EVALUATION OF SELECTED POTTED ORNAMENTAL PLANTS PERFORMANCE UNDER CAPILLARY WICK IRRIGATION AND FERTILIZER APPLICATION METHODS

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DECLARATION

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

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This thesis has been submitted for examination with our approval as university supervisors.

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DEDICATION

This thesis is dedicated to my dear parents Mr. and Mrs. Delaide Mungai, who always believed in me and encouraged me that I could be anyone I wanted to be in life, if I just worked at it. God bless you always.

"...being confident of this, that he who began a good work in you will surely carry it on to completion until the day of Christ Jesus." (Philippians 1:6, NIV)

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TABLE OF CONTENTS

DECLARATION .... **ii**
DEDICATION .... **iii**
ACKNOWLEDGEMENTS .... **iv**
TABLE OF CONTENTS .... **vi**
LIST OF TABLES .... **x**
LIST OF FIGURES .... **xi**
LIST OF PLATES .... **xiv**
LIST OF APPENDICES .... **xvi**
LIST OF ABBREVIATIONS AND ACRONYMS .... **xvii**
ABSTRACT .... **xix**
CHAPTER ONE **1**
INTRODUCTION **1**
1.1 Background Information 1
1.2 Potted/Landscape plants 2
1.3 Ornamental Potted Plant Species Used In This Experiment 7
1.3.1 *Epipremnum aureus,* Money Plant 7
1.3.2 *Spathiphyllum clevelandii,* White Anthurium 9
1.3.3 *Chlorophytum comosum,* Spider Plant 9
1.3.4 *Dracaena fragrans,* Corn Plant 10
1.3.5 *Cordyline terminalis,* Red Dracaena 11
1.4 Statement of the Problem 12
1.5 Justification 16

1.6 Objectives 17

1.6.1 General Objective 17

1.6.2 Specific Objectives 18

1.7 Research Questions 18

CHAPTER TWO 19

REVIEW OF LITERATURE 19

2.1 Ornamental Horticulture Production 19

2.2 Water Scarcity 23

2.3 Ornamental Crops Response to Water Scarcity 27

2.4 Irrigation Systems for Ornamental Crops 27

2.4.1 Overhead Watering/Irrigation 27

2.4.2 Sub Irrigation Systems 28

2.5 Capillary Wick Irrigation System 31

2.5.1 Wicks for Capillary Wick Irrigation System 33

2.6 Fertilizer Application methods for Ornamental Crops 34

CHAPTER THREE 40

MATERIALS AND METHODS 40

3.1 Study Site 40

3.2 Soil Analysis 43

3.2.1 Determination of Nitrogen by Kjeldahl method 43

3.2.2 Determination of Phosphorus by Olsen method 45

3.2.3 Determination of Potassium by Flame Photometry method 46

3.3 System Design and Installation 46

3.3.1 Determination of the Amount of Water Used Under CWS and CIS for the Selected Potted Ornamental Plants Production. 46

3.4 Treatments and Experimental Layout..49

3.5 Experimental Layout 49

3.6 Plant Establishment 50

3.7 Data Collection 57

3.7.1 Collection of Weather Data..57

3.7.2 Determination of Water Use and Plant Growth 57

3.7.3 Determination of plant growth 59

3.7.4 Assessment of Fertilizer Application Method on Plant Growth Under CWS 61

3.8 Data Analysis...62

CHAPTER FOUR 63

RESULTS AND DISCUSSION...63

4.1 Soil Analysis...63

4.2 Weather During the Growing Period...67

4.3 Water use for the selected potted ornamental plants 69

4.3.1 Plant Water Use...69

4.3.2 Water Use Under CIS and CWS 71

4.4 EC and pH of the Water Throughout the Season 72

4.5 pH of Drainage Water 75

4.6 Plant Growth and Development 75

4.6.1 Leaf expansion 76

4.6.2 Number of leaves per plant 80

4.6.3 Plant Height 84

4.6.4 Leaf length as Influenced by Irrigation System 88

4.6.5 Leaf length as Influenced by Fertilization Method 93

4.7 Relevance to Landscape Planning and Conservation: Water Conservation 95

CHAPTER FIVE 98

CONCLUSIONS AND RECOMMENDATIONS 98

5.1 Conclusions 98

5.2 Recommendations 99

REFERENCES 101

APPENDICES 122

LIST OF TABLES

Table 1. 1: Different types of water scarcity 15

Table 2. 1: Attributes considered when purchasing ornamental plants........................22

Table 4. 1: Soil Analysis results for the soil used in the experiment 64

Table 4. 2: Greenhouse average monthly temperature during the experimental period of May, 2015 to April, 2016 67

Table 4. 3: Water use in litres under CIS and CWS between May, 2015 and April, 2016 70

Table 4. 4: Average EC and pH values for water supplied to CWS and CIS and drainage from CIS 73

LIST OF FIGURES

Figure 1. 1: Areas of physical and economic water scarcity. 14

Figure 3. 1: Location of the study site: situated within Juja Sub County in Kiambu County, Kenya 42

Figure 3. 2: Schematic diagram of capillary wick irrigation system. Water is conducted from the piping system via the capillary wick to the plant growth media in the container for plant uptake... 48

Figure 3. 3: Experimental layout in the greenhouse for the selected potted ornamental plants under CIS and CWS 49

Figure 4. 1: Average monthly temperature in the greenhouse during the growth period (May, 2015-April, 2016) 68

Figure 4. 2: Cumulative amount of water use under CIS and CWS between May, 2015 and April, 2016. 71

Figure 4. 3: Expansion of *Spathiphyllum clevelandii* leaves grown under CIS and CWS 77

Figure 4. 4: Expansion of *Epiprepnum aureus* leaves grown under CIS and CWS...... 77

Figure 4. 5: Expansion of *Chlorophytum comosum* leaves grown under CIS and CWS 78

Figure 4. 6: Expansion of *Draceana fragrans* leaves grown under CIS and CWS....... 79

Figure 4. 7: Expansion of *Cordyline terminalis* leaves grown under CIS and CWS 79

Figure 4. 8: Number of leaves in *Spathiphyllum clevelandii* plants grown under CIS and CWS 80

Figure 4. 9: Number of leaves in *Epipremnum aureus* plants grown under CIS and CWS 81

Figure 4. 10: Number of leaves in *Chlorophytum comosum* plants grown under CIS and CWS..81

Figure 4. 11: Number of leaves in *Dracaena fragrans* plants grown under CIS and CWS 82

Figure 4. 12: Number of leaves in *Cordyline terminalis* plants grown under CIS and CWS..83

Figure 4. 13: Stem length expansion of *Epipremnum aureus* plants grown under CIS and CWS..84

Figure 4. 14: Stem length expansion of *Epipremnum aureus* plants grown under CIS and CWS..85

Figure 4. 15: Stem length expansion of *Chlorophytum comosum* plants grown under CIS and CWS..86

Figure 4. 16: Stem length expansion in Dracaena fragrans plants grown under CIS and CWS..86

Figure 4. 17: Stem length expansion in *Cordyline terminalis* plants grown under CIS and CWS....87

Figure 4. 18: Leaf length as influenced by irrigation system....88

Figure 4. 19: Leaf length as influenced by fertilizer application method....93

LIST OF PLATES

Plate 3. 1: (a) Cuttings of *Cordyline terminalis,* Red Dracaena and (b) divisions of *Chlorophytum comosum,* Spider Plant, growing in JKUAT, Department of Horticulture tunnels..51

Plate 3. 2: (a) Cuttings of *Epipremnum aureus,* Money Plant; *Dracaena fragrans,* Corn Plant; and (b) divisions of *Spathiphyllum clevelandii,* White Anthurium, growing in JKUAT, Department of Horticulture tunnels 51

Plate 3. 3: *Epipremnum aureus,* Money Plant growing in the greenhouse during the experimental period..52

Plate 3. 4: *Spathiphyllum clevelandii,* White Anthurium growing in the greenhouse during the experimental period 52

Plate 3. 5: *Chlorophytum comosum,* Spider Plant growing in the greenhouse during the experimental period..53

Plate 3. 6: *Draceana fragrans,* Corn Plant growing in the greenhouse during the experimental period..54

Plate 3. 7: *Cordyline terminalis,* Red Draceana growing in the greenhouse during the experimental period..54

Plate 3. 8: The selected potted ornamental plants growing under conventional irrigation system and capillary wick irrigation system, at two leaf stage ..55

Plate 3. 9: The selected potted ornamental plants growing under conventional irrigation system and capillary wick irrigation system at 12 months growth stage..56

Plate 3. 10: A plastic rod used to determine irrigation scheduling in plants grown under CIS 58

Plate 3. 11: Data collection on leaf expansion (a), plant height (b) and number of leaves (c) in the greenhouse as indicated 60

Plate 3. 12: A sample of tagged leaves of *Chlorophytum comosum* and *Cordyline terminalis* for data collection on leaf expansion 61

LIST OF APPENDICES

Appendix 1: Publication 1:..122

Appendix 2: Data analysis 132

Appendix 3: Daily temperature in the greenhouse..134

LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ASALs	Arid and Semi-Arid Lands
BMPs	Best Management Practices
CEC	Cation Exchange Capacity
CIS	Conventional Irrigation System
CRFs	Controlled Release Fertilizers
CWS	Capillary Wick based Irrigation System
dS	deciSiemens
EC	Electrical Conductivity
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
g	Gram
ha	Hectare
HCD	Horticulture Crops Directorate
JICA	Japan International Cooperation Agency
JKUAT	Jomo Kenyatta University of Agriculture and Technology

kg	Kilogram
km	Kilometres
m	metres
ml	Millilitres
MoA	Ministry of Agriculture
MoWID	Ministry of Water and Irrigation Development
NASA	National Aeronautics and Space Administration
pH	Potential of hydrogen
PVC	Polyvinyl chloride
RH	Relative humidity
SAS	Statistical Analysis Software
UN	United Nations

