeat system and 3 cycles to 6 cycles in soil system for the experimental

period. The cycles in cocopeat system were set at approximately 0.5 l m^{-2} whereas those of the soil were set at 1.0 l m^{-2}.

This data was received and stored as the amount of irrigation water supplied, the number of irrigation cycles given and amount of drain water. Amounts of water applied to both systems, and drained by the cocopeat system were obtained from the fertigation computer. Net water use by the cocopeat system was determined as the difference between the amounts applied and drained.

Net water use for the soil system was determined as the amount of water applied, since drain water could not be recovered. The difference in amounts of net water use was defined as the water savings for the cocopeat system compared to the soil. The drain from soil system was calculated as follows as per the developed formulas:

$$W_{u,s} = W_{a,s} - W_{e,s} - W_{d,s} \qquad \text{Equation 5}$$
$$W_{u,s} = 0.9 * W_{u,h}$$
$$W_{e,s} = 0.1 * W_{u,h}$$
$$W_{d,s} = W_{a,s} - W_{e,s} - W_{u,s}$$

Where:

$W_{u,s} = Water\ uptake\ by\ crop, soil$
$W_{e,s} = Water\ evaporation, soil$
$W_{a,s} = Water\ application, soil$
$W_{d,s} = Water\ drained, soil$

From observations in rose production units, soil evaporation was assumed to be 10% of the plant water uptake in cocopeat system while water uptake by the plants in soil was assumed to be 90% of water uptake by the crop in the cocopeat system. This is based on observations by researchers at Wageningen UR (Elings, pers. comm.). Finally, water drained was computed as the difference between water applied, and plant water uptake and evaporation. Monthly and annual averages for daily water savings were calculated as percentage of the water applied.

To understand the influence of radiation on water supply and use, days with highest and lowest radiation were identified and the water supply and use determined over the day. For the dry season and the rainy (cloudy) season, the months of February and June were used, respectively. These months were taken to represent seasons since the radiation received throughout the year differed for every month.

3.4.5 Determination of drainage water quality

The quality of drainage water was assessed to determine whether it could be recycled. The quality parameters determined included:

EC and pH of drainage water: The EC and pH of the drain water were monitored regularly by Van den Berg's laboratory services provider (Relab den Haan BV, Lookwatering 62635 EA DEN HOORN, The Netherlands, www.denhaan.nl). Data from the consulting company was used to assess the trends in EC and pH trends of the drainage solution.

Nutrient content of drainage water: Elemental nutrients were monitored by the laboratory services provider and data used to assess the trends in EC and pH trends of the drainage solution. The analysis was done for N, P and K which are the key elements.

Microbial contaminants of drainage water: To assess the safety of the drain water, samples from the cocopeat system were taken and analyzed in the laboratory for presence of pathogens common to cause soil borne diseases in roses. These included bacteria such as *Agrobacterium tumefaciens* and *Pseudomonas* spp., fungi such as *Alternaria* spp., *Fusarium* spp. and *Phytophthora* spp. and nematodes such as free-living root nematodes (*Helicotylenchus* spp.), virus transmitting nematodes (*Xiphinema* spp., *Longidorus* spp., *Paratrichodorus* spp.), root-knot nematodes (*Meloidogyne* spp.), root-lesion nematodes (*Pratylenchus* spp.), burrowing nematodes (*Radopholus similis*) and saprophytic nematodes.

The number of free-living nematodes was determined by the Van den Berg's laboratory services provider per 100 ml substrate by means of the Oostenbrink method which uses

Oostenbrink's reproduction factor R = Pf/Pi, where Pi = the initial inoculum level and Pf = the final inoculum level (Oostenbrink, 1966).

The scale for the number of observed fungi, bacterium and nematodes was provided by the farm's laboratory service provider.

Number observed can be classified per class as follows:

a) **(For fungi and bacterium)**

1 Starting infection

2 Light infection

3 Moderate infection

4 Infected

5 Severely infected

6Very severely infected

b) **Harmful nematodes and the Action**

0-59	No visible damage in the crop, consider a treatment with a nematicide
60-159	Damage is visible in your crop. Do a treatment with a nematicide
160-more	Serious damage in your crop. Do a treatment right away

3.4.6 Water productivity

Water productivity (WP) was presented in terms of weight of stems and number of stems. In terms of weight of stems, WP was calculated as a ratio of cumulative fresh weight of stems and cumulative water used in production at the end of the year in g m^{-2} l^{-1}. In terms of number of stems, WP was calculated as the ratio of cumulative number of stems and cumulative water used in production at the end of the year in stems m^{-2} l^{-1}. This was done for both systems separately. Water used for cocopeat system was the amount of water applied less the drainage, and for the soil system it was simply the amount of water applied.

3.4.7 Substrate characteristics

The main physical properties and the chemical characteristics of soil were assessed. Bulk density, water holding capacity, pH and CEC were also assessed. Amount of cations (NH_4^+, K^+, Na^+, Ca^{2+} and Mg^{2+}), anions (NO_3^-, Cl^-, SO_4^{2-} HCO_3^- and $H_2PO_4^-$) and micro elements (Fe, Mn, Zn, B and Cu) were also assessed.

3.4.7.1 Hydroponics (cocopeat)

The cocopeat growth media was supplied in blocks by Van der Knaap (Aalsmeer, the Netherlands, www.vanderknaap.info). Its brand name is Forteco Power Substrate 60 of block size 100/12/12 in length, width and height in cm, respectively. The total water holding capacity at saturation was 9.5 liters of water per growbag. Forteco Power 60 is a growbag, made of crushed husk and fine coco material, which was excellent for vegetative and generative steering of the crop.

Figure 3.3: Cocopeat bag holding the media

Physical properties and chemical characteristics of the cocopeat medium were determined by the manufacturer. These are presented in Table 3.2 and Table 3.3.

Table 3.2: Physical properties of cocopeat medium

Property	**Analysis**
Moisture content dry material (w/w)	< 20%
Water absorption capacity of 1 kg dry material	6.8 l
Air filled porosity at saturation (slab height of 7.5 cm)	23.5 (± 2.5) volume %
Air filled porosity at saturation (slab height of 10 cm)	26.0 (± 2.5) volume %

The EC was lowered by washing the material and this resulted to:

EC ≤0.5 mS cm^{-1} and pH-H_2O of 5.5-7.0

Table 3.3: Chemical characteristics of cocopeat medium

Cations	mmol l^{-1}	mg l^{-1} (ppm)	**Anions**	mmol l^{-1}	mg l^{-1} (ppm)	**Micro elements**	µmol l^{-1}	mg l^{-1} (ppm)
NH_4^+(N)	< 0.1	< 2	**NO_3^-(N)**	< 0.2	< 12	**Fe^{3+}**	< 40	< 2.2
K^+	< 3.0	< 117	**Cl^-**	< 3.0	< 106	**Mn^{2+}**	< 10	< 0.5
Na^+	< 2.0	< 46	**SO_4^{2-}**	< 0.3	< 10	**Zn^{2+}**	< 10	< 0.7
Ca^{2+}	< 0.3	< 12	**HCO_3^-**	< 0.5	< 31	**B^{3+}**	< 40	< 0.4
Mg^{2+}	< 0.3	< 7	**P^{3-}**	< 0.2	< 6	**Cu^{2+}**	< 5	< 0.3

3.4.7.2 Soil at the experimental area

Secondary data from researches already done were used to determine the soil type at the Van den Berg Roses where the experiment was laid.

Various researches have been carried out on soils in Naivasha, Kenya. Sombroek *et al.*, (1982) indicated that soils distribution in Lake Naivasha area is complex and is influenced by intensive variation in climate, relief, underlying rocks and volcanic activities. There are seven major landscape units in the Lake Naivasha area: lacustrine plain, volcanic plain, hilland, high plateau, low plateau, step-faulted plateau and volcanic lava-flow plateau (Girma *et al.*, 2001).

The southern part of Lake Naivasha is dominated by two types of quaternary deposits, one of which is lacustrine and the other volcanic in origin (Thompson and Dodson, 1963). The older deposit vary in composition but largely comprises fine white ash with intercalations of pumaceous gravels deposited in lacustrine conditions during the various phases of the Gambian lake (Gatahi, 1986).

According to Kwacha (1998), the types of soils found in the study area are Haplic Luvisols and Eutric Cambisols. Haplic Fluvisols dominate on the lacustrine plain and Haplic Andosols dominate on the volcanic plain (FAO, 1988). In addition, according to Gatahi (1986), Lithic Regosols and Ando-calcaric Regosols dominate on the volcanic plain while Calcaric Fluvisols dominates on the lacustrine plain.

A soil survey by Girma (2001) was carried out in Naivasha area with Sher-Agency farm being part of the survey which is an adjacent farm to Van den Berg Roses. According to Girma (2001), the soil in this survey was Sodi-Fluvic Cambisol (Skeletic, Eutric) following the characterization by WRB (1998) with the diagnostic criteria being Ochric A and Cambic B-horizon. The depth of the profile was very deep and the soil well drained.

Secondary data was used to determine the soil type at the Van den Berg Roses where the experiment was laid out since this soil was not imported from elsewhere and Cambisols soil types were described by Gatahi (1986). Profile description by Gatahi (1986) of Calcic Cambisol began by a general description which showed that the soils were well drained, very deep, dark greyish brown sandy loam soils. They had a weakly developed A-B-C horizon sequence with a sodic subsoil. There were $CaCO_3$ concretions and pumice gravels whose quantity increased with depth. The horizon transitions were clear and smooth. A-horizon had a colour of dark greyish brown (10YR 4/2) and B-horizon of dark greyish brown to yellowish brown (10YR 4/2 to 10YR 5/6). The texture of A-horizon was sandy loam and sandy loam to gravelly sandy loam in B-horizon. The structure of A-horizon was porous massive to weak fine subangular and B-horizon was weak fine subangular to porous massive in lower subsoil (Gatahi, 1986).

A profile description of 0-12 cm was that the soils were very dark greyish brown (10YR 4/2, dry; 10YR 3/2, moist); sandy loam; porous massive to weak, fine subangular blocky structure; slightly hard when dry; friable when moist, sticky and plastic when wet; abundant very fine to fine pores, common very fine to fine roots pH-8.8 and clear and wavy boundary. Depth of 12-77 cm was that the soils were dark greyish brown (10YR5/2, dry, 10YR 4/2, moist); sandy loam; weak, fine subangular blocky structure; slightly hard when dry, friable when moist, sticky and plastic when wet; abundant fine pores; slightly calcareous, very few, very fine to fine roots; pH 7.9; clear and wavy transition. The chemical description within the depth of 0-30 cm, pH-H_2O was found to be 6.5, percentage of Carbon (C) was 1.19 and percentage of Nitrogen (N) was 0.18. The available nutrients

in milli equivalent (me) per 100g was 0.2 for Sodium (Na), 1.55 for Potassium (K), 8.0 for Calcium (Ca), 2.0 for Magnesium (Mg) and 0.28 for Manganese (Mn) (Gatahi, 1986).

3.4.8 Benefit analysis

The scope of benefit analysis of the cocopeat system was defined to be the benefit from marketed stems and from fertilizers in the drainage water. This was as a result of limitations arising from the experimental site being a commercial private flower farm. Restricted information was available from the farm owner and data on cost of cocopeat system hardware, installation costs, labour costs and cost of pests and diseases was confidential.

The calculation of fertilizers in the drain was done by use of nutrient analysis in the drain from laboratory results. The benefits analysis was done by following the procedures in Table 3.4.

Table 3.4: Steps of benefit analysis

Fertilizer in drain	**Financial savings**
Step 1: Convert nutrient content to g l^{-1}	**Step 4**: = Amount of fertilizer in drain
Step 2: Sum up all the nutrients in drain to form concentration	**Step 5**: =Fertilizer in drain X average fertilizer price
Step 3: Concentration of fertilizer in drain X drain volume for whole year	**Step 6**: =Marketed stems X price of stem length

Due to re-use of drain water, the fertilizers used in cocopeat system was computed as fertilizers applied minus fertilizers in the drain. On the other hand, fertilizers used in the soil system were computed as simply fertilizers applied plus fertilizers from drain water.

The cut flowers turnover per unit area was calculated for both systems and the difference was computed.

3.5 Data analysis

The differences in plant growth, yield and quality between hydroponic and soil production system was assessed using a 2-tailed t-test using Genstat Version 14 (Nelder, 2011). The influence of weather parameters (temperature, radiation and RH) on the growth in the two production system was assessed through regression analysis using Genstat Version 14 (Nelder, 2011).

CHAPTER FOUR

4.0 RESULTS

4.1 Weather

Greenhouse and outdoor temperature, relative humidity and radiation were collected and mean, maximum and minimum values computed for 2013 (Table 4.1).

Table 4.1: Weather conditions during the experimental period of January to December 2013

Factor	Annual Mean	Maximum	Minimum	Total
Temperature (^oC)				
Greenhouse	18.3	34.8	5.9	-
Outdoor	17.2	30.4	6.1	-
Relative humidity (%)				
Greenhouse day	69	90	48	-
Greenhouse night	91	100	78	-
Greenhouse average	80	94	66	-
Vapour Pressure Deficit (kbar)				
Day	2.41	1.45	3.00	-
Night	1.15	0.55	1.85	-
Radiation				
Daily total Radiation (MJ m^{-2})	19.74	28.32	8.28	7205

The annual mean temperature inside the greenhouse was 18.3^{o}C and the annual mean temperature outside was 17.2^{o}C (Table 4.1). The range of daily average greenhouse temperature was 20.7^{o}C–24.5^{o}C for day and 13.0^{o}C–16.2^{o}C for night. The annual mean outdoor day and night temperature range was 17.9^{o}C–21.6^{o}C and 13.2^{o}C–16.7^{o}C, respectively. The absolute minimum and maximum greenhouse temperature during the day

were 6.9ºC and 34.8ºC, respectively, and 5.9ºC and 22.7ºC at night, respectively. The absolute minimum and maximum outdoor temperature during the day were6.4ºC and 30.4ºC, respectively, and 6.1ºC and 23.8ºC at night, respectively (Fig, 4.1).

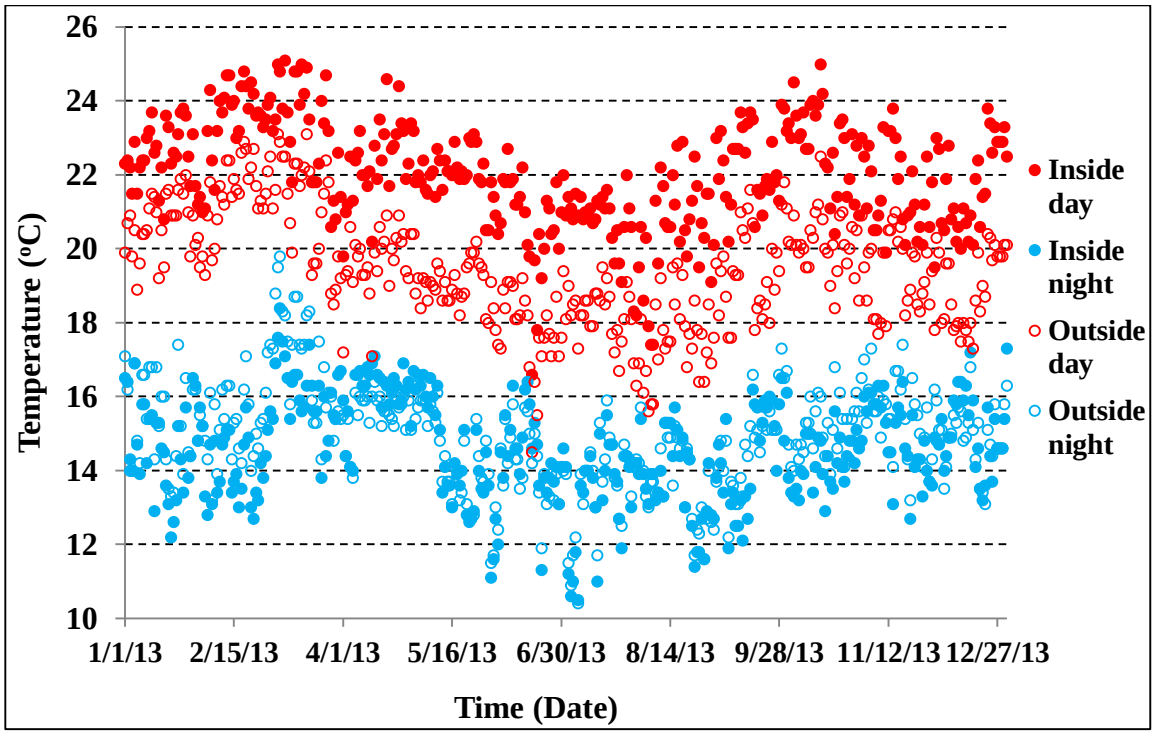


Figure 4.1: Greenhouse and outdoor temperature for January to December 2013

There was variation in temperature in the greenhouse during a sunny and a cloudy day. In both days, temperature began increasing from around 0700Hrs to the peak at 1400Hrs before decreasing (Figure 4.2). The day temperature pattern followed the radiation pattern with the highest temperature being recorded when highest radiation level was received at around midday. The cloudy day recorded fluctuating temperature while the sunny day showed a clear peak of temperature around midday.