ABSTRACT

Ornamental horticulture industry is a major industry in the world, comprising a complex group of enterprises which consume a lot of water. Water resources are limited all over the world and there is an urgent need to adopt effective irrigation management strategies. With 640m^3 water per capita availability, Kenya for example, is classified as a water deficit country. A number of approaches are being used to enhance efficient water use and to minimize the detrimental effects of water stress in plants. Capillary Wick Irrigation System, (CWS), a subirrigation system, is an innovative technique of irrigation that is simple to install, operate and uses minimal amount of water and fertilizer. This system is not currently widely used in Kenya despite her water scarcity status. It is therefore necessary to evaluate its performance in order to determine its suitability in greenhouse potted ornamental plants production. This study was therefore carried out from May, 2015 to April, 2016 in a greenhouse in JKUAT farm, Juja, Kenya; to evaluate water use and plant growth of the selected potted ornamental plants *(Epipremnum aureus,* Money Plant; *Spathiphyllum clevelandii,* White Anthurium; *Dracaena fragrans,* Corn Plant; *Chlorophytum comosum,* Spider Plant; and *Cordyline terminalis,* Red Dracaena*)* under CWS, Conventional Irrigation System (CIS) of overhead hand watering and different fertilizer application methods in Kenya. The potted ornamental plants were grown in a medium constituted of soil, sand and manure in the ratio of 3: 2: 1 respectively, under CWS and CIS. The experiment was laid out in a split-split plot design replicated three times. The amount of water applied in the two systems was determined weekly throughout the growing period. Vegetative growth in both systems was assessed in terms of leaf expansion, number of leaves and plant height. Leaf length expansion was recorded daily throughout the growing period. Stem length and leaf number were assessed weekly throughout the growing period. The growth data (leaf length expansion, number of leaves, plant height) was subjected to Analysis of Variance (ANOVA) at 5% level of significance. Means separation was accomplished using Tukey's test. After the twelve-month growing period of the ornamental plants, this study revealed that gross water use of the CIS was higher compared to the CWS. Gross water use for the CIS and CWS was 9725 and 3529 litres respectively. The difference was significant ($p \leq 0.05$). This was a 63.75% reduction

in water use when using the CWS compared with CIS. Thus, CWS offers promising potential for water saving during potted ornamental plants production when compared with CIS, given the added benefits of water conservation and reduced nutrient runoff. Leaf expansion was characterized by an initial slow expansion rate followed by a fast expansion rate before levelling off. This study also showed that *Chlorophytum comosum, Dracaena fragrans,* corn and *Epipremnum aureus*; had better growth in terms of leaf expansion and plant height, under the CWS as compared to *Spathiphyllum clevelandii* and *Cordyline terminalis*; which performed better under CIS. However, the differences were not significant ($p \leq 0.05$). The number of leaves produced did not differ between the CWS and CIS. There was no significant difference in plant height of plants in CWS (965 mm) and CWS (935 mm) ($p \leq 0.05$). In this study, it was also observed that fertigation was the best fertilization method for the selected potted ornamental plants under CWS followed by top fertilization and then side fertilization. Therefore, CWS is suited for effectively growing potted ornamental plants without lowering their quality. Adoption of the CWS for potted ornamental plants production is therefore recommended in greenhouses and/or commercial production, since it conserves water and minimizes runoff. This would also translate to increased incomes thus improved standards of living for growers. These findings form a basis for testing the system with a wider range of potted ornamental plants, other crops and ultimately commercialization of the system for the Kenyan conditions. It is expected that this will benefit growers and conserve water as well as the environment from pollution resulting from the application of excess fertilizer.

CHAPTER ONE

INTRODUCTION

1.1 Background Information

The world's supply of fresh water is finite and is threatened by pollution from various sources. Rising demands for water supply for agriculture, industry, and cities are leading to competition in the allocation of limited fresh water resources. Water conservation and water reuse produce substantial environmental benefits, arising from reductions in water diversions and reductions in the impacts of wastewater discharges on environmental water quality (Anderson, 2003). Any attempt to protect water requires a good understanding of the processes involved in leaching (Home, 2000; Home *et al.*, 2002). Leaching causes contamination of ground water and results in higher production costs since more fertilizer is added to replenish lost nutrients (Home *et al.*, 2002).

Water plays an important role in the growth and productivity of plants and must be well managed to maximize production and minimize water use and nutrient loss from the system. Since high quality fresh water is a finite resource and is becoming scarce or very limited in certain areas of the world, the economic and social implications of inefficient water use are becoming more evident. Kenya is such a country, which was classified as a water scarce nation where agriculture consumed 70% of the available water limiting access to water for domestic, industrial, environmental, recreational and energy production uses (Marshall, 2011). In addition, agricultural chemicals in water lost from irrigation systems can result in contamination of ground and surface waters. Minimizing runoff and deep percolation protects the environment by ensuring excess water does leave production units.

An ideal irrigation system allows for optimum moisture conditions in the plant root system and applies just the required amount of water for the plants, with minimum loss. In addition, the irrigation system and its management, should minimize water withdrawals from the water source and keep the source from being polluted by percolation or runoff water that carries agrochemicals, such as fertilizers (Beeson Jr. & Haydu, 1995). Therefore, research on irrigation systems that utilize water efficiently and avoid runoff need to be adopted.

1.2 Potted/Landscape plants

The integration of plants in daily human life has a long history and substantiates our appreciation for their delicacy and wide variation in possible positive attributes such as attractive shapes and colours. Since the very early civilizations, plants were used for medicinal purposes and above all have been part of important cultural and religious customs. Records of their use have been preserved over centuries in different parts of the world and in most, if not all major religions, plants have a featuring role (Labour, 2007).

The ornamental horticulture industry produces all kinds of plants – including trees and shrubs, perennials and annuals, cut flowers and foliage and foliage and flowering pot plants. It is a major industry in the world comprising a complex group of enterprises involved in the production and sale of plants in nurseries and florist crops, design of interior and exterior landscapes and the development of recreational areas for enjoyment.

Production of ornamental plants, most of which is under intensive cultivation consumes a lot of water. Water resources are limited all over the world and there is an urgent need to adopt effective irrigation management strategies (Zegbe-Domínguez *et al.,* 2003). Improvement of efficiency in agricultural water use is of major concern with drought problems being one of the most important factors limiting potted ornamental plants production worldwide (El-Hendawy, Hokam, & Schmidhalter, 2008). Thus, techniques that optimize growth and water conservation are crucial for the Kenyan ornamental horticulture industry.

Growing plants in containers is a unique production system compared to growing plants in field soil open system. According to Van Os (1999) savings of up to 30% of water and up to 40% of fertilizers are possible in closed systems when compared to traditional open system production. Various methods geared towards reducing environmental impacts of ornamental container crops production include irrigation and water runoff management strategies. Best management practices, BMPs, prevent or reduce discharges of pollutants (Yeager & Henley, 2004a). The BMPs philosophy emphasizes environmental stewardship without reducing crop quality. BMPs can conserve and protect water resources from adverse environmental impacts which might result from cultural practices used to produce plants. BMPs include schedules of activities, maintenance procedures, grading vegetation, structural land modification and other management strategies found practical and effective. BMPs are site specific, therefore not all can be implemented everywhere, but as many as possible should be incorporated into the production systems. BMPs provide uniform production guidelines regardless of nursery or greenhouse acreage or location (Labour, 2007).

Effective management of water for ornamental pot plant production in water-scarce areas requires efficient approaches. A limited water supply inhibits photosynthesis in plants, causes changes of chlorophyll content and components and damage to photosynthetic apparatus. High yields in ornamental plants are dependent on adequate water supply. Internal plant water stress limits photosynthesis through stomatal closure and thereby decreased net carbon dioxide assimilation rate. Water stress is one of the important factors inhibiting the growth and photosynthetic abilities of plants through disturbing the balance between the production of reactive oxygen species and the antioxidant defense, causing accumulation of reactive oxygen species which induce oxidative stress to proteins, membrane lipids and other cellular components (Flexas & Medrano, 2002; Lawlor, 2002; Medrano *et al.*, 2002; Shi *et al.*, 2008).

When fertilizer application is implemented through overhead irrigation systems, BMPs strongly recommend total capture of irrigation runoff with no runoff leaving nursery property. Much of the irrigation water falls between containers, so large quantities of runoff water contain nutrient levels sufficient for growing crops. Most ornamental potted plant growers use overhead irrigation sprinklers to irrigate small container plants because they do not consider individual irrigation emitters on small containers to be economically feasible.

Container grown potted plants in Kenya are commonly irrigated from the top with an overhead irrigation system, usually hosepipes in a greenhouse environment. For home owners, in offices and hotels, the watering is usually done through watering cans. This type of production is especially common for 15 litre container sizes or smaller. However, the overhead method of irrigation is a very inefficient irrigation method for container grown plants since the actual percentage of water reaching the substrate media is in the range of 12 to 50% (Beeson & Knox, 1991).

A number of approaches are being used to enhance efficient water use and to minimize the detrimental effect of water stress in plants. Sub irrigation systems such as ebb-and-flow and capillary wicks (Bainbridge, 2002; Bryant and Yeager, 2002; So *et al.,* 2003; Son *et al.,* 2006) have been developed in response to the limitations of the overhead irrigation systems. While conventional drip systems offer potential solutions to the various problems associated with overhead irrigation, these systems tend to be costly making it difficult for poor Kenyan growers to use them.