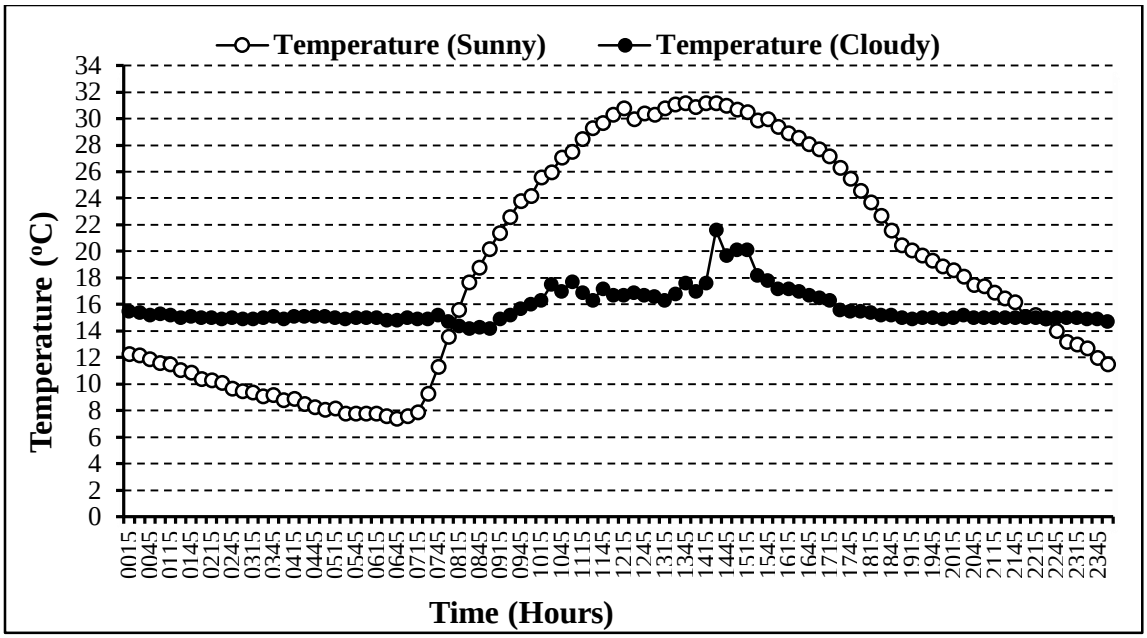


Figure 4.2: Temperature variation in the greenhouse during a sunny day (23rd February) and a cloudy day (18th June)

4.1.1 Relative air humidity

Over the one year period, the average relative humidity inside the greenhouse was 91% at night and 69% during the day (Figure 4.3). The lowest average relative humidity was 78% at night and 48% during the day. Similarly, the average highest average was 100% at night and 90% during the day. The lowest relative humidity was recorded in Week 8 of 2013. During this week the average day relative humidity was 54% which was the lowest weekly average in the whole year. The inside night relative humidity of 100 % was recorded thrice (twice in Week 13 and once in Week 14 of 2013). The weekly average relative humidity for the two weeks was 97% and 99% respectively.

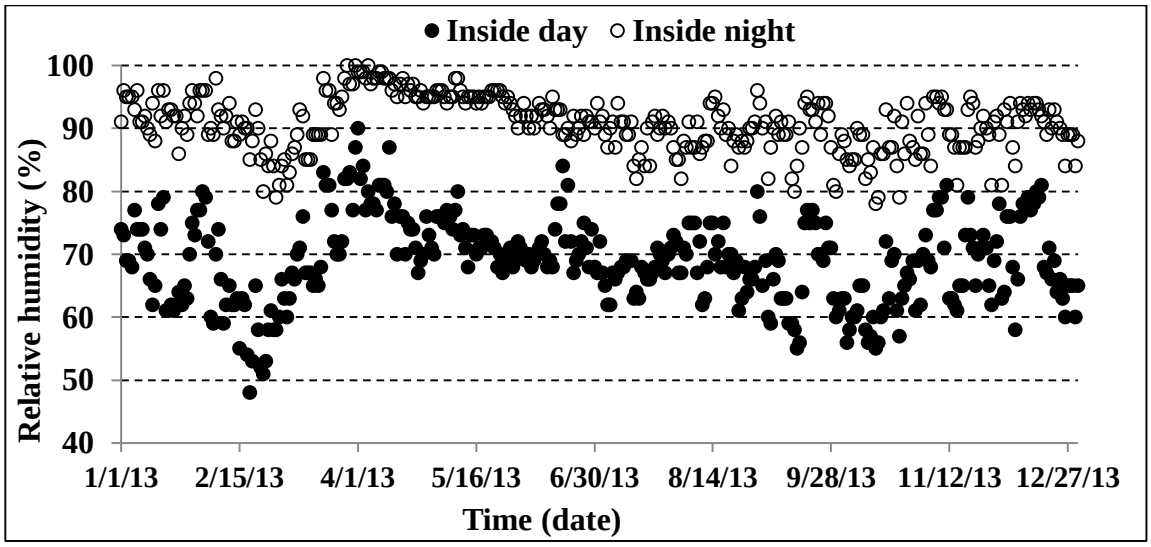


Figure 4.3: Greenhouse day and night relative air humidity for January to December 2013

Relative humidity of a cloudy day was high at night and dropped to a minimum at around 15:30Hrs after which it started increasing again. The drop in relative humidity coincided closely with the peak radiation. The lowest RH recorded on the cloudy day was 67% compared to 29% recorded for the sunny day (Figure 4.4). Even on the same day, highest relative humidity was associated with lowest radiation.

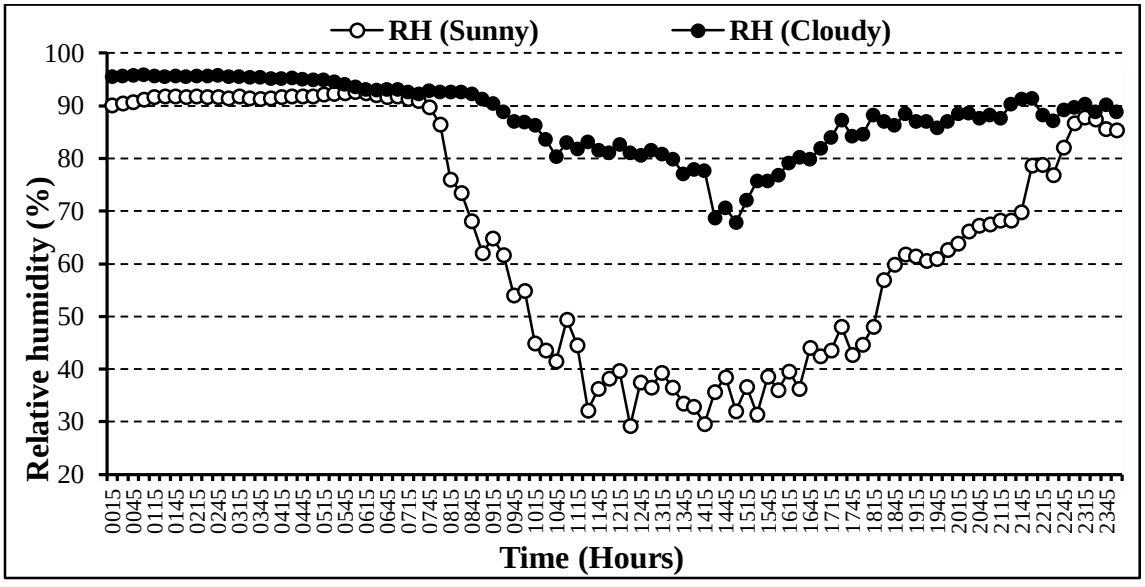


Figure 4.4: Relative air humidity variation in the greenhouse during a sunny day (23rd February) and a cloudy day (18th June)

4.1.2 Radiation

4.1.2.1 Total Radiation

Outdoor radiation sum for the entire period of one year (January to December 2013) was 7205 MJ m^{-2} y^{-1} (Table 4.1). The outdoor radiation range was 828–2832 J cm^{-2} d^{-1}, with the lowest radiation being recorded 303 days after planting and the highest 188 days after planting (Figure 4.5).

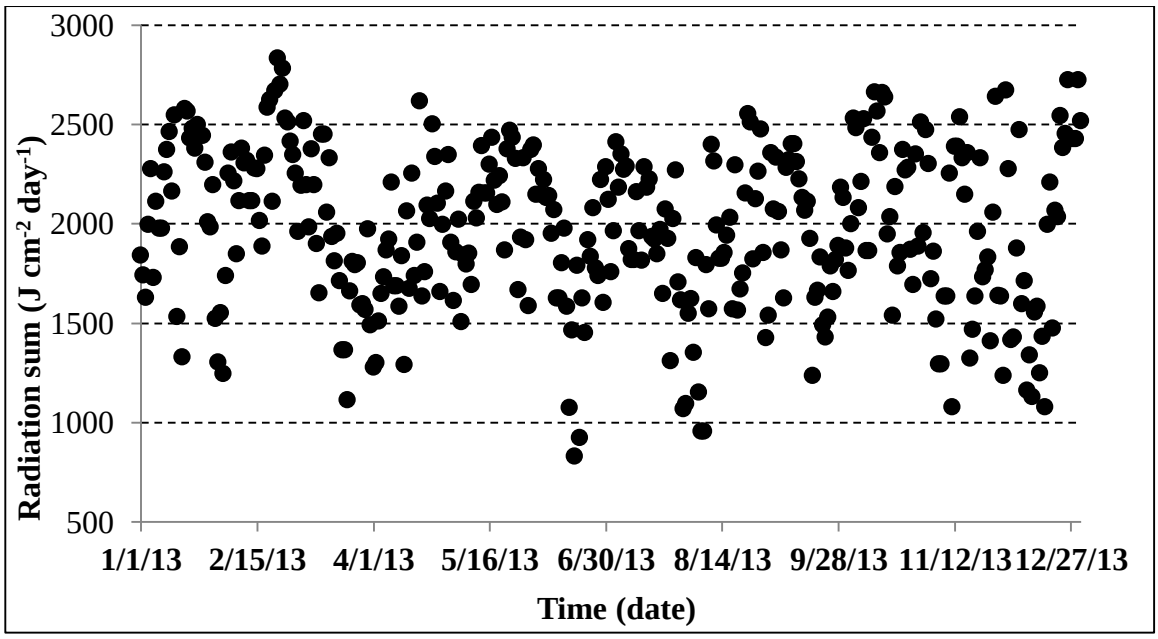


Figure 4.5: Total daily outdoor radiation received for January to December 2013

4.1.2.2 Sunny and cloudy day radiation

Radiation on a sunny day began increasing from around 0830Hrs daily and increased gradually up to between 1530Hrs and 1730Hrs when it levelled off. The sunny day radiation reached a peak of 96 J cm^{-2} s^{-1}, at around 1245Hrs. For the cloudy day there was no obvious peak and radiation fluctuated with the highest radiation reaching around 69 J cm^{-2} s^{-1}at around 1430 Hrs (Figure 4.6).

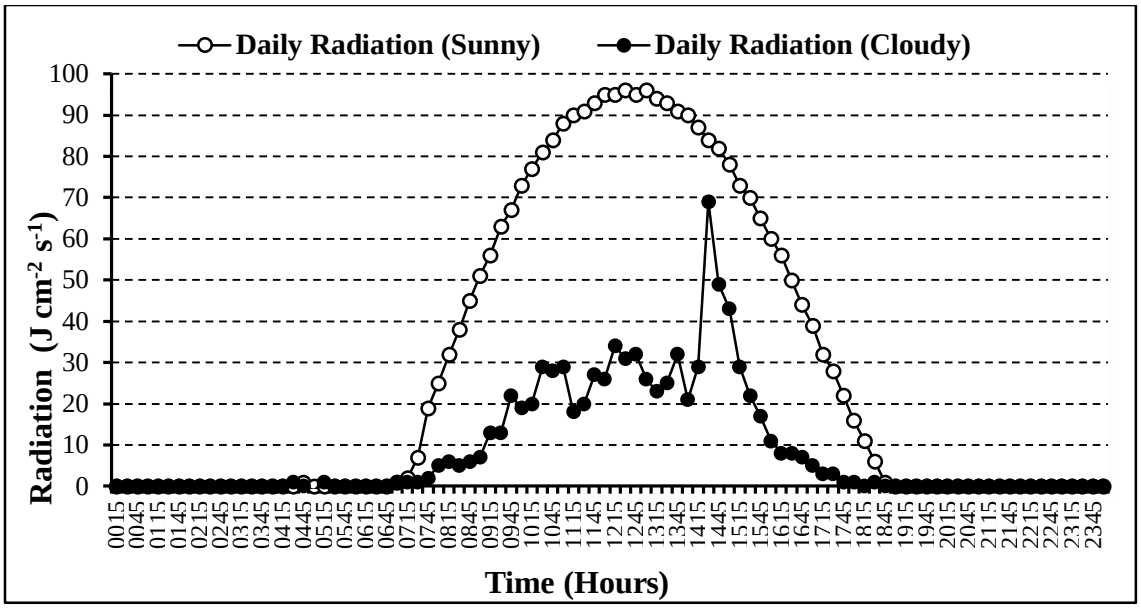


Figure 4.6: Radiation variation outside the greenhouse during a sunny day (23rd February) and a cloudy day (18th June)

4.1.2.3 Relationship between relative humidity and radiation

Based on all year data on relative humidity and radiation, regression showed that low relative humidity was associated with higher radiation (Figure 4.7).

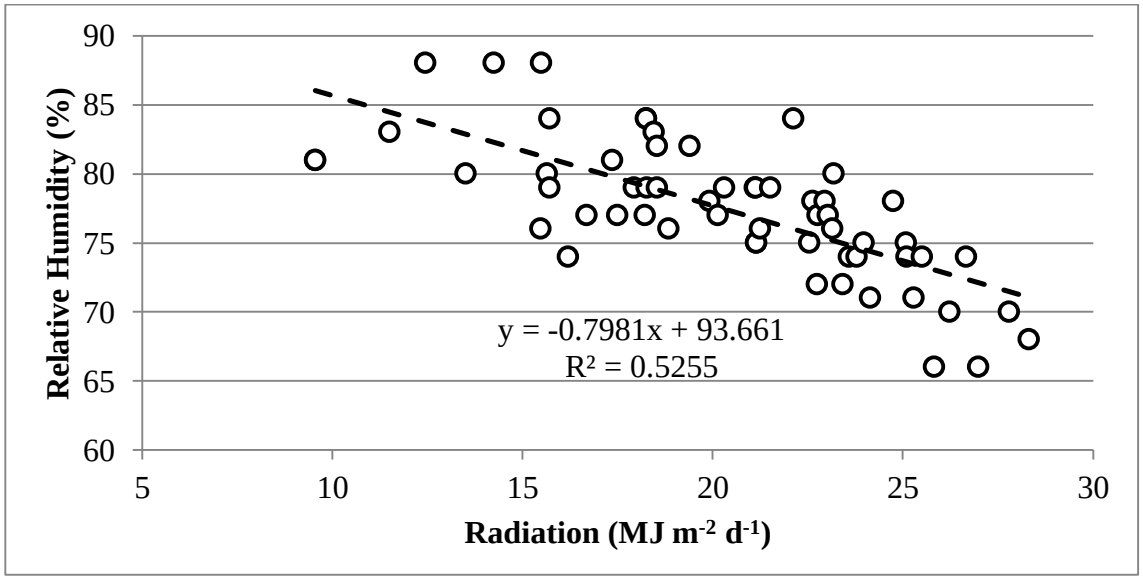


Figure 4.7: Regression between relative air humidity and daily radiation

4.1.3 Vapour pressure deficit

The vapour pressure deficit during the day ranged between 1.4 and 3.0 kPa while at night it ranged between 0.5 and 1.7 kPa (Figure 4.8). The average VPD during the day was 2.4 kPa and at night it was 1.1 kPa.