Capillary wick irrigation system, a sub irrigation system, which involves the use of a device that delivers water by capillary movement from a reservoir to the plant growing medium has potential to enhance crop production and contribute to food security in Kenya. This innovative technique of irrigation is simple and cheap to install and operate, and uses minimal amount of water and fertilizer (Bainbridge, 2002) making it particularly suitable for resource poor farmers in Kenya. This method has been used in *Prosopis grandulosa*, mesquites (Bainbridge, 2002); *Cercidium floridium,* Palo verde (Bainbridge, 2002);

Kalanchoe blossfeldiana, Kalanchoe (Son *et al.*, 2006) and *Spathiphyllum* plants (Bryant & Yeager, 2002; Yeager & Henley, 2004a).

Wesonga *et al.* (2014) tested the capillary wick based irrigation system with the tomato crop (*Solanum lycopersicon* Mill. cv. Anna F1) with promising results under Kenyan conditions. The same study was able to identify a locally available wick material for use to deliver water into the plant media. Use of this locally available wick material can ensure that the system is affordable to the majority of resource poor growers. Previously, the system had been tested with vegetables such as Swiss Chard and Spinach but the system had not been tested for potted ornamental plants. It was therefore necessary to evaluate its performance in order to determine its suitability in greenhouse potted ornamental plants production. Capillary Wick Irrigation System is suitable for greenhouse production of potted plants to increase efficiency of water and nutrient use (So *et al.*, 2003). This study therefore sought to evaluate the CWS for selected potted ornamental plants production in Kenya, as compared to the CIS, overhead hand irrigation.

Because landscapes are often over-irrigated, there is a great potential for significant water conservation without negative effects by using sub irrigation systems such as the Capillary Wick System. As populations increase there will unavoidably be less water available to meet crop demands. The ability to properly manage and conserve this water will thus have a great effect on the future quality of life in our country.

1.3 Ornamental Potted Plant Species Used In This Experiment

Human ecology, that is, humans in their relationships with the environment, has a history extending up to the times of the Garden of Eden (Genesis Chapter 2:8-14, New International Version). Human species have continued to be biologically well adapted to nature as we have encountered it over that period. Humans are still reliant on plants for everything we need - from food to shelter, supply of the life-giving oxygen, and they also provide the sink for carbon dioxide. Their ancestors also recognized essential roles of plants in providing pleasure, perfumes, peace, piety and glimpses of ‘paradise’(Bergs, 2002). Humans still have the same requirements as our forebears. In contrast, the increasingly rapid growth of modern cities has been only over the last two hundred years (Bergs, 2002).

Plants bring beauty and comfort to our surroundings and contribute to the psychological wellbeing of the people, and remind us of nature (Manaker, 1997; Shibata & Suzuki, 2004). They cleanse our environment, provide natural cooling, sustain wildlife, and provide many other important benefits. Their value is extensive and they are without question a worthwhile asset for healthy sustainable human living.

The selected ornamental plants were chosen due to their availability and also due to the fact that they represent some of the largest families of ornamental plants.

1.3.1 *Epipremnum aureus,* Money Plant

Epipremnum aureum, Money Plant, is native to South Eastern Asia and New Guinea. It belongs to the Araceae family, which contains more than 100 genera. The plant is called a Money Plant because its leaves (round, flat, heart-shaped, dark green and plump) resemble coins. It is a perennial and may be grown as either a trailer or a climber. Young plants bear three to four-inch-long heart-shaped leaves. This plant is grown mainly indoors.

Money Plants require warmer temperatures (15^o to 30^oC) for effective growth. At a temperature lower than 10^oC, the leaves will turn yellow and develop spots. It thrives best in medium to bright indirect sunlight (bright but filtered light); its growth is slowed in environments with low light. In too little or too much light, the leaves will become discolored.

Money Plant requires frequent watering throughout the growth, but over-watering should be avoided. It grows well if the top layer of soil is dried out occasionally. It can be propagated from stem cuttings. It can be grown on moss sticks as a climber or allowed to trail down.

A special characteristic of Money Plant is that it can grow in a water-filled container without any soil. It can survive in a bottle filled with water alone for a reasonable time, if you simply keep changing or refilling the water. Although many plants can be grown hydroponically, money plants can survive on the naturally occurring minerals in plain water, without the addition of nutrients.

Money Plants grown in soil-filled pots prosper if they are fertilized well with organic and inorganic fertilizers. Urea should be applied to the pot frequently, with occasional additions of phosphorus (in the form of single superphosphate or any other phosphate fertilizer). Whether or not it brings you greater material abundance, *Epipremnum aureum*, is a powerful air purifying plant that will clean the air in your house very effectively, due to its particular affinity for Volatile Organic Compounds, VOCs, most commonly in the form of off-gassing from synthetic paint or carpets.

1.3.2 *Spathiphyllum clevelandii,* White Anthurium

Spathiphyllum clevelandii, Peace Lily, is a deep, forest green plant with beautiful white flowers. It's a great general cleanser and air purifying plant that effectively removes all common indoor pollutants generated by furniture, electronics and cleaning products, so much so that it is one of NASA's top-ranked plants for this purpose. The peace lily does well in indirect light and requires minimal watering with the general guideline being once every four to five days. In hotter climates, one may need water more frequently, and water stress is indicated when the leaves begin to weep. It belongs to the Araceae family.

1.3.3 *Chlorophytum comosum,* Spider Plant

Chlorophytum comosum, Spider Plant is a member of the lily family that produces a cluster of foot-long leaves from a crown of fleshy roots. The variegated sort called *vittatum*, with a wide central band of white down the center of the leaf, is most common. A variety called *variegatum* has a white band down the outer margin of the leaf. In hot climates, Spider Plant produces dime-sized, six-petaled white flowers along sprawling, much-branched scapes that may reach 2 feet long. The flowers are interesting but insignificant.

Spider Plant is of South and West African origin and seems to have been introduced into Europe by the end of the 18th century, most likely by the intrepid plant explorer Carl Peter Thunberg (1743-1828). Thunberg, after whom the flowering vine *Thunbergia* is named, was a student of Linnaeus who traveled in South Africa during 1772 and 1773 where he collected seeds, bulbs and dried plant specimens for his botanical work. Capetown was a popular resting place for ships heading home from China and passengers often took home souvenir plants on their return voyage just as we take home trinkets from our travels. It belongs to the Liliaceae family.

1.3.4 *Dracaena fragrans,* Corn Plant

Dracaena fragrans, Corn Plant is a slow-growing, upright evergreen shrub or small tree native to tropical Africa. It belongs to the Dracaenaceae family. The leaves are arching lush green sword-shaped. Only mature plant can produce flower and fruit. The flower is creamy white with a pleasant fragrance; the fruit is an orange berry. Indoor specimens grow best in bright, indirect light and require humidity and warm conditions. If planted outside avoid windy locations. The best know variety is the *Massangeana* with yellow green striped leaves.

Corn Plant requires shade and is tolerant of drought and a wide variety of soil types, though preferring an organic soil. Do not overwater as root rot can cause the plant to die. The cane of the Corn Plant is usually cut into various lengths and rooted into a container in the nursery. Two to several stems grow from the top of the cane cutting, creating multiple head of foliage. Individual leaves can last several years on the corn plant. Propagation is by tip cuttings.

1.3.5 *Cordyline terminalis,* Red Dracaena

The colorful *Cordyline terminalis,* Red Dracaena is perfect for creating a tropical landscape effect, with its smooth, flexible leaves ranging in color from variegated light greens and pinks to very dark reds. It belongs to the *Liliaceae* family. Performing well in full sun or partial to deep shade, Red Dracaena plant needs fertile, well-drained soil and can tolerate only brief periods of drought. Leaf coloration is more pronounced in sunnier locations.

Although Red Dracaena plants represent only a small portion of the potted foliage plant product mix, they are among the most colorful foliage plants. Small leaved selections of Red Dracaenas are finished as small and medium pots and for use in combination planters. Larger multi-branched plants in 6–17-inch pots are produced for largescale interior planting projects.

Larger plants are stepped up to larger pot sizes. Many of the highly colored cultivars are propagated by terminal stem cuttings (tips) which are directly stuck in pots, then eventually sold. If the propagative cane diameter is too small, there could be a problem with cane rot. Colored Red Dracaenas have a higher light requirement (medium to higher light intensity). Leaves of both green Red Dracaena and cultivars of other colors are used in arrangements by florists and can be exported as cut foliage. They are frequently packed with mixed tropical flowers.

1.4 Statement of the Problem

Water is an essential component of every country's economy and quality of life. As a country continues to grow, so does its demand for domestic, industrial, environmental, recreational and energy production uses. Kenya is a generally dry country, as about 80 percent of the country is arid and semi-arid. The high potential agricultural land amounts to only 17 percent, which sustains 75 percent of the population. The average annual rainfall in Kenya is 630 mm with a variation from less than 200 mm in Northern Kenya to over 1,800 mm on the slopes of Mount Kenya.

A principal limitation to increased production of potted ornamental plants is availability and scarcity of water. Most of the production is irrigation supported and is located nearby rivers and streams making it very difficult to produce potted ornamental plants effectively elsewhere. These constraints in production leads to lower quality plants yields and seasonality in production. This is further exacerbated due to the fact that greenhouse potted ornamental plants production is on the rise among both large scale and most small-scale growers and it has provided higher yields and net returns. Water is an important input for greenhouse potted ornamental plants production because irrigation is the only means of application of water to the plants.