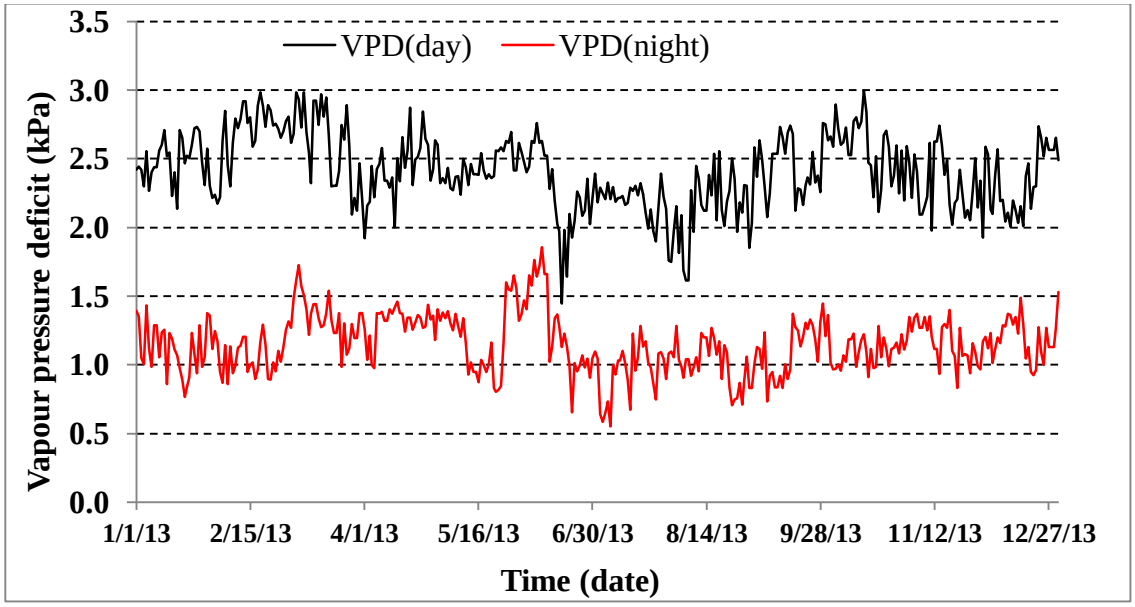


Figure 4.8: The pattern of vapor pressure deficit during the day and at night in 2013

4.2 Water

4.2.1 Water supply

4.2.1.1 Water supply to soil and hydroponic system

The amount of water supplied to the hydroponic system was higher than in the soil system except in August. The amount to hydroponic system was highest in February decreasing in the subsequent months up to August where it was minimal and increasing in September and October (Figure 4.9).

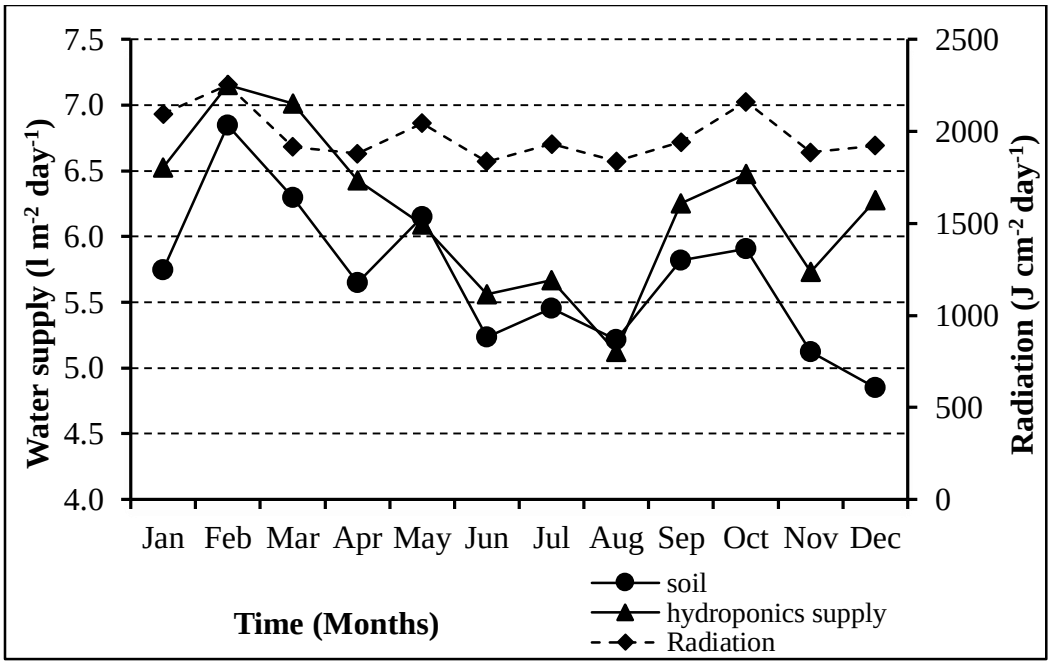


Figure 4.9: Average daily water supplied to soil and cocopeat systems and radiation in 2013

4.2.1.2 Water supply during sunny and cloudy days

The amount of water supplied on a sunny day and a cloudy day differed. More water was supplied during a sunny day compared to a cloudy day with significant difference ($P<0.01$). Within each day the amount of water supplied every 30 minutes also depended on the radiation. The amount increased up to a peak with increase in radiation. After peak radiation was reached the cumulative amount of water supplied remained constant for the remaining part of the day (Figures 4.10 and 4.11).

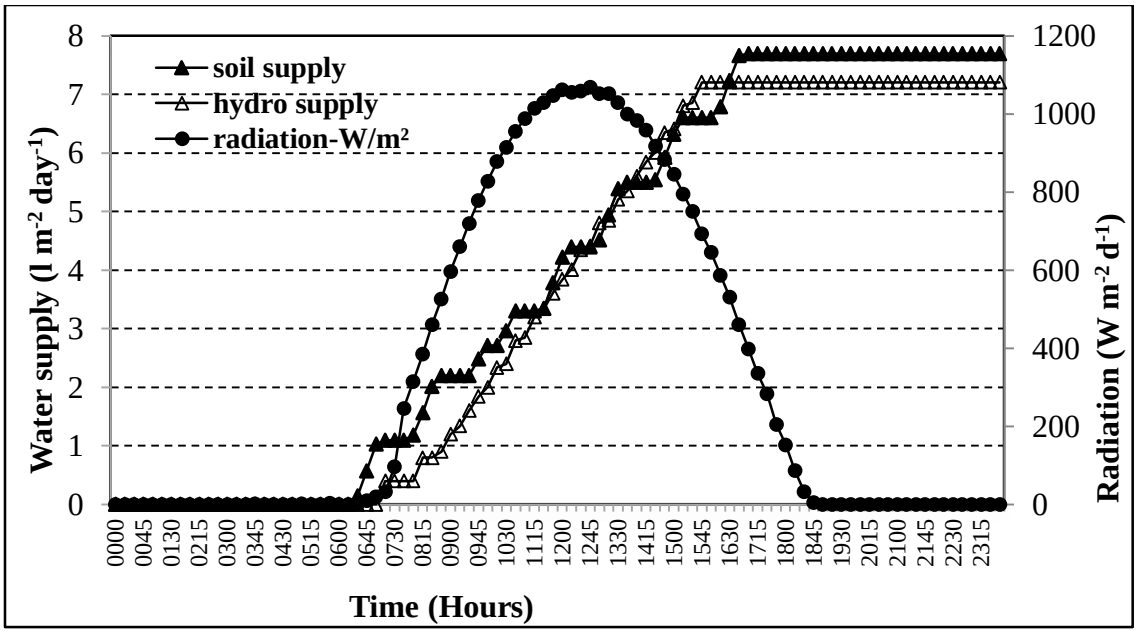


Figure 4.10: Water supply and radiation levels on a sunny day (23rd February)

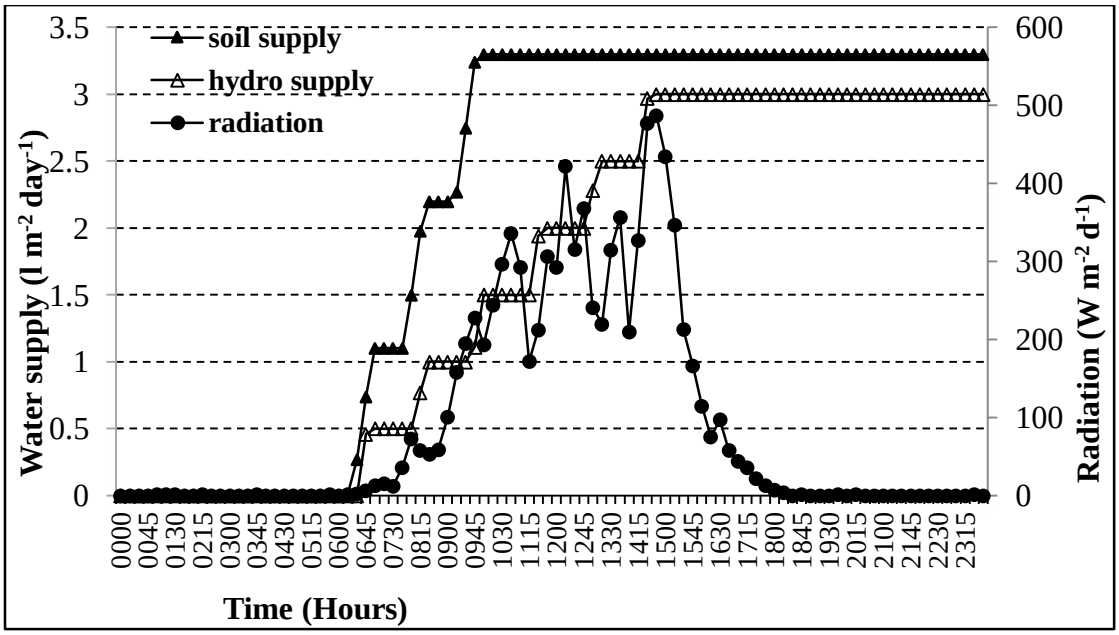
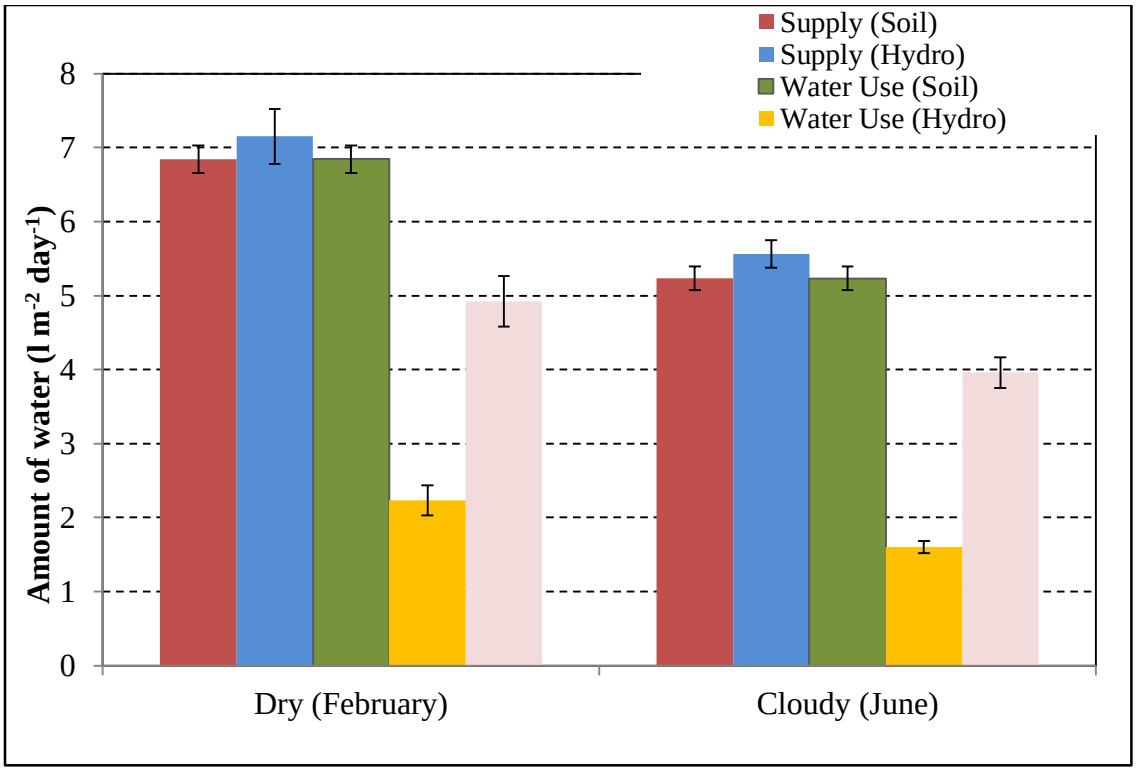


Figure 4.11: Water supply and radiation levels on a cloudy day (18th June)

4.2.1.3 Water supply during dry and wet seasons

The month that recorded the highest radiation sum was taken as the dry season and that which recorded the lowest radiation sum as the wet season. Months were taken to represent

seasons since the radiation received throughout the year differed for every month. Daily supply amounts were higher during the dry month compared to the cloudy month. On the other hand, the amounts were lower in hydroponic compared to soil system (Figure 4.12).



Vertical lines represent ± standard error

Figure 4.12: Daily water supply and use for soil and cocopeat during a dry month (February) and a cloudy month (June)

4.2.1.4 EC and pH of supply and drain water

Average EC and pH of supply water to soil and cocopeat systems differed slightly. This difference was not significant (P>0.01). For soil EC and pH was 1.4 mS cm^{-1} and 5.6 respectively while for cocopeat it was 1.5 mS cm^{-1} and 5.5 respectively. The average EC and pH of drainage water from cocopeat was 2.0 mS cm^{-1} and 5.4 respectively. EC ranged between 1.8 mS cm^{-1} and 2.3 mS cm^{-1} while pH ranged between 3.9 and 6.6 (Table 4.2).

Table 4.2: Average EC and pH values for supply water to soil and cocopeat systems and drainage from cocopeat system

	Soil supply		Cocopeat supply		Cocopeat drain	
Month	**EC (mS cm^{-1})**	**pH**	**EC (mS cm^{-1})**	**pH**	**EC (mS cm^{-1})**	**pH**
January	1.4	5.7	1.4	5.7	1.9	4.1
February	1.4	5.7	1.4	5.8	1.9	4.7
March	1.4	5.7	1.5	5.5	2.1	3.9
April	1.5	5.7	1.4	5.2	1.8	4.5
May	1.5	5.7	1.5	5.4	1.9	5.4
June	1.6	5.3	1.5	5.4	2.0	6.1
July	1.5	5.5	1.6	5.3	2.1	6.1
August	1.3	5.7	1.4	5.4	2.0	6.6
September	1.4	5.6	1.5	5.4	2.2	6.0
October	1.2	5.6	1.5	5.4	2.3	5.1
November	1.4	5.6	1.5	5.5	2.0	5.8
December	1.4	5.6	1.5	5.5	2.0	6.2
Daily Maximum	**1.7**	**6.2**	**1.7**	**5.8**	**2.3**	**6.6**
Daily Minimum	**1.1**	**5**	**1.1**	**5**	**1.8**	**3.9**
Average (±SD)	**1.4 (±0.10)**	**5.6 (±0.12)**	**1.5 (±0.06)**	**5.5 (±0.16)**	**2.0 (±0.14)**	**5.4 (±0.90)**

4.2.1.5 Nutrient content of supply and drain water

Primary and secondary nutrients had higher volumes in drainage water compared to supply water. Nitrates, for example, were recorded as 8.3 mmol l^{-1}in supply water and 10.74 mmol l^{-1} in drainage water (Table 4.3). However, ammonium was in lower amounts in drainage water compared to supply water recording 0.15 mmol l^{-1} and 0.58 mmol l^{-1} respectively. Fe, Zn, Bo, Cu, Na, Cl, Si and HCO_3 showed higher volumes in drainage water compared to supply water except Mn and Mo.