Water supply is limited worldwide (Zegbe-Domínguez *et al.*, 2003) and agriculture being a major user of fresh water is greatly affected by decreased supply (El-Hendawy *et al.*, 2008). There is therefore an urgent need to identify and adopt water saving and effective irrigation management strategies. Kenya is classified as a water scarce nation, economic water scarcity (Figure 1.1 and Table 1.1) whose challenges have increased due to deforestation, wetlands encroachment, over grazing and increase of human settlements into areas previously under forest cover. These activities, have grossly contributed to degradation of forest and vegetation cover with a corresponding decline in renewable water resources. As a result, springs, aquifers, rivers and lakes water levels are reducing alarmingly. Agriculture consumes 70% of the available water limiting access to water for domestic, industrial, environmental, recreational and energy production uses (Marshall, 2011). Kenya's water availability per capita is estimated to be standing at 647 m^3 and further projections indicate that it may fall to 245 m^3 per capita by the year 2025. This is way much below the global recommended minimum of 1000 m^3 per capita (Marshall, 2011).

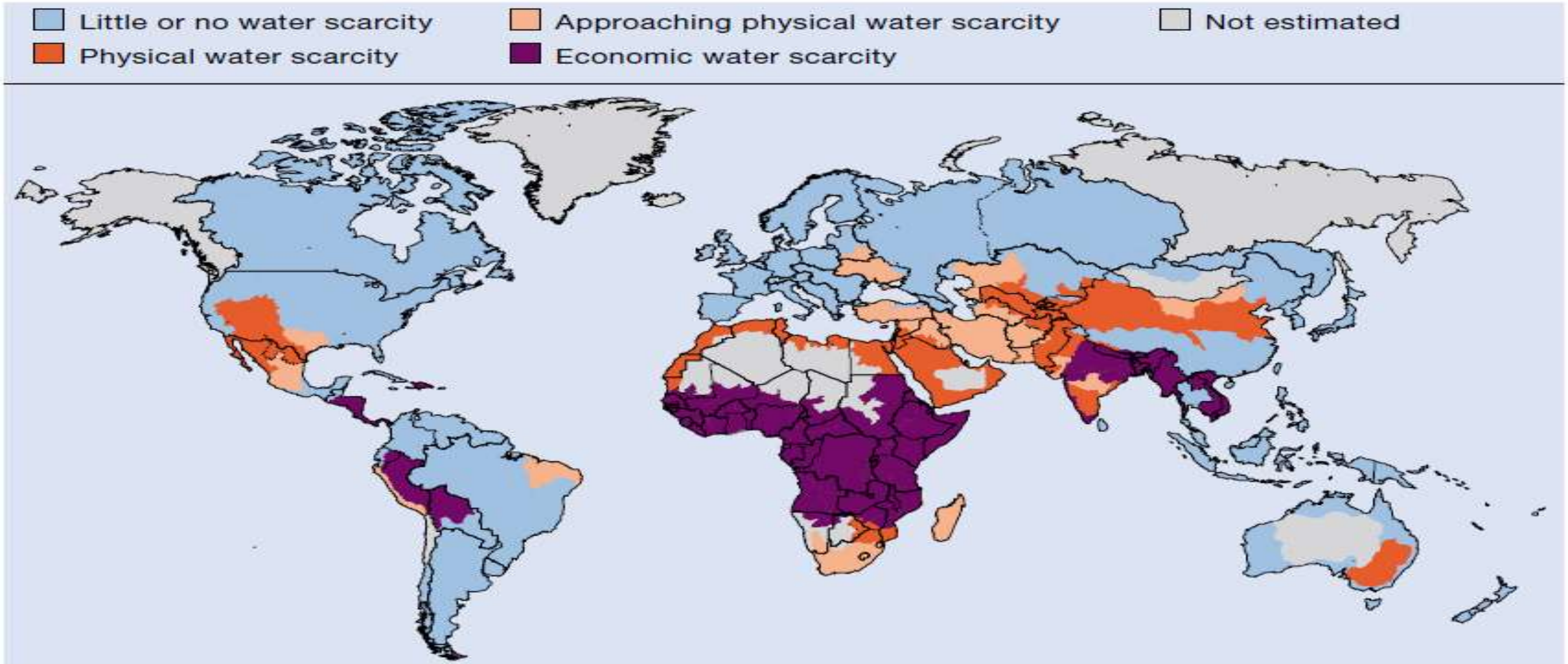

Figure 1. 1: Areas of physical and economic water scarcity (Source: Water Research Institute http://www.wri.org/resource/physical-and-economic-water-scarcity)

Table 1. 1: Different types of water scarcity

Scarcity	Description
Little or no water scarcity	Water resources are abundant relative to use, with less than 25% of water from rivers withdrawn for human purposes
Physical water scarcity	Water resources development is approaching or has exceeded sustainable limits: more than 75% of river flows are withdrawn
Approaching physical water scarcity	More than 60% of river flows are withdrawn and these basins will experience physical water scarcity in the near future
Economic water scarcity	Water resources are abundant relative to water use, with less than 25% of river flows withdrawn, but lack of human, institutional, and financial capital limits access to water and malnutrition exists

(Source: Water Research Institute http://www.wri.org/resource/physical-and-economic-water-scarcity)

The use of drip irrigation system is one effort of making use of water as efficiently as possible under protected cultivation (Hanson & May, 2004; Xie *et al.*, 1999). However, most of the small-scale growers lack capital to install drip irrigation systems. This further becomes a challenge since most potted ornamental plants are consumed indoors in which installation and maintenance of drip irrigation systems is a challenge. Thus, irrigation systems which are simple and affordable to the majority small scale potted ornamental plants growers, with the capacity to improve crop water productivity, need to be adopted.

Majority of these small-scale potted ornamental plant growers apply water manually using buckets and hosepipes, methods that are laborious and inefficient in water utilization. This in turn increases the production cost of the production units for potted ornamental crops and thus making it very expensive and out of reach for small holder growers. Further, the CIS, overhead watering, leads to over watering, results in a lot of water loss and runoff(Dole *et al.*, 1994; Klock-Moore & Broschat, 2001; Son *et al.*, 2006). Also, overhead irrigation systems wet the plant canopy encouraging development of fungal diseases such as powdery mildew (Carroll & Wilcox, 2003) that lower plant quality.

1.5 Justification

Historically, potted ornamental plants greenhouse industry all over the world applies copious amounts of water and fertilizer to maximize crop production. However, contamination of ground water from greenhouse fertilizer runoff has become an increasingly important concern. There are numerous methods for managing water and fertilizer runoff in the greenhouse, including changes in both the type of irrigation system and the type of fertilizer used. Greenhouse container crop production requires frequent irrigation and high fertilization rates, which can result in possible contamination of groundwater sources. Thus, growers must be concerned with environmental conservation practises, as well as producing high quality plants (Dole *et al.*, 1994).

Ornamental horticulture is a major industry in the world comprising a complex group of enterprises involved in the production and sale of plants in nurseries and florist shops, design of interior and exterior landscapes and the development of recreational areas for enjoyment.

Capillary wick is a system of irrigation that is simple to install, operate and can save water and fertilizer. Capillary wicks had not been used previously for potted ornamental plants production and especially under the Kenyan conditions, whether small scale or commercially. It was therefore necessary to evaluate its performance in order to determine its suitability in potted ornamental plants production. The information gathered will provide necessary information that can contribute to adoption of this technology under Kenyan conditions.

1.6 Objectives

1.6.1 General Objective

The general objective of this study was to assess water usage and crop performance of selected potted ornamental plants (*Epipremnum aureus,* money plant; *Spathiphyllum clevelandii*, white anthurium; *Draceana fragrans,* corn plant; *Chlorophytum comosum,* spider plant; and *Cordyline terminalis,* red draceana) under Capillary Wick Irrigation System and Conventional Irrigation System in Kenya and the most suitable fertilizer application method under Capillary Wick Irrigation System.

1.6.2 Specific Objectives

1. To determine the amount of water used under Capillary Wick Irrigation System and Conventional Irrigation System for selected potted ornamental plants production.

2. To determine the effect of Capillary Wick Irrigation System and Conventional Irrigation System on growth of selected potted ornamental plants.

3. To evaluate the effect of fertilizer application method on growth of the selected potted ornamental plants under Capillary Wick Irrigation System.

1.7 Research Questions

This research aimed to provide answers to the following questions:

1. What is the amount of water used to grow the selected potted ornamental plants under Capillary Wick Irrigation System and Conventional Irrigation System?
2. What is the effect of Capillary Wick Irrigation System and Conventional Irrigation System on growth of the selected potted ornamental plants?
3. What is the effect of fertilizer application method on growth of the selected potted ornamental plants under Capillary Wick Irrigation System?

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Ornamental Horticulture Production

For centuries, plants have been a strong influence on our living environment. First century Romans had a highly developed flower trade. They manipulated plants to bloom out of season and used hot water generated in a central location to heat baths and greenhouses. The ornamental horticulture industry is a major industry in the world comprising a complex group of enterprises involved in the production and sales of plants in nurseries and florist crops, design of interior and exterior landscapes and the development of recreational areas for enjoyment. The initial benefits from increased horticultural investment and production are often replacing the gathering of food from the wild and moving to managed cropping (Labour, 2007).

Many people usually take the benefits of amenity and ornamental horticulture for granted, but the benefits can be seen in office blocks and holiday resorts, zoos, urban buildings and offices. In every part of the world, ornamental horticulture, is on display in the home gardens of those who understand and value the beautifying aspects of growing things. The beautification of parks and streets, the green foliage on freeways and the ornamental plants that are the essence of urban landscapes are all part of horticulture's bounty (Labour, 2007).

Every day, about 200,000 people worldwide migrate from the countryside to the cities and on average, people spend more than 8 hours per day indoors (Mburu *et al.*, 2014). This is why the United Nations dedicated the World Environment Day 2005 to “Green Cities”. More than fifty of the world’s largest cities committed themselves to “build an ecologically sustainable, economically dynamic and socially equitable future for our urban citizens.” The agreements call for action aimed at putting cities on a path to greener, cleaner, and healthier environments for their current residents as well as the estimated 1 million people moving into cities each week (Labour, 2007). Increasing density of urban populations is occurring all over throughout the world as people move away from rural agricultural areas.

Landscaping involves engaging in landscape design, construction and maintenance, which includes instruction in constructing and maintaining parks, airports, communities and resorts. It also involves clearing and preparing areas for planting installations, amending soils and installing new ornamental plants. It may also involve building pathways, decks and pods and installing landscape lighting. Landscaping also focuses on caring for properties on which the landscape has already been established. This may include landscape maintenance tasks that are daily, weekly, seasonal and yearly, or done based on need. Such work includes basic irrigation, fertilization, prunning, shaping trees, and mowing lawns. Ultimately, landscaping aims at aesthetic and functional landscapes through proper plant selection, quality and nutritional value (Labour, 2007).

Attributes considered when purchasing potted ornamental plants for use include foliage colour, pests and diseases, quality leaves and stems, ratio of plant to container size, number of stems and container size (Table 2.1);

Table 2. 1: Attributes considered when purchasing ornamental plants

Attribute	Description
Foliage colour	The colour of the foliage should be the correct one for the particular species
Pests and diseases	The plant should be free from damage of pests and diseases so that they can have a high aesthetic value as well as minimize cost of control from pests and diseases
Quality leaves and stems	The stems of the plants should be strong and upright thus exposing the plant to maximum light for photosynthesis. The leaves should be free of for example leaf chlorosis or necrosis
Ratio of plant to container size	The ratio of the plant to the container installed should be appropriate in that it can be as attractive as possible. The pot should not overshadow the plant
Number of stems	Crowded foliage plants in terms of having many stems in relation to the size of the container should be avoided as this increases competition for water, minerals and nutrients thus reducing its successfulness when installed in an interior space
Maintenance practices	This includes inspection, watering, dusting, cleaning, pruning, trimming and so on. The maintenance should be appropriate for the particular pot plantscape that the plant is to be installed in

(Source: Labour, 2007)

There is mounting empirical evidence that interacting with nature delivers measurable benefits to people. In nearly all developed countries, the Ornamental Horticulture industry is well established while in poorer nations it is considered a luxury. Indeed, products and services of the Ornamental Horticulture industry can be placed low on the human hierarchy of needs. However, the industry provides products and services that are of great health, social, economic and environmental benefit. This is especially so in urban landscapes where the danger of people being overwhelmed by the concrete jungles and small spaces is increasingly real.

Ornamental Horticulture products enhance the quality of life inside our buildings (Kariuki *et al.*, 2011). This applies to all kinds of buildings: private houses, apartments, offices, hotels or shopping centres.

2.2 Water Scarcity

Water is one of the most important element for growing a crop, yet it is often the most neglected. Water serves as a medium in which chemical processes such as nutrient uptake and photosynthesis take place. It acts as a coolant through transpiration for both the crop and its environment. Both quantity and quality of water are critical for a good crop (Cornic, 2000; D. W. Lawlor & Cornic, 2002).

Kenya is a largely agricultural economy, with agriculture contributing 27 percent of Gross Domestic Product, employing an estimated 80 percent of the workforce, and providing 57 percent of exports (Musyoka *et al.*, 2010). According to Kenya national water development report, Ministry of Water and Irrigation Development, 2005, the area under irrigation was 120,000 ha, out of a potential area of 539,000 ha (Marshall, 2011).

Water is a finite and life sustaining resource and covers about 70 % of the physical environment, fresh water resources are scarce and unevenly distributed. The amount of water available globally is about 1.4 billion cubic kilometres. Of this amount, 97 % is saline, and is in seas and oceans and is a habitat to diverse marine ecosystems. Of the 3 % fresh water, only less than 1 % is found in lakes and rivers, supporting all our developmental activities. About 2 % of the available fresh water resources is locked up in glacial ice at the poles (www.village – foundations.org, 2009). The fresh water in rivers and lakes thus needs to be managed well for our sustenance and that of future generations.

Freshwater resources are also susceptible to projected climate change impacts. If the observed changes in climate in the last decades persist into the future, the potential impacts on water resources are likely to increase in magnitude, diversity and severity (IPCC, 2007; Kusangaya *et al.*, 2014). Studies show that as demand for water increases across the globe, the availability of freshwater in many regions is likely to decrease because of climate change (WWAP, 2014). The African continent, whose countries' economies are mainly natural resource-based, has been identified as particularly susceptible to the changing climate due to its envisaged low adaptive capacity (Callaway, 2004). Given the already large spatial and temporal variability of climatic factors in areas such as sub-Saharan and Southern Africa (Gallego-ayala & Juízo, 2011), climate change impacts on water resource availability are likely to be more pronounced in the near future than previously foreseen (Gain & Wada, 2014; IPCC, 2007).

To ensure that the world is supplied with food sufficiently, a lot of crops are grown under irrigation (Home *et al.*, 2002). The common methods of irrigation used are surface methods (flood and furrow) and overhead sprinkler irrigation (Clarke, 1993; Home *et al.*, 2002; Pereira *et al.*, 2002). These methods are extensively considered simple and convenient. However, they cause profound water loss through surface runoff that lead to deep percolation that causes leaching(Taiz & Zeiger, 2002). Leaching causes pollution and contamination of ground water and results in higher production costs since more fertilizer applications are needed to replace the lost nutrients (Home *et al.*, 2002).

Greenhouse production is one of the most important sheltered production systems for supply of vegetables, fruits, and ornamental plants. Greenhouse production is an intensive farming method that involves heavy fertilizer and irrigation water use (Ling, 2005). Greenhouse production systems are also some of the highest energy consuming crop production systems. A lot of energy is usually used to maintain optimal environmental conditions for plant growth, fertilization and irrigation (Canakci & Akinci, 2006). Due to its dependence on irrigation, greenhouse production is highly susceptible to effects of currently increasing water scarcity and decreasing water quality (Lea-Cox & Ross, 2001), which may lower profit margins (Nelson, 1990) due to poor quality crops and increased cost of irrigation. Thus, efficient water and nutrient management is critical for continued sustainability and profitability of greenhouse production (Jovicich *et al.*, 2007). Using efficient irrigation methods that reduce or eliminate leaching can reduce water wastage, and reduce costs of greenhouse production (Majsztrik *et al.*, 2011; Million *et al.*, 2007).

Ornamental pot plant production in greenhouses is facing increasing challenges to replace its own Convectional Irrigation System (Klock-moore & Broschat, 2001). The shortage of water has been a severe problem all over the country (E. James & Van Iersel, 2001). The CIS and over watering, results in lots of water loss and runoff. It is very hard to water efficiently pot plants requiring to grow for more than three months because the top portion of plants might cover the surface of pot soil and keep it away from absorbing water (Kimberly A. Klock-Moore & Broschat, 1999). Alternative irrigation systems are needed to supply water efficiently into pot substrate. Over watering, results in infection of disease from soil, contamination of ground water, failure of uniform pot production and low quality of plants (Klock-Moore & Broschat, 2001). Many studies have attempted to find simple and efficient ways to irrigate pot plants in greenhouses (Dole *et al.*, 1994).

With increasing scarcity and growing competition for water, judicious use of water in the agricultural sector will be necessary. This means that exact or correct amount and correct timing of water application should be adopted. In addition, it will need more widespread adoption of deficit irrigation, especially in arid and semi-arid lands (ASALs). Recent advances in new irrigation technologies, such as the CWS, will help to identify irrigation scheduling strategies that minimize water demand with minimal impacts on yield and yield quality, leading to improved food security and enhanced incomes (Marshall, 2011).

The use of drip irrigation system is one effort of making use of water as efficiently as possible under protected cultivation (Hanson & May, 2004; Xie *et al.*, 1999). However, most of the small-scale growers lack capital to install drip irrigation system. This further becomes a challenge since most potted plants are consumed indoors in which installation and maintenance of drip systems is a challenge. Thus, irrigation systems which are simple and affordable to the majority small scale ornamental potted plants growers, with the capacity to improve crop water productivity, need to be adopted.

The availability of water is a major factor limiting crop production in most regions of the world. Inadequate and/or non-uniform distribution of rainfall, low waterholding capacity of most soils, and sensitivity of many crops to water stress and consequent economic yield loss, result in irrigation application to crops. The objective of irrigation is to maintain a favorable plant water environment for proper growth. The irrigation water should be applied in such a manner that it is most effective and efficiently used by the plants (Marshall, 2011).

2.3 Ornamental Crops Response to Water Scarcity

Several ornamental crops including *Pelargonium x hortorum L*. (bedding geranium), *Salvia farinacea* Benth. (mealycup sage), and *Plumbago auriculata Lam.* (plumbago) have been noted to have reduced leaf area, height, and dry weight when exposed to limiting water conditions (Niu *et al.*, 2006; Sánchez-Blanco *et al.*, 2009; Starman & Lombardini, 2006).

Efficient water use depends on timely application of water at right amount at right time in the right way or method. Irrigation scheduling means when to irrigate and how much water to apply in crop field. In other words, irrigation scheduling is the decision of when and how much water to be applied in a crop field. The objectives of irrigation scheduling are to maximize yield, irrigation effectiveness and efficiency, and crop quality by applying the exact amount of water needed by the crop (Morvant *et al.*, 1997).