Copper and silicates had the least volumes in the supply water of less than 2 µmoll^{-1}while nitrates and potassium had the highest volumes.

Table 4.3: The average values of nutrients in supply and drain water in 2013

Ion	Symbol	Supply water (mmol l^{-1})	Drain water (mmol l^{-1})	Drain molar mass (g/mol)	Drain water (g l^{-1})
Ammonium	NH_4^+	0.58	0.15	18.04	0.003
Calcium	Ca^{2+}	2.4	3.7	40.08	0.148
Magnesium	Mg^{2+}	1.65	2.29	24.31	0.056
Potassium	K^+	3.28	4.32	39.10	0.169
Phosphorus	$H_2PO_4^-$	1.09	1.46	30.97	0.045
Nitrate N	NO_3^-	8.33	10.74	62.01	0.666
Sulphur	SO_4^{2-}	1.45	2.21	32.07	0.071
Sodium	Na^+	0.45	0.81	22.99	0.0186
Chlorides	Cl^-	0.3	0.42	35.45	0.015
Bicarbonate	HCO_3^-	0.2	0.23	61.02	0.0137
		Supply water (µmol l^{-1})	Drain water(µmol l^{-1})		
Iron	Fe	34.58	37.26	55.85	0.002
Manganese	Mn	11.65	10.91	54.94	0.0006
Zinc	Zn	4.7	6.11	65.38	0.0004
Boron	B	23.75	35.11	10.81	0.0004
Copper	Cu	1.63	1.94	63.55	0.0001
Molybdenum	Mo	2.55	0.33	95.94	0.00003
Silicates	Si	0.1	0.13	28.09	3.51E-06
Sum of drain water					1.209

4.2.2 Drainage water

4.2.2.1 Drainage water and its percentage to supply water

Drainage water was collected in a drainage pit and the volume recorded automatically. Days in the month of February recorded highest average amount of drainage water of 4.9 l m^{-2} day^{-1} (Figure 4.13). Drainage decreased in subsequent months up to August where the lowest drainage water of 2.6 l $m^{-2}day^{-1}$ was collected. The drained volume rose in the months of September and October and dropped in November to 3 l m^{-2} day^{-1} (Figure 4.13).

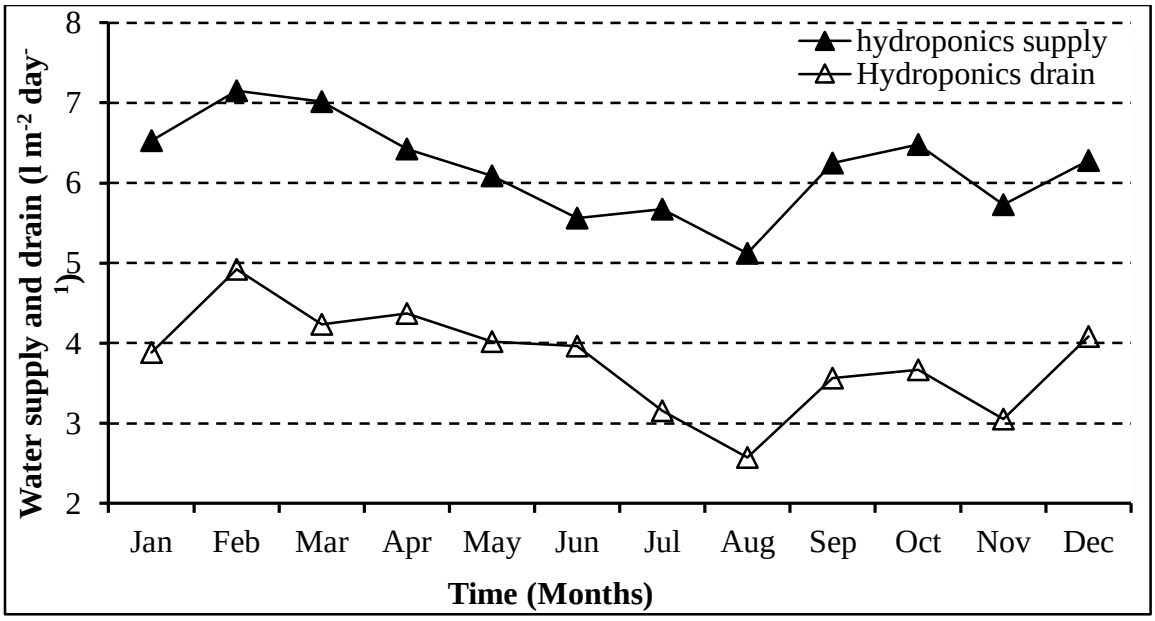


Figure 4.13: Average daily water supplied and drained per month from cocopeat system.

Drainage percentage ranged between 50% and 70%. The first half of the year recorded a higher drainage percentage of 60-70% compared to the second half of the year which recorded a drainage percentage of 50-65% (Figure 4.14). Annual average drainage percentage of 61% was recorded throughout the year.

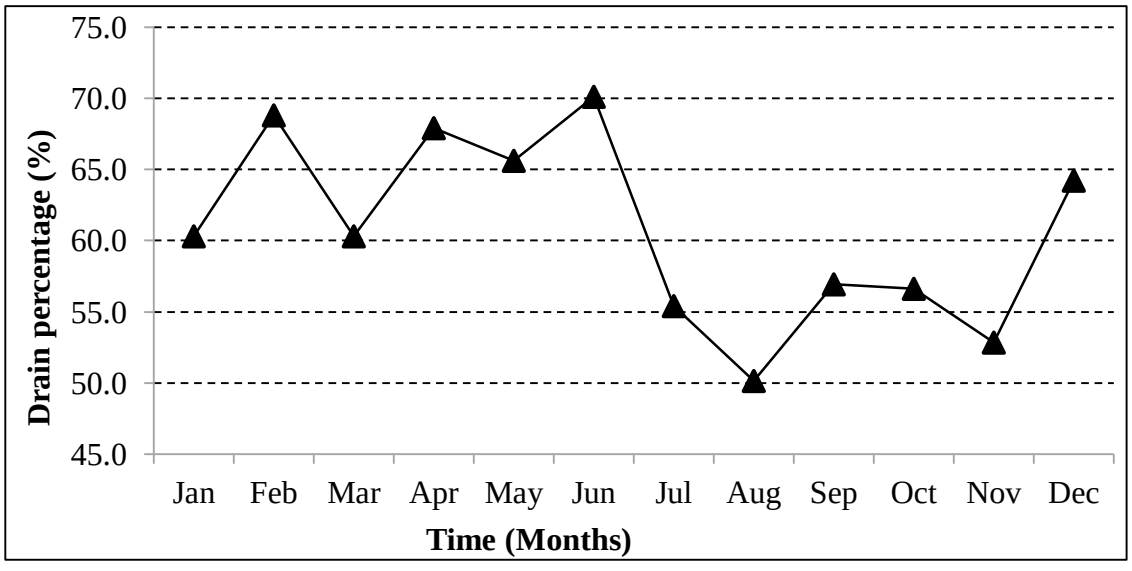


Figure 4.14: Average daily drainage water percentage per month in cocopeat system in 2013

4.2.2.4 Microbes in the drainage

No bacteria were observed in the analyzed sample of drainage water and the only fungus detected was *Fusarium oxysporum* (Table 4.4). No harmful nematodes were detected in the sample water

Table 4.4: Microbes analysis results in the drainage water

Analysis	Class I (number per 100ml of sample)
A. Bacterium	
Agrobacterium tumefaciens	0
Erwinia carotovora subsp. carotovora	0
Pseudomonas syringae	0
Ralstonia solanacaerum	0
Xanthomonas fragariae	0
B. Fungi	
Alternaria sp.	0
Fusarium oxysporum	**1**
Other *Fusarium* spp.	**4**
Phytophthora sp.	0
C. Nematodes	
Free-living root nematodes (*Helicotylenchus* spp.)	0
Virus transmitting nematodes (*Xiphinema* spp., *Longidorus* spp., *Paratrichodorus* spp.)	0
Root-knot nematodes (*Meloidogyne* spp.)	0
Root-lesion nematodes (*Pratylenchus* spp.)	0
Burrowing nematodes (*Radopholus similis*)	0
Saprophytic nematodes	**2110**

4.2.3 Water use

4.2.3.1 Volume of water used

Average daily net water use, water uptake by crop, in the soil system ranged between 4.85 and 6.85 l m^{-2} day^{-1} while for cocopeat system, it ranged between 1.60 and 2.81 l m^{-2} day^{-1} (Figure 4.15). The average daily water use for the hydroponics was 2.4 l m^{-2} compared to 5.7 l m^{-2} representing 58% savings on water used per day. The daily average savings for individual months ranged between 48% (in the month of September) and 69% (in the month of October).

The daily water use was associated with radiation only to a small extent. The association between water used and radiation was better seen when daily averages over individual months were considered.

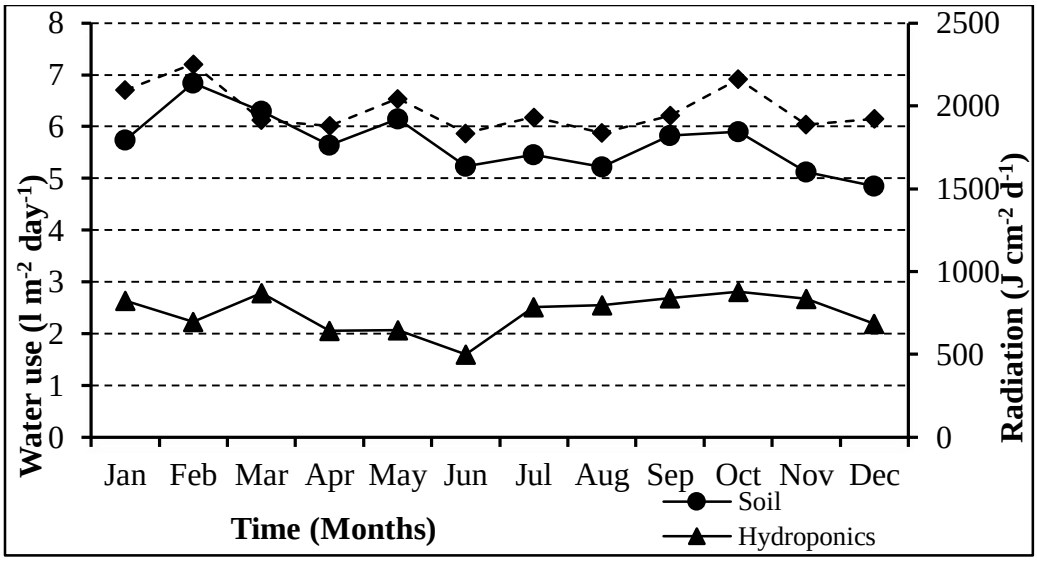


Figure 4.15: Average daily water use for soil and hydroponic systems and radiation over a 12 month period

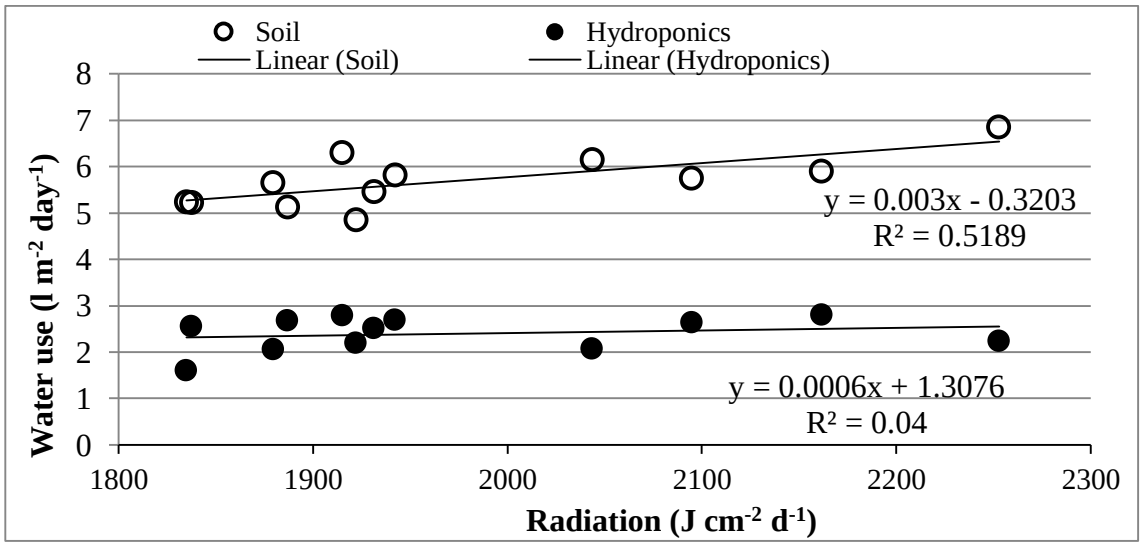


Figure 4.16: Relationship between water use and radiation for a 12 month period of 2013

A regression analysis showed a relationship between daily water use and daily radiation. There was a positive correlation between amount of water used in a day and radiation received in that day. For example more than 6 l m^{-2} was supplied to soil system in days receiving more than 2000 J cm^{-2} d^{-1} compared to less than 6 l m^{-2} in days receiving less than 2000 J cm^{-2} d^{-1} (Figure 4.16).

There was more water use in the soil system during sunny days such as the months of February, May and October and less water use during cloudy days in April, June, August and December (Figure 4.17). In the cocopeat system the amount of water used was almost constant and varied much less with radiation.

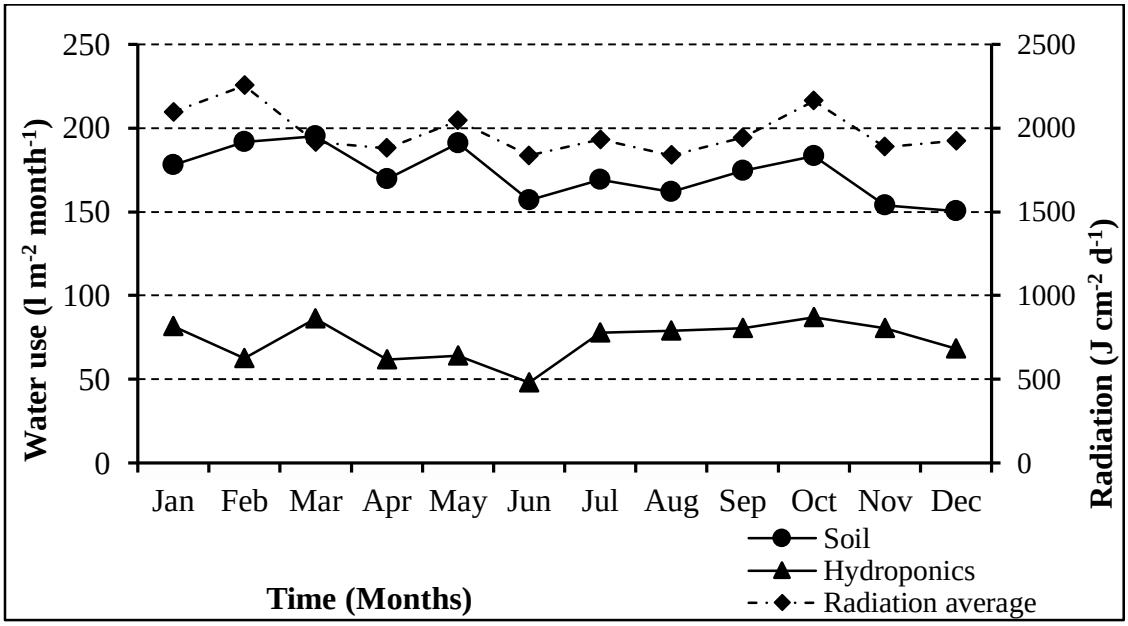


Figure 4.17: Relationship between water use and radiation for a 12 month period of 2013

The cumulative water use in the soil was 2074 l m^{-2} over the 12 month period while it was only 877 l m^{-2} in hydroponics representing a saving of 58% (Figure 4.18). The monthly total water use for the soil ranged between 150 and 191 l m^{-2} compared to hydroponics where it ranged between 48 and 87 l m^{-2} representing savings of between 48 and 69% (Figure 4.17).