2.4 Irrigation Systems for Ornamental Crops

2.4.1 Overhead Watering/Irrigation

Overhead irrigation is often the most practical and most commonly used irrigation system for small tropical plant nurseries, producing a wide diversity of species with radically different water requirements, or nurseries in the start-up phase. Overhead watering requires simple and inexpensive equipment; a hose, a couple of different nozzle types, and a long-handled spray wand are all that are absolutely necessary. The watering job will be more pleasant and efficient with a few additional small investments, such as overhead wires to guide the hoses and rubber boots for the staff (Argo & Biernbaum, 1995).

However, even though the task may appear easy, a good technique and the application of the proper amount of water to diverse species of plants in different containers and at different growth stages is very challenging. Therefore, nursery managers all over the world need to ensure that irrigators have a conscientious attitude and are properly trained to work effectively with water application. Overhead irrigation leads to water wastage, unnecessary weed pressure, nutrient leaching, nitrogen loss to the atmosphere, disease pressure, and soil compaction.

Within greenhouses, overhead irrigation is the most widely used system to irrigate plants. Greenhouse technology is the best alternative for using water, land and other resources more efficiently compared to conventional production techniques (Franco & Leskovar, 2002). Overhead irrigation systems are chosen for their simplicity, low-cost, and for reducing fertilizer salt build-up, which can be detrimental to plant growth (Argo & Biernbaum, 1995; Biernbaum, 1992; Molitor, 1990).

2.4.2 Sub Irrigation Systems

Three or four types of sub irrigation systems have been reported since 1970's. Generally used, ebb-and-flow has been highly reported as one way to reduce water use and runoff in Europe and America. However, it needs delicate skill and experience to make water level evenly and more space to arrange pots in greenhouses (E. James & Van Iersel, 2001).

Thus, simple and less expensive systems, which perform as well as the ebb and flow system would be desirable. Pot plant production on a mat moistened with nutrient solution is another way to sub irrigate. However, the roots might come out of the bottom of the pot and penetrate into the mat (Klock-Moore & Broschat, 2001). Whenever the pots are removed from the mat, the roots are injured so severely that the quality of plants decrease remarkably after selling to their final consumers (E. James & Van Iersel, 2001).

Sub irrigation systems have some clear environmental benefits with the most significant being that they use 70 % to 90 % less water compared with many forms of CIS. Sub irrigation improves crop uniformity because plants have access to equal amounts of water thereby reducing or eliminating the edge effect (Schmal *et al.*, 2011). Part of this improvement is because sub irrigation avoids problems with canopy interception and redistribution from overhead irrigation systems.

Several studies have indicated that high quality plants can be grown using sub irrigation systems (Dole *et al.*, 1994; Yelanich & Biernbaum, 1990). Yelanich and Bienabaum (1990) found out that subirrigated plants were of acceptable quality and that excessive runoff produced in greenhouse production can be controlled by decreasing the amount of water and fertilizer solutions. When compared with overhead or top irrigation, an ebb-and-flow sub-irrigation system produced higher quality plants (Dole *et al.*, 1994).

Recirculating sub irrigation systems that capture and reuse the irrigation water have been promoted as a way to reduce greenhouse fertilizer runoff while conserving water. Several reports have been published comparing sub irrigation to CIS for the growth of flowering ornamental crops such as *Euphorbia pulcherrima*, poinsettia (Argo & Biernbaum, 1995; Dole *et al.*, 1994), *Lilium longiflorum*, Easter lilies (Argo & Biernbaum, 1995), *Kalanchoe blossfeldiana*, kalanchoe (Holcomb *et al.*, 1992), *Impatiens hawker,* new guinea impatiens (Kent & Reed, 1996), *Pelargonium hortorum*, geranium (Jaime K. Morvant *et al.*, 1997), *Viola wittrockiana,* pansy (E. James & Van Iersel, 2001), *Petunia hybrid,* petunia (Kimberly A. Klock-Moore & Broschat, 1999), and *Impatiens wallerana,* impatiens (Kimberly A. Klock-Moore & Broschat, 1999).

For example, Cox (2001), found out that poinsettia irrigated by subirrigation have better uniform growth as those watered from the top. In fact, many studies have now shown that subirrigation delivers nutrients in a uniform manner, offers greater flexibility in pot spacing and sizing, reduces the run-off of nutrients, simplifies the nutrient solution management, and increases the nutrient and water use efficiencies (Montesano *et al.*, 2010).

Irrigation methods affect the growth of potted plants regardless of source and rate of nutrient solution (Argo & Biernbaum, 1995; Dole *et al.*, 1994; Molitor, 1990). They influence the water-absorption pattern and various other factors that may affect plant growth (Argo & Biernbaum, 1995; Ku & Hershey, 1992; Molitor, 1990). In a number of studies where current irrigation methods were compared, sub irrigation systems were found to be more economical and efficient than overhead irrigation systems in container plant production (Klock-Moore & Broschat, 1999; Morvant *et al.*, 1998).

Capillary Wick System has many advantages such as continuous water-supply, reducing labour and being able to control the temperature of root medium, however, it also has many disadvantages such as susceptibility to excessive evaporation, algal growth associated with nutrient solution and wick and leakage from culture beds (Jaime K. Morvant *et al.*, 1997).

2.5 Capillary Wick Irrigation System

For greenhouse vegetable and ornamental potted plants production, getting the most water and nutrients to the plants with the least amount of time and money is a significant goal. Growth of containerized plants is affected by irrigation method. A popular method of greenhouse sub irrigation called Capillary Wick Irrigation System (CWS) has been gaining approval in Japan since the 1980s. CWS eliminates the need for irrigation equipment for example, pumps, timers and sensors; because it uses capillary forces to supply the water, and this method is also labor-efficient and economical (Klock-moore & Broschat, 2001; Son *et al.*, 2006).

CWS which involves the use of a device that delivers water by capillary movement from a reservoir to the plant growing medium (Figure 3.2) has potential to enhance crop production and contribute to food security. This irrigation technique combines both the capillarity and suction principles to supply water for plant growth (Budiarto *et al.*, 2013). This innovative method is easy and cheap to install and operate (Bainbridge, 2002), making it particularly suitable for resource poor farmers in Kenya. The benefitial impact of this method has been demonstrated in the production of mesquites, *Prosopis* *grandulosa* (Bainbridge, 2002), Palo verde, *Cercidium floridium* (Bainbridge, 2002), Kalanchoe, *Kalanchoe blossfeldiana* (Son *et al.*, 2006) and Spathiphyllum plants (Bryant & Yeager, 2002; Yeager & Henley, 2004b) among others in various countries, with excellent results.

Although the method is labor-efficient and economical for use with vegetables, it was originally not recommended for long-term use in growing produce, because plants roots can penetrate the wick over time, disrupting and interrupting the water flow and eventually causing lower crop yields. A new root-proof CWS was developed in Japan in 2008 that makes the wick impenetrable to plants roots. In this irrigation system, water is stably supplied by capillary action from the side of the substrate without root invasion into the wick (Masuda, 2008). Plants placed on it get all the water they need through the pot holes because it moves upward through the potting mix by capillary action. The thicker the fabric, the greater the reservoir of water. Many studies have attempted to determine a suitable nutrient concentration to improve tomato cultivation by using this system (Masuda & Fukumoto, 2008; Morishige *et al.*, 2009).

CWS was attempted at several nurseries for mass pot plant production in Japan and South Korea and found to have many benefits such as: avoidance of excess water loss, uniform pot production, reduction in herbicide use, and increase in water use efficiency (E. James & Van Iersel, 2001). A capillary fabric strip (bonded non-woven fabric, manufactured by Wonjin layon Company, Seoul Korea) was put into the pot and used to absorb water in the funnel acting as water reservoir. Dole *et al.* (1994) reported that capillary mat and ebb-and-flow sub irrigation methods did not reduce the amount of water applied but the amount of runoff compared to CIS in poinsettia pot production. Advantages of capillary wick system include continuous controlled water-supply without use of electricity, limited water loss, reduction in labour requirements, time saving and ability to control the temperature of root medium (Klock-Moore & Broschat, 2001; Son *et al.*, 2006). Another major advantage of the capillary wick system is that the use of water in this system will be controlled by the crop water demand and therefore improved crop water productivity meaning more crop per drop of water used.

There has been ongoing research to develop a CWS for use under the Kenyan conditions which has identified a locally available wick material (Wesonga *et al.*, 2014). The performance of the system with different crops has been evaluated and certain challenges identified which require further attention. These include high incidence and severity of blossom end rot in tomatoes which is attributable to inappropriate nutrient management. Wesonga *et al.* (2014) also found out that a 4 L media volume is the most appropriate quantity for use in production of tomato under Capillary Wick Irrigation system. So far, the study focus has been on vegetable production but the system could also be utilized in other areas such as potted ornamental pants whose management is challenging. Thus, application to other crop situations such as potted ornamental plants is also desirable.

2.5.1 Wicks for Capillary Wick Irrigation System

There is limited literature currently on local wick materials for use in Capillary Wick System. Materials which have been tested and used in wick culture systems elsewhere include bonded non-woven fabric (So *et al.*, 2003), polyester capillary mat (Chanseetis *et al.*, 2001) and rolled polyester clothes (Kang & Han, 2005).

Cloth material demonstrated the best attributes for capillary wick irrigation system and was therefore recommended as best suitable wick material (Wesonga *et al.*, 2014). This cloth material is commonly used as a shoulder shawl and is composed of cotton. It was good in water absorption and was not susceptible to rotting thus can be reused in production. Capillary action and durability of the wick material are therefore important attributes for success of Capillary Wick Irrigation System.

Use of locally available material can ensure that the system is affordable to the resource poor growers. In addition to that, generally used, overhead watering results in infection of disease from soil, contamination of ground water, failure of uniform pot production and low quality of plants (Klock-Moore & Broschat, 2001).

2.6 Fertilizer Application methods for Ornamental Crops

Nursery growers and producers fertilize plants to maintain maximum growth, but woody plants grown in containers may have low nutrient use efficiency rates due to inefficient application rates, nutrient addition rates or use of slow-release fertilizers that do not release when plants are in demand for them (Stoven *et al.*, 2006).

The greenhouse industry applies more fertilizer per unit area than any other agricultural system (Molitor, 1990). Minimizing fertilizer and water requirements for greenhouse production has become increasingly important to growers, because many are faced with higher water and fertilizer costs, decreasing availability of quality water, and government regulations aimed at protecting surface and groundwater (James & Van Iersel, 2001; Uva *et al.*, 2001). The only possibility, both to optimize fertilization and keep environmental contamination under control, is to adopt cultivation systems that collect and reuse the extra irrigation water. Hence, closed-soilless systems have been declared ‘‘environmentally friendly’’ because they drastically improve the water and fertilizer use efficiency compared with systems allowing drainage water runoff (E. James & Van Iersel, 2001; Massa & Mattson, 2008; Y. Rouphael *et al.*, 2004; Youssef Rouphael & Colla, 2004).

Greenhouse container crop production requires frequent irrigation and high fertilization rates, which can result in possible contamination of ground and surface water sources. Growers must be concerned with conservation practices, as well as producing high quality plants. The amount of water applied and the frequency at which the plants are irrigated can greatly affect plant growth and runoff (Marshall, 2011).

Recirculating sub irrigation culture has lower nutrient and water requirements, delivers nutrients in a uniform manner, avoids foliar wetting thus preventing diseases, offers greater flexibility in pot sizing and spacing, and reduces the discharge of nutrients to surrounding ecosystems(Santamaria *et al.*, 2003; Yelanich & Biernbaum, 1990). Once a commercial nursery is equipped with CWS, one person is able to manage all the watering works of the nursery. Additional research is needed to verify these benefits in other crops and produce an eye-catching potted ornamental plant with high quality. These benefits lead to savings in labour, material input and product losses (Purvis *et al.*, 2000; Uva *et al.*, 2001).

In sub irrigation systems, elements that are not absorbed by the plant accumulate in the upper part of the substrate where roots are less present rather than accumulating in the nutrient solution as it would do in a drip irrigation system (Incrocci *et al.*, 2006; Rouphael *et al.*, 2008; Rouphael & Colla, 2009). However, salt accumulation at the substrate surface is a major drawback of this cultural technique (Argo & Biernbaum, 1995; Morvant *et al.*, 1998; Rouphael *et al.*, 2008; Rouphael & Colla, 2009). This problem can be exacerbated by high fertilizer application rates. Commercial greenhouse growers typically use high nutrient concentrations in an attempt to maximize crop yield.

This practice does not present an economically optimized production strategy, since excessive nutrients do not necessarily translate into higher yields. Several publications have documented the advantages of using a low nutrient solution concentration for greenhouse cultivation of pot ornamentals. For instance, Rouphael *et al.* (2008) showed that macronutrient concentrations, commonly used by commercial greenhouse geranium growers, can be reduced by 50 % during the winter cropping cycle without having any adverse effect on shoot dry weight, growth and quality index. Similarly, for potted gerbera production, Zheng *et al.* (2004) demonstrated that current nutrient application rates could be reduced by at least 50 % without any detrimental effect on plant growth and quality.

Waste water discharged from nurseries presents a significant threat to ground and surface water; the primary concern being the release of nutrients resulting from regular use of water-soluble fertilizers. This is because the rate of fertilizer application is higher in greenhouse production than many other forms of agriculture (Molitor, 1990).

Part of this improvement is because sub irrigation avoids problems with canopy interception and redistribution from overhead irrigation systems. In container nurseries, as leaf area and density increase, irrigation application efficiency decreases (Beeson & Knox, 1991). Further, container size may also affect irrigation efficiency, for example, small container sizes at high densities combined with large leaf areas will likely cause a decrease in efficiency. Along the same lines, studies characterizing water use have found improved efficiency in sub irrigation versus overhead irrigation systems (Morvant *et al.*, 2001; Santamaria *et al.*, 2003), assuming tanks are not emptied and refilled regularly.

Similarly, because no nutrients are lost from the system, nutrient use efficiency has also been shown to be similar or better in sub irrigation systems, especially when combined with controlled-release fertilizer (Morvant *et al.*, 2001; Richards & Reed, 2004). Further benefits may include improved growth and flowering (Yeh *et al.*, 2004).

When fertilizer is injected in the overhead irrigation systems, best management practices strongly recommend total capture of irrigation runoff with no runoff leaving nursery property. Much of the irrigation water falls between containers, so large quantities of runoff water contain nutrient levels sufficient for growing crops. Controlled release fertilizers, CRFs, are synthetically produced products with extended sustained release patterns ranging from several weeks to several months. Growers frequently choose between products with a longevity of 5 to 6 months, 8 to 9 months and 11 to 12 months based on the crops need and how long the crop will remain at the nursery. Most controlled release fertilizers used to supply Nitrogen, Phosphorus and Potassium to nursery crops are plastic, resin or sulphur encapsulated. These fertilizers are more efficient than water-soluble fertilizers, in that a greater percentage of applied nutrients are used by the plant. Conversely, fewer nutrients leach from the root zone since only small nutrient amounts are released through the coating at any point in time. However, this technology is expensive.

Therefore, nurseries diligently employ practices that will maximize the efficiency of the control release fertilizers products. Controlled release fertilizers have labels that provide low, medium and high application rates based on university and growers research for particular container size, application method and plant growth characteristics. Monitoring container leachates can help growers take preventive steps to reduce possible damage to roots due to high electrical conductivity before visible symptoms occur. Some nurseries monitor ECs weekly to determine how they will irrigate each irrigation zone the following week. If leachate ECs are elevated, more water will be applied the following week; if ECs are low, irrigation volume will be decreased in those zones the following week. The BMP manual recommends that growers monitor EC at least once a month (Labour, 2007).

Due to different container and media properties, and frequent irrigation, nutrient use efficiency and potential for runoff and/or leaching are factors that affect water quality and plant growth. Nursery producers must carefully consider irrigation volume to avoid nutrient leaching from containers, but apply enough so that plants can obtain sufficient nutrients for maximum growth (Scheiber *et al.*, 2008). The end product must be saleable to consumers and plant qualities depend on water and nutrient availability during production (Cameron *et al.*, 2008; Sharp *et al.*, 2009). It appears that container-grown plants can maintain optimal growth with varying levels of media moisture capacity, that is, 40% to 100%, (Beeson, 2006), but nutrient availability may be significantly reduced with drier media moisture levels (Buljovic & Engels, 2001; Scheiber *et al.*, 2008; Silber *et al.*, 2003; Xu *et al.*, 2004).

In conclusion, conventional irrigation practices of potted ornamental plants often involve high frequency irrigation events to prevent excessive soil drying given the limited rooting zone (Beeson, 1992). This can be further complicated if growers use outdated approaches to assess water availability (such as feeling how dry the soil is by hand), which is inaccurate and does not account for the water status of the plant. Furthermore, it is still common for ornamental growers to use overhead sprinklers which are inefficient for irrigation placement and thus consume large volumes of water (Cameron *et al.*, 2008). Increasing pressure from consumers, competition from other industries for water availability, and rising water prices is provoking change in the attitude of growers to begin adopting more sustainable approaches to irrigation (Knox *et al.*, 2008).

Since the Capillary Wick System is not currently used in Kenya and its performance with potted ornamental plants has not been studied, there is therefore need to evaluate the performance of the system with the ornamental crops to determine its suitability under the Kenyan conditions.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Site

The experimental site was located within the experimental farm area of the Department of Horticulture at Jomo Kenyatta University of Agriculture and Technology (JKUAT), Juja. (See Figure 3.1). The selected potted ornamental plants were grown in a polythene covered greenhouse at the JKUAT farm, Block A field. Juja is in Thika Sub County of Kiambu County in the southern part of Central Kenya; 36 km North-East of Nairobi along the Nairobi-Thika highway and 1530 meters above sea level (Batjes, 2006). Juja lies between latitudes 3° 35" and 1°45" south of the Equator and longitudes 36º 35" and 37º 25" East (GoK, 1997). The area is generally semi-arid and receives average annual rainfall of 856 mm with a bimodal distribution. The mean annual temperature is 20 ºC while the mean annual maximum temperature is 30 ^{o}C (Kaluli *et al.*, 2011; Muchena *et al.*, 1978).

Muchena *et al.* (1978) described the experimental site to have three types of soils; shallow clay soils (Murram), deep clay soils (Vertisols) and soil associations and complexes. The vegetation is characterized by species which tolerate flooding such as *Acacia-themeda* and common grasses such as *Themeda triandra* and *Aristida adoensis* (Muchena *et al.*, 1978) (Muchena *et al.*, 1978).

The laboratory analyses of the soil samples were carried out at the Horticulture Department Laboratories, Jomo Kenyatta University of Agriculture and Technology (JKUAT).