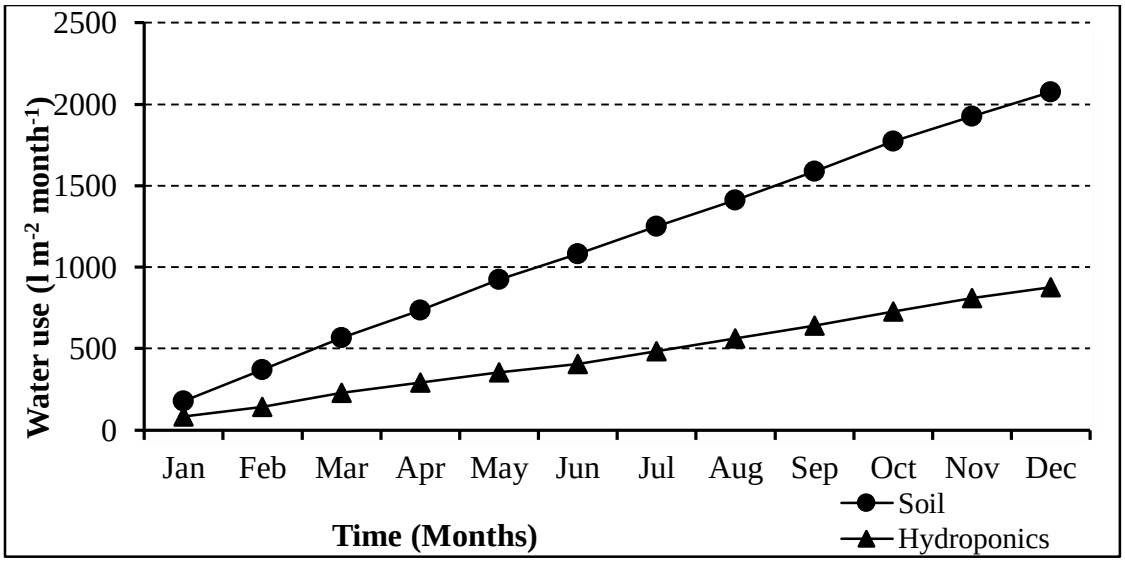


Figure 4.18: Cumulative water use in soil and cocopeat systems over the 12 month period

The drainage from the two systems remained between 50 and about 70%. It tended to follow the radiation patterns to some extent (Figure 4.19).

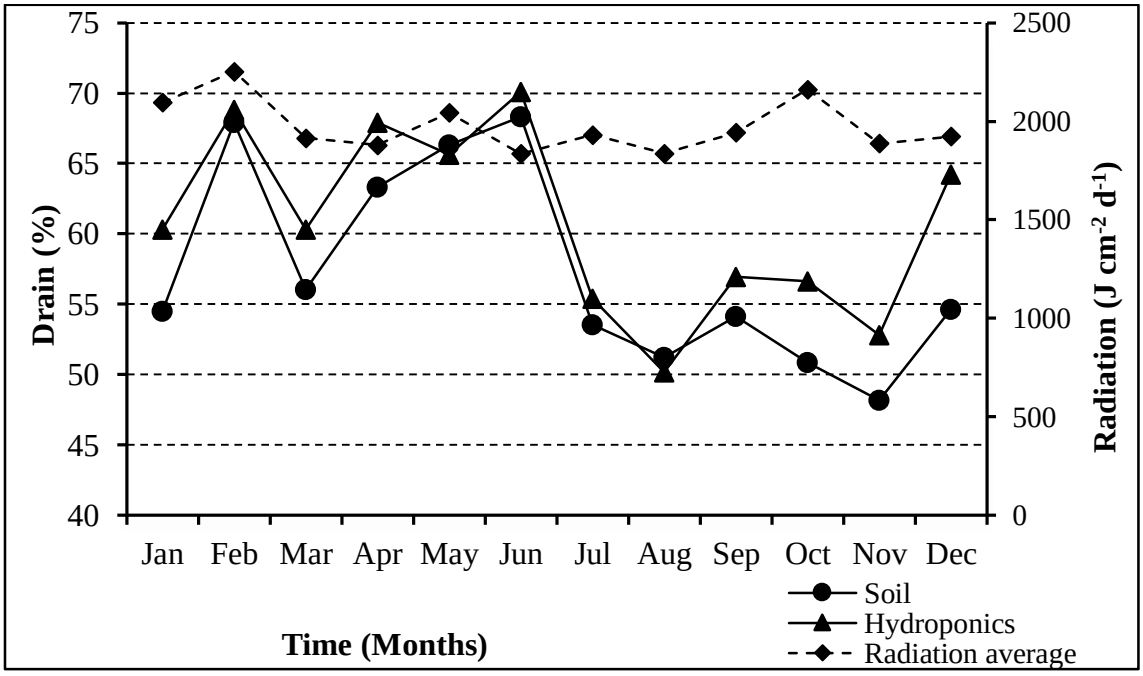


Figure 4.19: Drainage water for soil and cocopeat systems and radiation for the 12 month period of 2013

4.2.3.2 Water use and vapour pressure deficit (VPD)

In both systems, more water was used when there was high VPD (Figure 4.20). About 6 l m^{-2} day^{-1} in soil system and 3 l m^{-2} day^{-} in cocopeat system, was used when VPD was above 1.2 kPa. Some association was noted between water use and VPD (Figure 4.20).

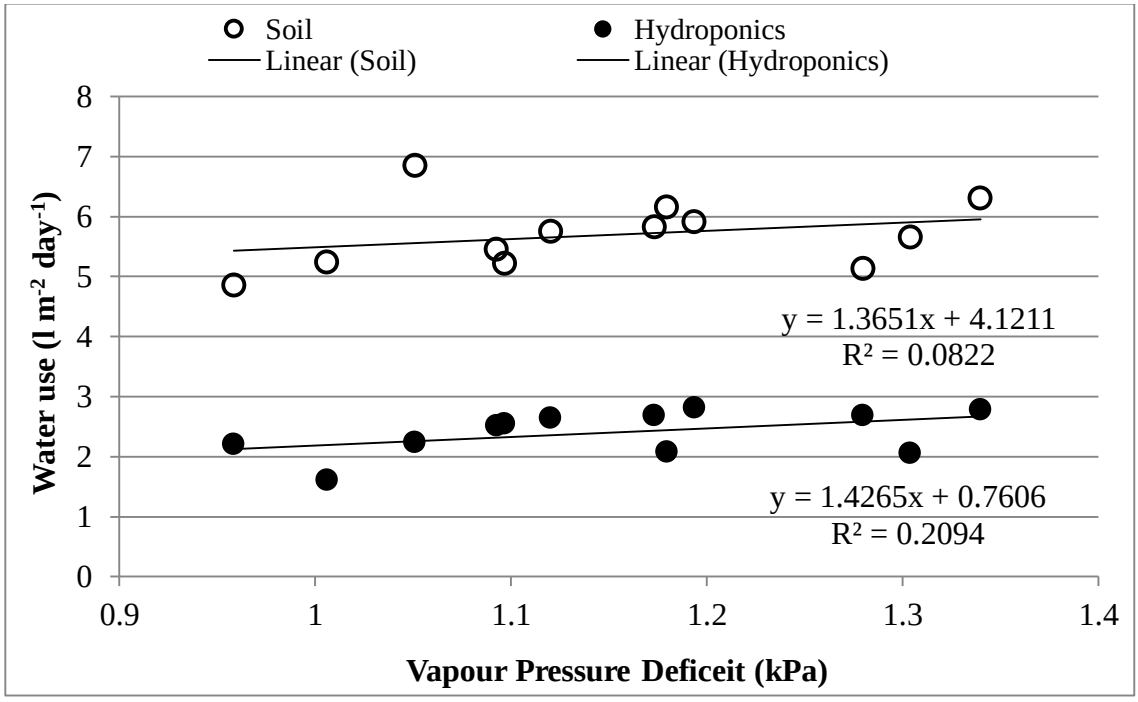
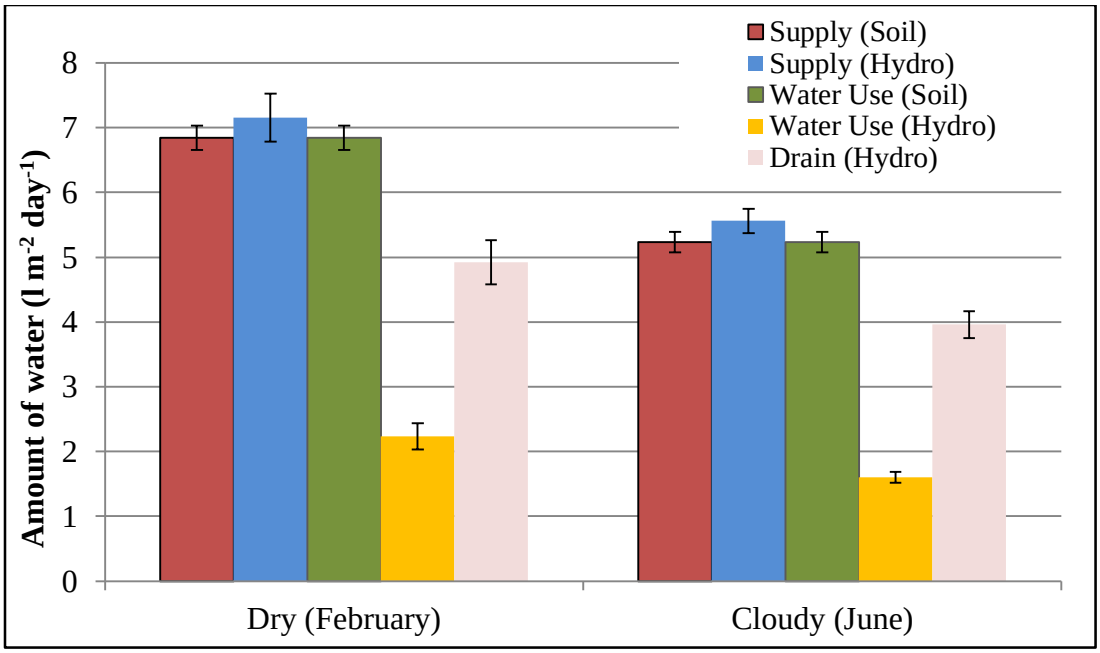


Figure 4.20: Relationship between water use and vapour pressure deficit (VPD) for a 12 month period of 2013

4.2.3.3 Water use during dry and wet seasons

Daily supply and drain water amounts were higher during the dry month of February compared to the cloudy month of June. 6.8 l m^{-2} d^{-1} was supplied to soil in the month of February compared to 5.2 l m^{-2} d^{-1} in the month of June (Figure 4.21). On the other hand, the amounts of water use were lower in cocopeat compared to soil system.



Vertical lines represent ± standard error

Figure 4.21: Daily water supply use and drain in soil and cocopeat during dry (February) and cloudy (June) months

4.3 Plant growth and development

4.3.1 Leaf expansion

Leaves expanded faster in the cocopeat system than in the soil system, though the difference was not significant (df=16, P>0.01). For an average of fifteen plants in each system, maximum leaf length reached was 6.3 cm in the cocopeat system and 6.0 cm in soil system (Figure 4.22). Leaf expansion was characterized by initial slow expansion rate followed by a fast expansion rate before levelling off.

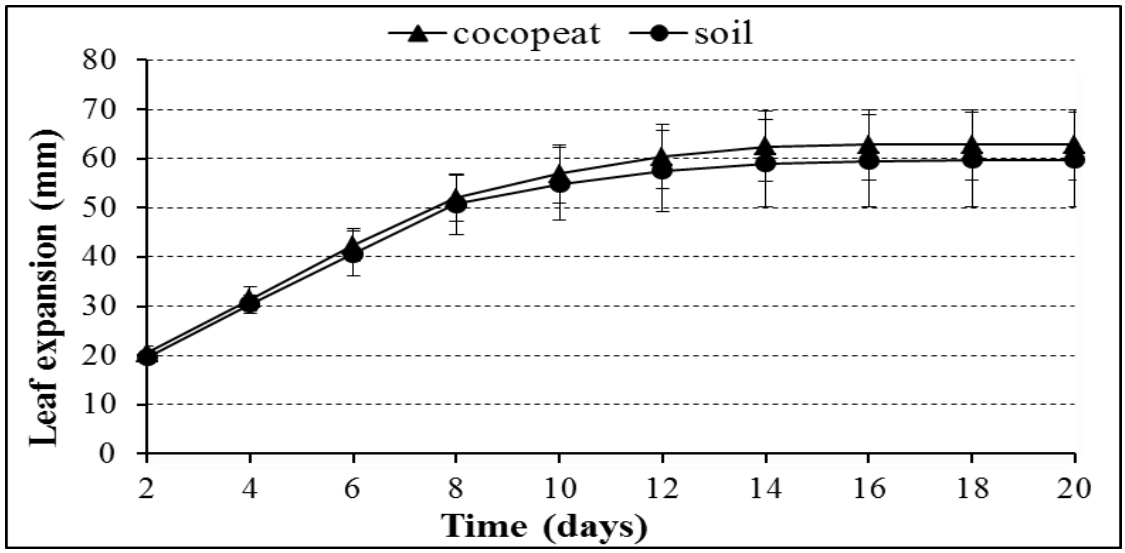


Figure 4.22: Expansion of leaves in plants grown in soil and cocopeat systems.
Vertical lines represent ± standard error

4.3.2 Number of leaves per stem

The number of leaves did not differ significantly between soil and cocopeat system. The maximum number of leaves observed was 20 per plant for both systems which was not significantly different (df=10: P>0.01) (Figure 4.23).

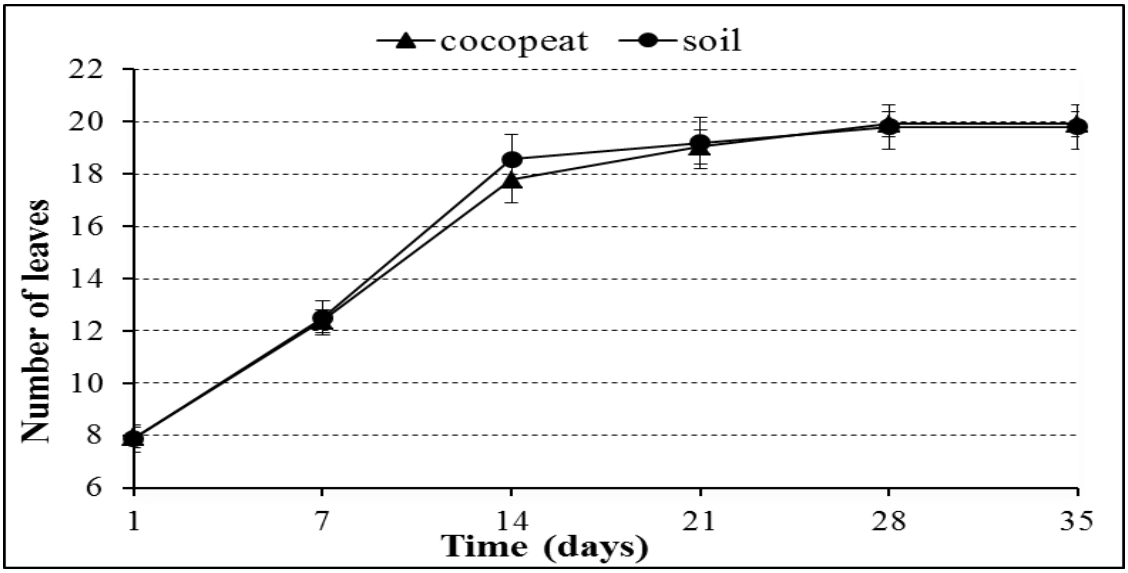


Figure 4.23: Number of leaves per stem in plants grown in soil and cocopeat systems.
Vertical lines represent ± standard error

4.3.3 Stem elongation

Stems were longer in cocopeat system than in the soil system reaching 63 cm for soil system and 65 cm for cocopeat system for an average of fifteen plants each. The difference was however not significant (df=10: P>0.01) (Figure 4.24).

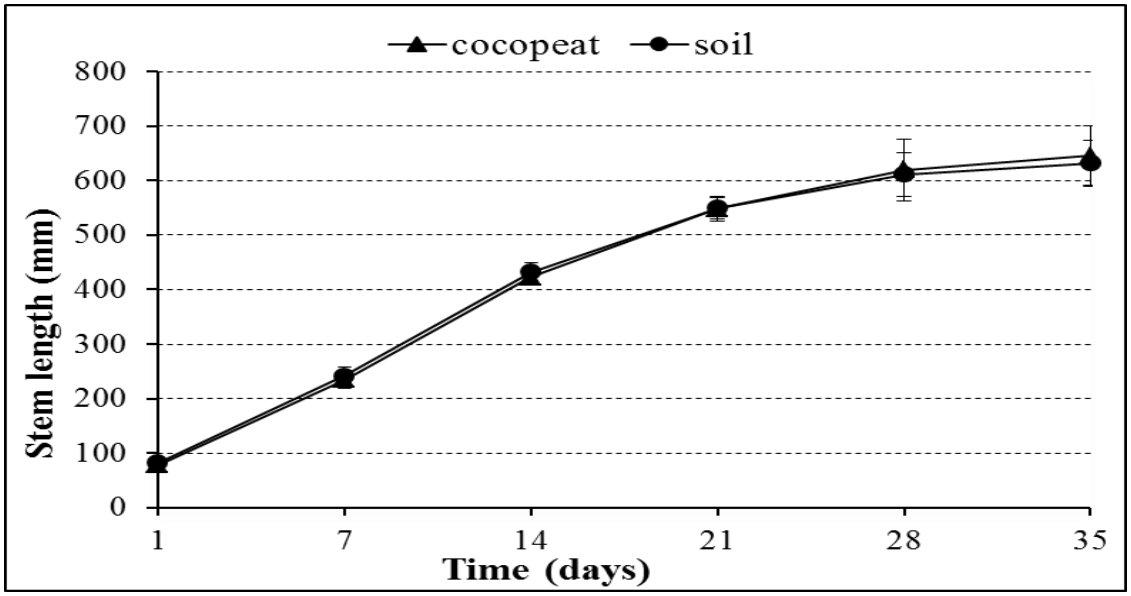


Figure 4.24: Stem length expansion of plants grown in soil and cocopeat systems. Vertical lines represent ± standard error

4.3.4 Bud expansion

For an average of fifteen plants in each system the head length reached 34.1 mm and 30.8 mm for cocopeat and soil system respectively and head width 25.4 mm and 23.2 mm for cocopeat and soil system, respectively (Figure 4.25). This was not significantly different (df=20, P>0.01and df=20, P>0.01, for head length and head width, respectively).

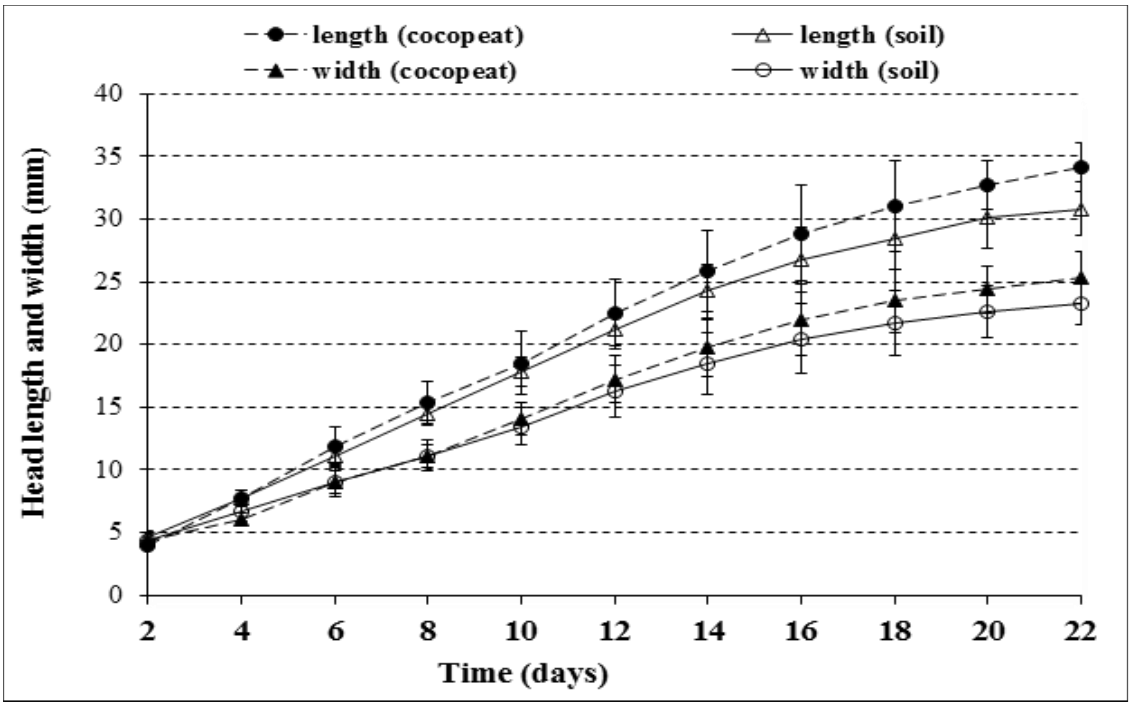


Figure 4.25: Flower head length and width in plants grown in soil and cocopeat systems.
Vertical lines represent ± standard error

4.3.5 Leaves chlorophyll content

The SPAD reading at the top and middle canopy of the plants grown in cocopeat system differed significantly from soil system (P<0.01) (Table 4.5).

Table 4.5: Leaf chlorophyll content (interpreted from measured SPAD value) of plants grown in soil and cocopeat systems

System	SPAD value	N	df	*p*
Top leaves				
Cocopeat	51.7 a	150	257	<0.01
Soil	48.2 b	150		
Middle leaves				
Cocopeat	51.4 a	150	257	<0.01
Soil	49 b	150		

4.4 Crop production

4.4.1 Cut flower quality

The production quality was presented in terms of weight of stems, weight per stem and length classes.

4.4.1.1 Stem weight

The cumulative produced fresh weight of stems was significantly greater in cocopeat system compared to the soil system ($P<0.01$). By the end of the 12 month period the cocopeat system had 9.2 kg m^{-2} compared to 5 kg m^{-2} for soil system which represented 82% more weight of stems (Figure 4.26).

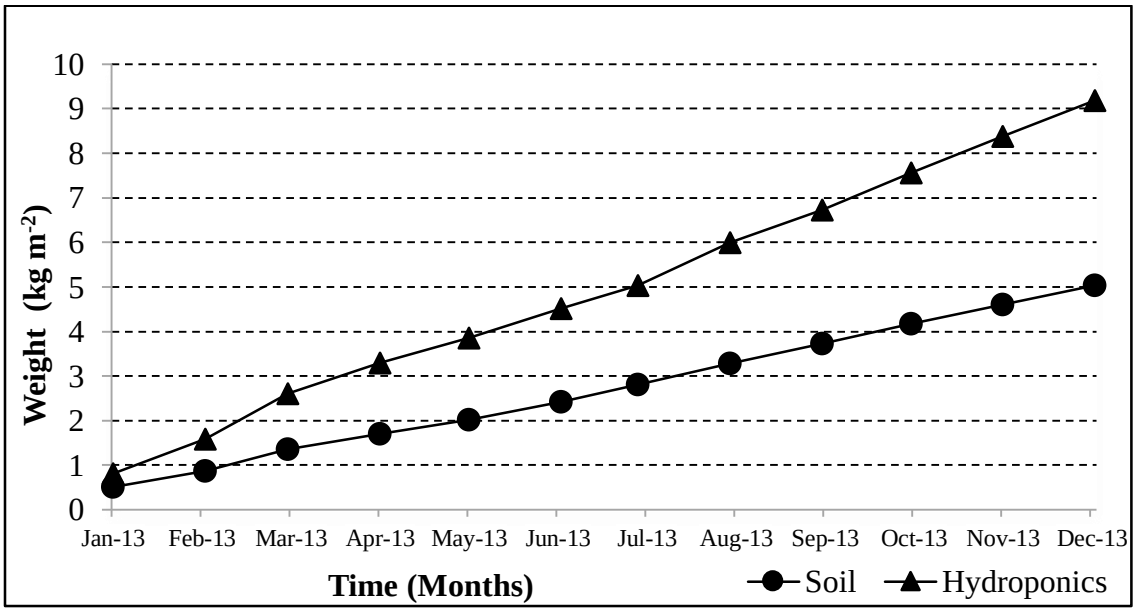


Figure 4.26: Produced fresh weight (cumulative) for 2013

4.4.1.2 Weight per stem

The average weight of stems ranged between 30 and 40 g $stem^{-1}$ for both soil and cocopeat systems (Figure 4.27). In March, weight of stems from soil system was lowest due to the failure of weighing balance on half part of the month. On average, stems from cocopeat system weighed 36.3 g $stem^{-1}$ while those from soil system weighed 35.3 g $stem^{-1}$. This difference was not significant ($P>0.01$).

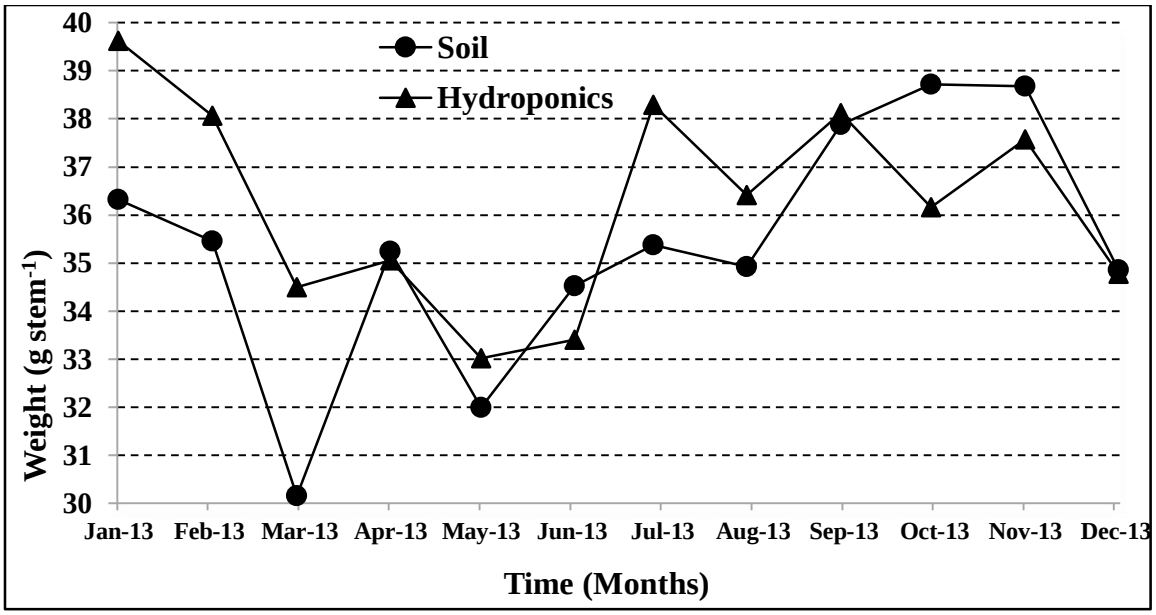


Figure 4.27: Average weight per stem of soil and cocopeat system in 2013

4.4.1.3 Proportion of stem category to the total production

This is the proportion of number of stems per quality (length) category. The cocopeat system had longer stems compared to the soil system. The percentage of 60 cm and 70 cm stems in soil was 28% and 11%, respectively and 32% and 23% in cocopeat, respectively (Table 4.6). These differences were significant (P<0.01).

Table 4.6: The stem length as a percentage of all stems produced

Stem length (cm)	Percentages (%)	
	Soil system	Cocopeat system
30	4	1
40	21 (59)	12 (38)
50	34	25
60	28	32
70	11	23
80	2	6

4.4.2 Production quantity

This is the number of stems produced from the two systems. Cumulative number of stems was significantly greater ($P<0.01$) in the cocopeat system compared to the soil system. By the end of the 12 month period the cocopeat system had 242 stems m^{-2} compared to 157 stems m^{-2} from soil system which represents 53% more stems (Figure 4.28).

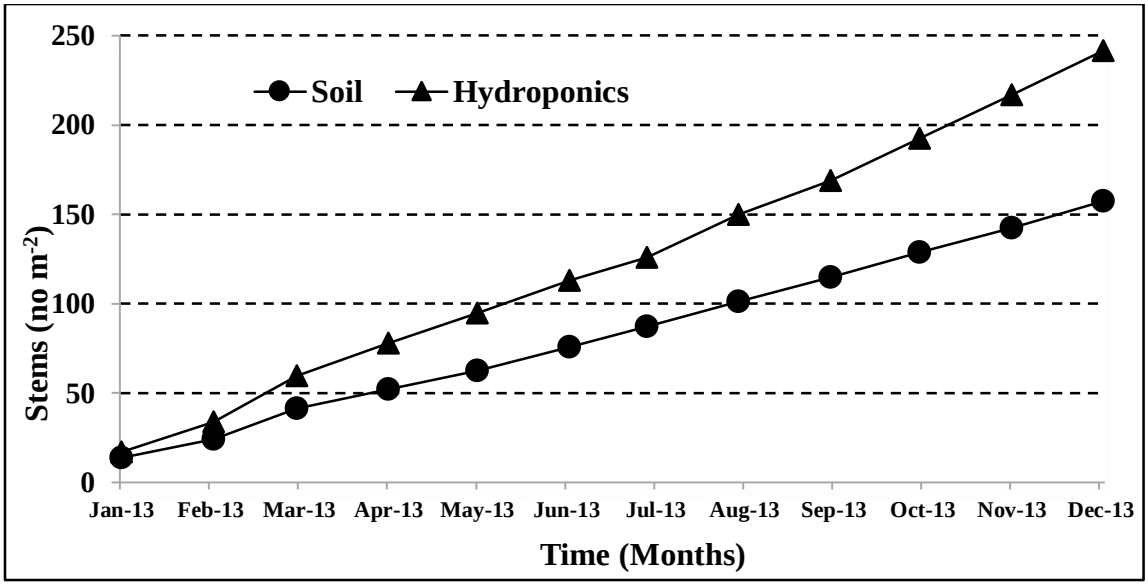


Figure 4.28: Production of stems (cumulative) from soil and cocopeat systems for 2013

4.4.3 Water productivity

Combining the water data with weight of stems gives a WP in terms of weight of 10.46 g m^{-2} per liter of water in cocopeat system compared to 2.43 g m^{-2} per liter of water in soil system. This represents a 77% increase in WP by use of cocopeat system. In terms of number of stems, the WP was estimated to be 0.28 stems m^{-2} per liter of water in cocopeat system compared to 0.08 stems m^{-2} per liter of water in soil system. This translates to 72% greater efficiency. This means that on comparing stem weight and number of stems for cocopeat system, the system contributed more to stem weight rather than increase in the number of stems on water productivity.Water use here was the water applied less the drainage for cocopeat system and for the soil system it was simply the water applied.

4.4.4 Postharvest loses from rejected stems

The rejected stems were calculated as a percentage of the total production. The yearly average of rejected stems was 6.01% and 5.99% for soil and cocopeat systems respectively. The difference was not significant (P>0.01). The rejected stems were 28% in cocopeat system and 9% in soil in the month of April (Figure 4.29). This was majorly caused by downy mildew (Table 4.7). Rejects due to downy mildew was higher in cocopeat system compared to the soil system.

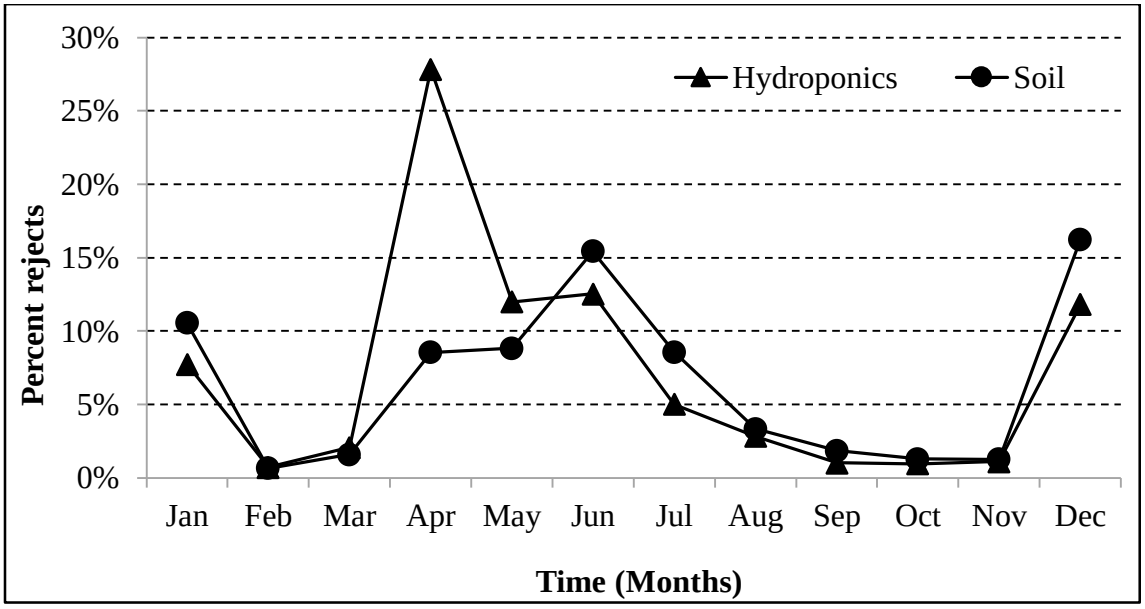


Figure 4.29: Average percentage of rejected stems for soil and cocopeat systems per month in 2013

The diseases that occurred were downy mildew, powdery mildew and botrytis while the pests were mites, thrips and caterpillars. Morphological causes of damage emanated from the plant physiology and stems resulting did not qualify for export. This included goose necks, bull heads, pale flower heads and stems below 25 cm in length. Some other stems were damaged during spraying, harvesting, transport and offloading in the grading hall. Some other stems had tight or too open flower heads due to failure to harvest them at the correct cut stage (Table 4.7).

Table 4.7: Cause of post-harvest rejection

Reject Cause	Reject Quantities for 16000m^2 of greenhouse space year^{-1}			
	Soil system		Cocopeat system	
	Number	%	Number	%
1. Diseases				
(a) Downy Mildew	**66060**	**54.29**	**106736**	**64.22**
(b) Powdery Mildew	776	0.64	861	0.52
(c) Botrytis	26	0.02	34	0.02
2. Pests				
(a) Mites	2054	1.69	3140	1.89
(b) Thrips	**22398**	**18.39**	**23442**	**14.11**
(c) Caterpillar damage on flower heads	46	0.038	66	0.04
3. Physiological		0		0
(a) Goose neck	**11601**	**9.53**	**11931**	**7.18**
(b) Bull heads and pelicans	4	0.003	514	0.31
(c) Pale colour on flower heads	0	0	0	0
(d) Undersize stems (below 25cm)	0	0	0	0
4. Human error		0		0
(a) Open flower heads (Late harvesting)	0	0	0	0
(b) Tight flower heads (Early harvesting)	0	0	2	0.001
(c) Damaged flower heads	6400	5.25	6309	3.80
(d) Bent stems	**9007**	**7.40**	**9105**	**5.48**
(e) Chemical scorching on leaves	1980	1.63	2679	1.62
(f) Broken Stems	1443	1.18	1375	0.83
Total (for 16000m^2)	**121,795**		**166,194**	
Total (m^{-2})	**7.6**		**10.4**	

4.4.5 Vase life

The vase life of the plants from both soil and cocopeat systems was an average of 8 days.

4.5 Benefit analysis

4.5.1 Fertilizers

4.5.1.1 Fertilizers applied to hydroponics

Fertilizers applied to soil system was the total of fresh fertilizers and those in the drain water collected from cocopeat system whereas fertilizers applied to cocopeat system was all fresh fertilizers. The fertilizers applied to cocopeat system amounted to 51,629.87 kg in 2013 which was equivalent to 3.2 kg m^{-2} yr^{-1}. The area under the cocopeat system was 16,000 m^2.

4.5.1.2 Fertilizers in drain water

The nutrient content in cocopeat drainage in mmols l^{-1} or mol l^{-1} was converted into g l^{-1} and summed up to obtain the concentration of composite fertilizer in the drainage solution. This concentration was multiplied by the volume of drainage from cocopeat system to obtain the amount of fertilizer in the drainage solution.

The sum of values in column 6 of Table 4.3 resulted to 1.209 g l^{-1}

Total weight of fertilizers in the drain was 1.209 g l^{-1}

Fertilizer in drain = Total drainage water * drain g l^{-1}

Fertilizer in drain = 1380.44 l m^{-2} * 1.21 g l^{-1}

Fertilizer in drainage (kg) = 1670.3324 g m^{-2} * Area (16000m^2)/1000,

Fertilizer in drain = 26,725.32 kg which was **1.67 kg m^{-2}.** This is the fertilizer that was available for re-use in the soil system.

4.5.1.3 Fertilizers applied to soil

The fertilizers applied to soil system amounted to 126,750 kg which is equivalent to 2.8 kg m^{-2}. The area under the soil system was 46,000 m^2.

The fertilizers that were applied in hydroponics were more than those applied to soil in kg m^{-2}.The average price of fertilizer mix for both soil and hydroponics system was 2.93$ kg^{-1}. The most expensive fertilizer was Ferrilene with 10.45 $ kg^{-1}, and the cheapest was Magnesium sulphate with 0.36 $ kg^{-1}. The most applied fertilizer for both systems was Magnesium sulphate and Calcium nitrate (Table 4.8)

Table 4.8: Fertilizer type and amount applied in soil and cocopeat systems in 2013

Fertilizers applied year^{-1}			**Treatment (kg)**		**Cost ($)**		
Fertilizer	**Units**	**Litre to kg**	**Soil**	**Cocopeat**	**($/kg)**	**Soil**	**Cocopeat**
Ammonium nitrate	kg		845.0	0	1.24	1047.8	0
Ammonium sulphate	kg		1780.0	179.0	0.46	818.8	82.3
Borax	kg		180.9	73.5	1.20	217.0	88.2
Calcium nitrate	kg		36415.0	18925.0	0.62	22577.3	11733.5
Copper sulphate	kg		42.2	15.9	3.00	126.7	47.6
Ferrilene	kg		643.5	155.0	10.45	6724.6	1619.8
Librel 3% liquid	l	1.25	2673.1	2250.0	1.74	5814.21	4649.1
Magnesium nitrate	kg		10347.5	1370.0	0.65	6725.9	890.5
Magnesium sulphate	kg		36895.0	12227.0	0.36	13282.2	4401.7
Manganese sulphate	kg		132.5	58.0	1.20	158.9	69.6
MAP	kg		305.0	0	1.85	564.3	0
MKP	kg		1592.5	4345.0	2.30	3662.8	9993.5
Nitric Acid	l	1.33	140.9	0	0.70	91.6	0
Phosphoric acid	l	1.6	325.6	0	1.30	657.3	0
Potassium nitrate	kg		34270.0	7048.0	1.40	47978.0	9867.2
Potassium sulphate	kg		0	925.0	1.15	0	1063.8
Sodium molybdate	kg		27.6	15.9	22.00	606.1	348.7
Zinc sulphate	kg		133.6	52.4	1.10	147.0	57.6
Total			**126750**	**51629.87**		**111200.5**	**44913.0**
Per m^2			**2.76**	**3.23**		**2.4**	**2.8**

4.5.1.4 Fertilizer used and costs

A summary of cost of fertilizers applied and used in the soil and the cocopeat system was computed for 2013 (Table 4.9).

Table 4.9: Summarized cost of fertilizers applied and fertilizers in the drain water

Fertilizer costs	Soil system	Cocopeat system	Difference (soil vs cocopeat)
Fertilizer applied (kg m^{-2})	2.8	3.2	+14.6%
Fertilizer in drain (kg m^{-2})	n.a.	1.7	
Costs applied fertilizer (USD m^{-2})	2.4	3.0	
Value re-used fertilizer (USD m^{-2})	n.a.	2.2	
Final costs (USD m^{-2})	2.4	0.8	-1.6 USD (-KES 137.8)* -66.7%

* Exchange rate of 2013: 1 USD=KES 86.1

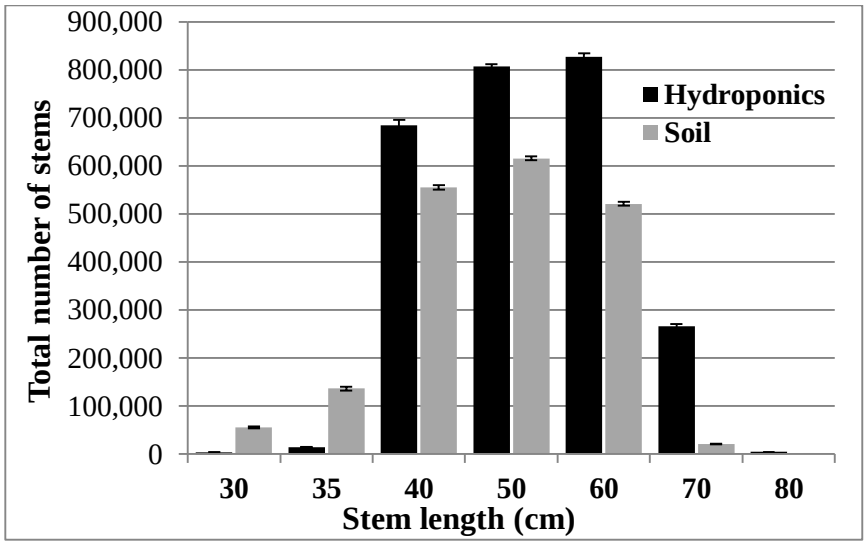
4.5.2 Income from marketed stems

The turnover was 53% higher in the cocopeat system compared to the soil system for the whole period. This difference was significant ($P<0.01$). The higher revenue is due to the overall higher number of stems produced in the cocopeat system (37% more stems) compared to soil system as well as higher number of longer stems that fetched a higher price. The total number of stems was 1,905,044 for soil and 2,608,661 for cocopeat system for the whole year, a difference of 703,617 in 2013. The turnover data is summarised in Table 4.10.

Table 4.10: Turnover from marketed stems of soil and cocopeat systems

	Turnover (€)		**Benefit (€)**
Treatment	Soil system	Cocopeat system	(Cocopeat – Soil)
For 16000m^2	€ 376,123	€ 576,015	€ 199,892
Per m^2	€ 23.5	€ 36	€ 12.5
Percentage			53 %

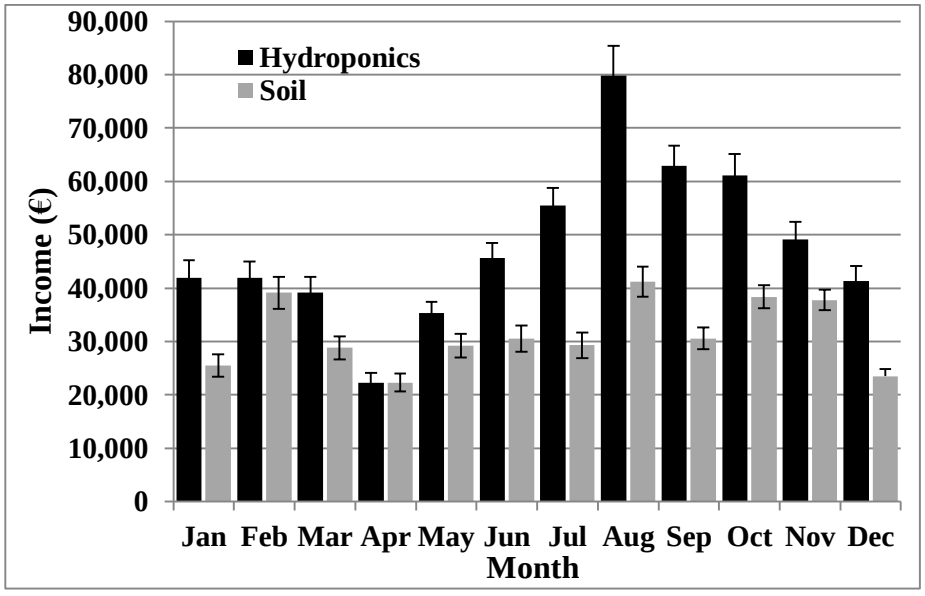
Stems in cocopeat system comprised mainly of 50 cm and 60 cm stem lengths whose volume amounted to a total 800,000 stems per stem length sold in 2013 (Figure 4.30). Soil system comprised 40 cm, 50 cm and 60 cm whose volume amounted to 500,000 stems per stem length.



Vertical lines represent ± standard error

Figure 4.30: Number of stems sold per length in 2013 for soil and cocopeat systems

There was more income earned from cocopeat system compared to soil system throughout the year (Figure 4.31). The month of August had the highest income for cocopeat system and the month of September for soil system. In the month of April, the income generated from sold stems was the lowest for both systems.



Vertical lines represent ± standard error

Figure 4.31: Income earned in Euros for soil and cocopeat systems per month in 2013

CHAPTER FIVE

5.0 DISCUSSION

5.1 Rose growth, production and quality

The SPAD reading at the top and middle canopy of the plants grown in cocopeat system differed significantly from soil system. This may be associated with differences in leaf chlorophyll and nitrogen content as was observed in Durum wheat by Wang *et al.* (2014). It has been proven that the cocopeat (soilless) system offers better possibilities for an optimized fertigation regime and better nutrient availability than soil system leading to higher growth rates, and a higher total weight of stems (Pardossi *et al.*, 2011).

The two treatments were placed in the same greenhouse, which led to plants in these treatments growing under the same air temperature. Since the number of leaves per stem is a developmental character that is mainly temperature-dependent (Marcelis-van Acker, 1995; Pasian & Lieth., 1994), there was no difference between the two treatments in number of leaves. ROSESIM, a computer simulation model of the growth which uses day and night temperatures to simulate vegetative growth of roses, is also indicative of the role of temperature in the developmental period of a stem (Hopper *et al.*, 1994).

The production in numbers and weight per m^2 was significantly higher in the cocopeat system compared to soil system, which resulted in a higher average stem weight. The higher cumulative weight and the greater number of stems that were obtained from the cocopeat system in comparison with the soil system were possibly associated with a higher total dry matter production as the result of a better water and nutrient management (Cabrera, 2002) and higher chlorophyll content in leaves which is associated with leaf nitrogen and photosynthesis (Wang *et al.*, 2014). Elsewhere, in India, a substrate with soil and cocopeat (2:1) was used among other substrates viz., soil: farmyard manure (F.Y.M) (2:1), soil: vermicompost (2:1) and soil: rice husk (2:1) to study the interactive effect of growing substrates and fertigation for commercial cut rose production in export market lead variety ‘Grand Gala’. This was along with four fertigation doses including various

doses of NPK viz., 50 ppm NPK, 100 ppm NPK, 150 ppm NPK and no fertilizers. Results showed that the soil: cocopeat along with 150 ppm NPK was the most effective in increasing the number of flowers per m^2 (Bisht *et al.*, 2013). When this is related to our study, it shows that cocopeat media results to a better production of roses in terms of quantity.

Crop management practices such as fertigation, irrigation, pruning, pinching, and disbudding were of great influence in levelling the number of stems and total fresh weight in soil and cocopeat systems. For instance, stems in the cocopeat system were initially (in 2012) longer than in the soil system in the first harvested flushes. Crop management was adjusted such that in 2013 stem length was similar for both treatments (driven by commercial motivation), and this resulted in a higher number of stems in the cocopeat treatment. Consequently, stem length, leaf length expansion, and flower head diameter and width did not differ significantly between both systems. These findings are similar to those of Jiao and Grodzinski (1998), who did not find significant differences for flower size, number of nodes and internodes for roses grown in soil and tuff. However, the significant treatment difference in chlorophyll content from our study does not correspond with some reported results (Maloupa *et al.*, 2001). These authors reported that there were no significant differences in net photosynthetic rate, stomatal conductance and intercellular CO_2 concentration for plants grown on different substrates. Also, Ahmad *et al.* (2013) did not find significant differences in total leaf chlorophyll of rose cultivars in cultivars grown in the open field and greenhouse systems. On the other hand, the distinct differences between their two systems led to higher values for parameters such as plant height, number of leaves per branch, leaf area, days to flower, number of flowers per plant per flush and, flower diameter for greenhouse grown plants compared with field cultivated. From our study, the rose crop grown on cocopeat enjoyed a more favourable nutrient application regime, which resulted in a higher photosynthetic capacity, as shown by the higher SPAD values, as well as higher total stem weight.

Water Productivity in terms of annual weight of stems was 77% increase by use of cocopeat system compared to soil system, and 72% increase in terms of number of stems produced by use of cocopeat system compared to soil system. The percentage of WP was higher in weight compared to number of stems indicating that cocopeat system contributed more to stem weight than increase in the number of stems.

Rose plants grown on cocopeat system performed better than in the soil system in terms of production of stems which was higher and could have been due to the elevated EC as was observed in cocopeat system. Research elsewhere done using lettuce showed that higher EC resulted in more nitrate and total reduced-N leading to a faster growth of lettuce (Gent, 2003).

In general, use of soilless media enables the realization of collection of drainage and its re-use in production. In this study, use of cocopeat media resulted in a significantly higher production of roses in terms of number and weight per square meter. Similar results have been shown by Treder (2008) who studied effects of cocopeat on growth and flowering of oriental lily 'Star Gazer' in Poland and found that lilies grown in cocopeat flowered earlier, had better quality expressed as higher fresh and dry weight of flowers and leaves and had longer flower buds compared to those grown in the control substrate which was a mixture of sphagnum peat, bark and sand (5:1:1 v/v).

5.2 Environmental parameters

The day-time absolute minimum and maximum temperatures in the greenhouse and outdoor were 6.9^{o}C and 34.8^{o}C, and 6.4^{o}C and 30.4^{o}C, respectively, which were within the expected range for Naivasha. The recorded day and night temperature ranges for Naivasha are 16-28^{o}C and 8-18^{o}C respectively (Jaetzold & Schmidt, 1983; Gitonga *et al.,* 2014). In this location, greenhouse day temperatures could go up as high as 35^{o}C while night temperatures could fall as low as 6^{o}C as was observed in our study. This is one reason why Naivasha is good for flower production since the DIF (difference between day and night temperatures) ensures high photosynthesis and low respiration. This difference results into

stem elongation when the day temperature is higher than the night temperature (+DIF) as was indicated by Myster and Moe (1995) in a mini review on effect of diurnal temperature alterations on plant morphology in greenhouse crops. The mean greenhouse day and night temperature ranges were21-25^{o}C and 13-16^{o}C, respectively. This was within the ideal temperature for rose production of 20-25°C during the day and 13-16°C at night along with 8 hours of sunlight as stated by Shin *et al.* (2001). There was a slight elevation of temperature in the greenhouse compared to the outside. This was because of the greenhouse effect that is experienced in the protected environments created by the polyethylene cover (Marucci *et al.*, 2012). Temperature in the greenhouse was controlled through natural ventilation by use of automated opening and closing of roof vents and manual opening and closing of side vents.

Day and night-time relative humidity inside the greenhouse were on average in the range of 60-90% for day and night which is expected for greenhouse conditions in Naivasha (Mpusia, 2006). Further specified, day-time relative humidity was in the range of 48-90% and night-time was 78-100%. Relative humidity during sunny days was low compared to cloudy days due to temperature difference. Changes in temperature and humidity involve loss or gain of moisture by air according to psychrometry. Psychrometry, which is a study of the physical and thermodynamic properties of moist air (Abbas *et al.*, 2010), gives an understanding of why heated air can hold more moisture and how moist air will result in condensation when cooled (Abbas *et al.*, 2010).

Outdoor radiation sum of 7205 MJ m^{-2} y^{-1} received for the whole year was high and recommended for production of roses (Abbouda, 2012; Jiao *et al.*, 1991). Indoor radiation was lower than outdoor radiation. If it is assumed that transmission of greenhouse is 90% being a single layer film as was measured by Giacomelli and Roberts (1993), then the indoor radiation sum for the entire one year period was 6485 MJ m^{-2} y^{-1}. Irradiance, which is the measurement of solar power, and temperature strongly influence growth and development of greenhouse roses (Hopper & Hammer, 1991) hence the high production received from our study.

5.3 Water parameters

Use of cocopeat substrate enabled drainage water to be collected from the system and re-used resulting in water savings. Good irrigation practices and technologies have been developed for efficient application of water. These include, and not limited to, recirculation system which involves application of water through drip system and collection of drainage water for re-use in production resulting in saving of fertilizers not utilized by the plant and protecting the environment such as surface water from eutrophication (Becht & Harper, 2002; Becht *et al.*, 2005).

The average daily water use for the cocopeat system was 2.4 l m^{-2} compared to 5.7 l m^{-2} in the soil system and cumulatively, water use in the cocopeat system was 877 l m^{-2} and 2074 l m^{-2} in the soil system representing a saving of 58% over the 12 month period. The amount of water supplied to the cocopeat system was higher than in the soil system. This was as a result of more cycles of irrigation per day and higher volume of water per cycle than in the soil system. In the cocopeat system, irrigation was set automatically to the radiation received per day whereas in the soil system, the conventional way of irrigation was used where the number of cycles per day was determined manually by entering a number. This number was decided upon by farm manager based on his experience and by looking at the prevailing weather conditions of the day though automation could be an option. A similar trend of high irrigation frequency has been observed by other researchers in production of roses and sorghum (O'Shaughnessy *et al.*, 2012; Katsoulas *et al.*, 2006; Bhosale & Dixit, 2012). For example, in a research to determine the effect of irrigation frequency on rose flower production in Greece, it was found that there was improved biomass production as a result of higher irrigation frequency (Katsoulas *et al.*, 2006). These researchers found similar results to our study since we also found that the rose flower production quantity was higher in cocopeat system which had a higher irrigation frequency compared to soil system.

Average EC and pH of the supply water to soil and cocopeat systems differed slightly. The EC of supply water to soil and cocopeat systems of 1.4 mS cm^{-1} and 1.5 mS cm^{-1} and the

pH of 5.4 and 5.6, respectively, were in the correct range for rose production as proposed by Brun and Settembrino (1995). According to them, the optimum EC value for the nutrient solution in soilless production of roses should be1.8 mS cm^{-1}. The pH of the supply solution ranging between 5.2 and 5.7 to the two systems was within the suitable range used for rose production since a pH of 5.5 was recommended by Ehret *et al.*, (2005).

The maximum EC of the irrigation water supplied to cocopeat system was 0.1 higher than that of the soil system which could be due to the buffering effect of the soil. It could also be due to the higher amount of nutrient solution applied to the cocopeat (1168 l m^{-2} yr^{-1}) compared to the soil (1082 l m^{-2} yr^{-1}) which often increases the resultant EC of nutrient solution.

The EC of the drainage solution was higher than that of the supply solution of the cocopeat system which indicated that the relative uptake of water was higher than the relative uptake of nutrients. For example, a linear correlation between fertilizer EC and Begonia leachate EC was observed in a study to assess the effect of water availability and quality on photosynthesis and production of soilless grown cut roses (Erin & Marc, 2001).

As it is practised in other countries, water drained from the greenhouses in Kenya should be re-used so as to reduce pollution of surface or under-ground water bodies. An example of such countries is the Netherlands who have implemented this practise for more than a decade now since total recycling of nutrients became compulsory from the year 2000 (Jolliet, 1999). The pH of the drainage water in our study was lower than the drip, probably due to accumulation of fertilizers which have been shown to decrease pH of leachate in petunia and begonia grown in soilless media MetroMix (Erin & Marc, 2001). The quality of drainage water from the cocopeat system was suitable for re-use in the soil system. The re-use of drainage water contributes to sustainable production since the drainage water is re-used avoiding its discharge into ground water. The nutrients in the drainage water are further used in the soil system reducing the amount of additional fertilizers required for production as was confirmed from the study.

Primary (N, P and K) and secondary (Ca, Mg and S) nutrients had higher concentration in drainage water compared to supply water. Assessment of the drainage solution in cocopeat system indicated accumulation of nitrates which was 29% more compared to supply solution to the system. Therefore, the effect of EC on increased production of marketable stems in cocopeat system could have been through its effect on leaf nitrate which plays the role of an osmoticum by supplementing osmotic pressure in plant cells (Gent, 2003).

Drainage percentage ranged between 50% and 70% and the annual average drainage percentage was 61%. This is similar to what was observed by another researcher working in Naivasha (Mpusia, 2006) in an experiment to compare water consumption between greenhouse and outdoor cultivation of roses. In that study, a complete re-circulation system and irrigation in the greenhouse was done with 30-50% leaching fraction in Oserian farm and an average of 66% in Bigot farm. This percentage was kept at these levels so as to maintain optimal conditions of water supply such as preventing decreased osmotic potential and built up of both essential and non-essential ions in the root zones (Mpusia, 2006). The result of this study showed that water consumption in the outdoor was higher than in the greenhouse hence higher water requirement of outdoor grown plants due to more evapotranspiration and leaching in the outdoor system.

There were no bacteria observed in the analyzed sample of drainage water and the only fungus detected was *Fusarium oxysporum*, which is seldom harmful to roses. Only a few strains of *Fusarium oxysporum* can block the veins of the rose plant which can result in wilting and yellowing of the leaves (Clematis *et al.*, 2009). The saprophytic nematodes detected in the samples of drainage water were not harmful to the crop as was advised by the consulting company. This was because the nematodes live on dead organic material, fungi and bacteria.

5.4 Benefit analysis

The fertilizer applied to soil system was 2.8 kg m^{-2} yr^{-1} (equivalent to 706 KSh m^{-2} yr^{-1}) and 3.2 kg m^{-2} yr^{-1} (equivalent to 807 KSh m^{-2} yr^{-1}) applied to the cocopeat system. Drainage water was collected from the cocopeat system and the fertilizer in this water was

1.67 kg m^{-2} yr^{-1} (equivalent to 421 KSh m^{-2} yr^{-1}) which was re-used in the soil system. As a result of the re-use of the drainage water, savings were made on the total costs of fertilizer used in cocopeat system resulting in a turnover of 53% higher in the cocopeat system compared to the soil system.

Water was saved from the cocopeat system through the collection of the drainage water and its re-use in the soil system, hence a lower net use of water and savings on fertilizers used in the cocopeat system. In a production system where water is not re-used, these findings would suggest a higher water use by the cocopeat system. This would depend on the fertigation strategy to maintain an EC level that is favourable to the crop. In the case of this experiment, a relatively high volume of drainage water was required to flush excess Na from the system. In practice, nearly always soil systems are nearby close to a hydroponic system and, therefore, cocopeat cultivation does offer water and nutrient saving strategies if the cocopeat and soil systems are combined in the water balance.

Cumulative number of stems produced in 2013 was greater in the cocopeat system compared to the soil system by 53%. Within a specific length grade, cocopeat system had longer stems compared to the soil system with a significant difference. This was shown by having more of 60 cm, 70 cm and 80 cm stems in cocopeat system compared to the soil system which had 30 cm, 35 cm, 40 cm and 50 cm stems. This resulted in more income being earned from the cocopeat system compared to the soil system throughout the year.

At a first glance, a cocopeat system seems to be more profitable than a soil system: savings on water and nutrients, and more harvestable quality stems. However, Van der Maden *et al*. (2011) indicated that the costs of using a cocopeat-based irrigation system were higher than using soil in Ethiopia. However, more data such as costs of pesticides, hardware installation of the system, electricity costs and any other cost is required to ascertain the economic benefits of using cocopeat system in Kenya. Further research could provide more detailed information on the farming system which could give more clarity and offer growers the information to make an informed decision.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

The environmental factors for soil and cocopeat systems were similar since rose plants grown on these systems were raised in the same greenhouse. These included day and night temperature, radiation, relative air humidity and VPD. Under these similar conditions, cocopeat system performed better in terms of number, weight, and length of stems than soil system. In addition, cocopeat system resulted in a higher turnover in terms of water and fertilizers used due to the drainage water collected from the system beingre-used in an adjacent soil system.This contributed to sustainable production since the drainage water was re-used avoiding its discharge into ground water.

Growth parameters of rose plants were not significantly affected by the substrate under the same greenhouse climatic conditions. However, there were significant differences in the number of stems and SPAD value. It is likely that the optimized fertigation regime in the cocopeat system led to higher growth rates and enabled a higher stem production.

From the laboratory analysis of drainage solution, a treatment against nematodes was not directly necessary as was advised by laboratory services provider to the farm where this study was taken. Substrate cultivation therefore offers the possibility to more directly control the availability of water and nutrients and avoid temporal shortages.

6.2 Recommendations

6.2.1 Recommendations for further research

This study was carried out for one and a half years with one variety called Upperclass of *Rosa hybrida*, produced in a commercial greenhouse with one substrate of cocopeat media and a control in soil. The systems were set up and planting done in the first half year and data collection in the next one year. The results of this research showed that cocopeat media was better performing than soil but this cannot be fully concluded since one variety, one media and a control were involved for one year. It is therefore recommended that further

research be carried out with different varieties of roses and for a longer period of two or three years since roses are perennial crops and better results can be achieved when data is collected for a longer period.

This study was done in one location, Naivasha, Kenya. More research can be carried out in different areas so as to have data of roses grown in different locations of Kenya and especially in the flower production areas.

In this study, open re-circulation system was used where drainage water from the cocopeat system was re-used in the adjacent soil system. It is recommended that further research be done on closed re-circulation system where drainage water collected from a cocopeat system is re-used in the same system. Better results will be achieved if this is done with replications, though it would be very expensive.

6.2.2 Recommendations for growers and policy makers

It is recommended that rose growers can adopt the use of soilless media and water recirculation to save on water and increase production based on the benefits realized from sales of marketable stems and fertilizer collected from the drainage. Different types of media apart from cocopeat used in this study can be exploited since cocopeat is mostly imported and has high initial costs. Pumice, or tuff as some call it, is locally available in Kenya and growers can cheaply acquire.

Growers would be able to meet the environmental regulations and policies if they implement this system because of the sustainable water use by recirculation of drainage water while saving on the fertilizers and increasing production at the same time.

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APPENDICES

Appendix 1: List of Publications

1. Ketter, N. C., Wesonga, J. M., Wariara, K., Elings, A., & Hoogerwerf, F. (2013, September). Evaluation of a Cocopeat-Based Substrate System for Rose Production in Naivasha, Kenya. In *I International Symposium on Ornamentals in Africa 1077* (pp. 111-119).

Appendix 2: Data analysis

t-Test: Two-Sample Assuming Equal Variances Top leaves

	Variable 1	*Variable 2*
Mean	51.66	48.17
Variance	27.45	11.71
Observations	150	150
Pooled Variance	19.58	
Hypothesized Mean Difference	0	
df	298	
t Stat	6.83	
P(T<=t) one-tail	2.39E-11	
t Critical one-tail	2.34	
P(T<=t) two-tail	4.78E-11	
t Critical two-tail	2.59	

t-Test: Two-Sample Assuming Equal Variances Mid leaves

	Variable 1	*Variable 2*
Mean	51.37	49.03
Variance	40.02	15.80
Observations	150	150
Pooled Variance	27.91	
Hypothesized Mean Difference	0	
df	298	
t Stat	3.83	
P(T<=t) one-tail	7.66E-05	
t Critical one-tail	2.34	

P(T<=t) two-tail	0.00
t Critical two-tail	2.59