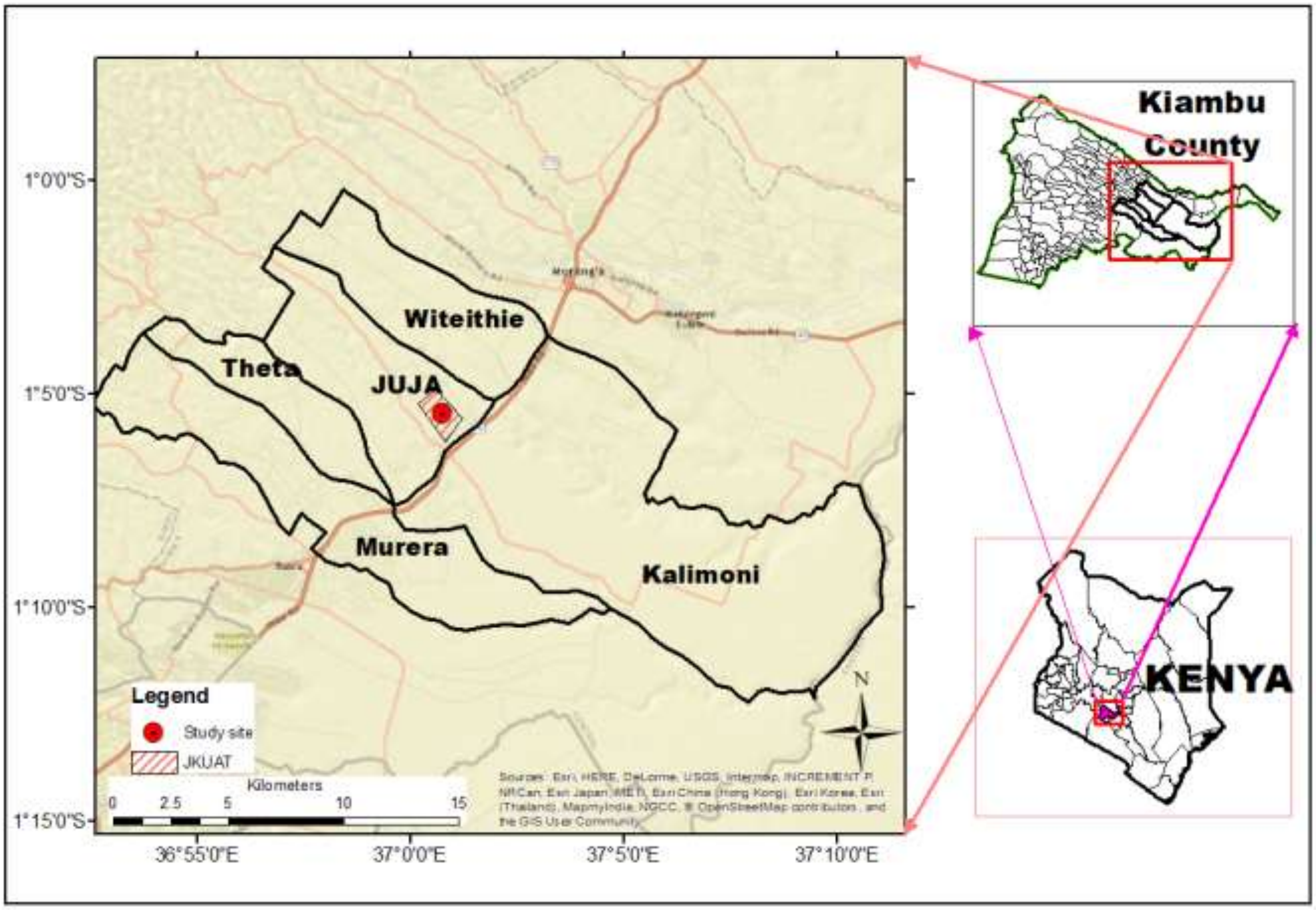

Figure 3. 1: Location of the study site: situated within Juja Sub County in Kiambu County, Kenya

3.2 Soil Analysis

Before setting up the greenhouse experiment, soil tests were conducted to determine initial levels of soil pH, electrical conductivity and percent Nitrogen, Phosphorus and Potassium according to the standard procedure as documented by Okaleboet *et al.* (2002).

The best media for use in the capillary wick irrigation system was selected based on results obtained from previous laboratory experiments. The media mix used was soil: sand: manure in the ratio 3:2:1 (Wesonga *et al.*, 2014).

Forest soil was used as it is more nutrient rich than locally available soil. The soil was black in colour and contained traces of tree leaves and roots; these were removed by passing the soil through a six (6) mm sieve.

The media mix was analyzed for pH, EC, N, P and K. The main objective of these analyses was to determine the nutritional composition of the soil so that necessary amendments could be done to allow vigorous plant growth.

3.2.1 Determination of Nitrogen by Kjeldahl method

The content of total nitrogen in the soil sample is measured in a digester obtained by treating the soil sample state with the digestion mixture which is made of 420 ml of concentrated sulphuric acid, 350 ml of 30 % hydrogen peroxide, 14 g of lithium sulphate and 0.4 ml of selenium powder inside the fume hood. The analysis of total nutrients requires complete oxidation of organic matter. The hydrogen peroxide in the reaction oxidizes the organic matter, while the selenium compound acts as catalyst for the process and the sulphuric acid completes the digestion at elevated temperature.

The immobilized organic nitrogen was mineralized through digestion of sample with concentrated sulphuric acid and digestion catalyst (Kjeldahl, 1883). Nitrogen was converted to ammonium sulphate. When the ash digest was made alkaline with Sodium Hydroxide in the sample solution, then the released ammonia was distilled off. The mixture was then reacted with acidity in boric acid indicator solution and titrated against standard acid 0.01N Hydrochloric acid. Boric acid (5 ml of 1 %) was transferred into 100 ml conical flasks and placed under the condenser of the distillation apparatus. Again, 10 ml of the sample with ash was placed in the boiling tube and 5 ml of 40 % Sodium Hydroxide was added. The contents were distilled till the color changed from red to green. The green color of ammonium borate was back titrated to the red colour. The % N was calculated after determining the amount of 0.01N standard Hydrochloric acid consumed by the sample minus that consumed by the blank over weight of the sample.

$$\% \mathbf{N\ in\ the\ soil\ sample} = \frac{\boldsymbol{a - b * 0.1 * v * 100}}{\boldsymbol{1000 * w * al}}$$

Equation 1

Where;

a = volume of the standard 0.01N HCL consumed by the soil sample

b = volume of the standard 0.01N HCL consumed by the blank

v = final volume of the digestion

w = weight of the soil sample taken

al = aliquots taken for analysis (10ml)

0.1= a constant

3.2.2 Determination of Phosphorus by Olsen method

Phosphorus was determined by Olsen method (Olsen *et al.*, 1954). Soil was extracted with 0.5M solution of sodium bicarbonate at pH 8.5 and extracted in a ratio of 1:20 soil to extracting ratio. Soil sample (2.5 g) was air dried and sieved through a two (2) mm sieve, hence, weighed accurately into a 150 or 250 ml plastic shaking bottles. Then 50 ml of the extracting solution was added (0.5M $NaHCO_3$ pH 8.5) to each bottle. Contents were shaken by a mechanical shaker for about 30 minutes and filtered using what man filter paper no 42 or 44. Filtrate sample (10ml) was pipetted into a 50 ml volumetric flasks; then 5ml of 0.8 M boric acid was added to each flask and 10 ml of the ascorbic acid reagent was added to each flask. The 50-volumetric flask with sample was filled to the mark using distilled water. After one hour, the absorbance of the solution was measured at a wavelength of 880 nm. The concentration of phosphorus in ppm was read from the calibration curve.

The concentration of phosphorus in the sample was expressed as percentage (%):

$$\boldsymbol{P\left(\frac{mg}{kg}\right) = \frac{(a-b) * v * f * 1000}{1000 * w}}$$

Equation 2

Where;

a= the concentration of P in the sample,

b= the concentration of P in the blank,

v= volume of the extracting solution,

f = dilution factor and

w = weight of the sample.

After obtaining P in mg/kg, then convert into mg/100 g soil by dividing by equivalent weight of phosphorus and finally divide by 10 to convert a kg into a g.

3.2.3 Determination of Potassium by Flame Photometry method

Potassium was determined using flame photometer method (Reed & Scott, 1961). The analysis in the photometer was based on the measurement of the intensity of characteristic line emission given by the element to be determined. Hence, 5 ml of the ashed sample was topped to 50 ml and pipetted into 50 ml volumetric flask. The diluted sample was aspirated to the machine just to be able to read the absorbance of the sample in question. Finally, the concentration of potassium was calculated from the constant obtained from the standards in the curve.

3.3 System Design and Installation

3.3.1 Determination of the Amount of Water Used Under CWS and CIS for the Selected Potted Ornamental Plants Production.

The capillary wick irrigation system was laid out in a polythene covered greenhouse using 150 mm diameter reservoir plastic pipes, raised 30 cm above the ground on a metal framework while the conventional irrigation system containers were placed directly opposite beside them on the same metal framework. The metal framework was used as a raised stand on which the potted plants were placed. The distance between the pipes was one meter. The CWS pots were first drilled with three drainage holes of 5 mm diameter at the bottom of the pots, and then on each pipe, holes 4 cm by 0.5 cm were drilled with a spacing of 40 cm through which capillary wicks were to be inserted into the piping system. Capillary wicks, 4 cm in width and 45 cm in length were then dipped in water to saturate them and then inserted to the inside of the pot through the slits of the pots and aligned to the pot's inner wall perpendicularly to the media's surface. Media was then added into the pots. The treatment pots were then transferred to the CWS pipes in the greenhouse and the wicks inserted into the piping system. The part of wick material exposed to the outside was maintained at 4 cm. Plants were fertilized at planting and thereafter at three weeks with 10 grams (g)/plant of Multicote (15:7:25) slow release fertilizer (Amiran Kenya Limited). The troughs in the CWS were held at 1 percent slope. Irrigation water was contained in a 460-litre tank raised 1.8 metres above the ground. The flow of water from the tank into the piping system was automatically controlled using a float valve as shown in Figure 3.2. Water was applied to the conventionally irrigated plants from the top using a calibrated watering can, which required the plants to be watered one by one. The excess water was collected into a saucer drain under each pot for CIS system.

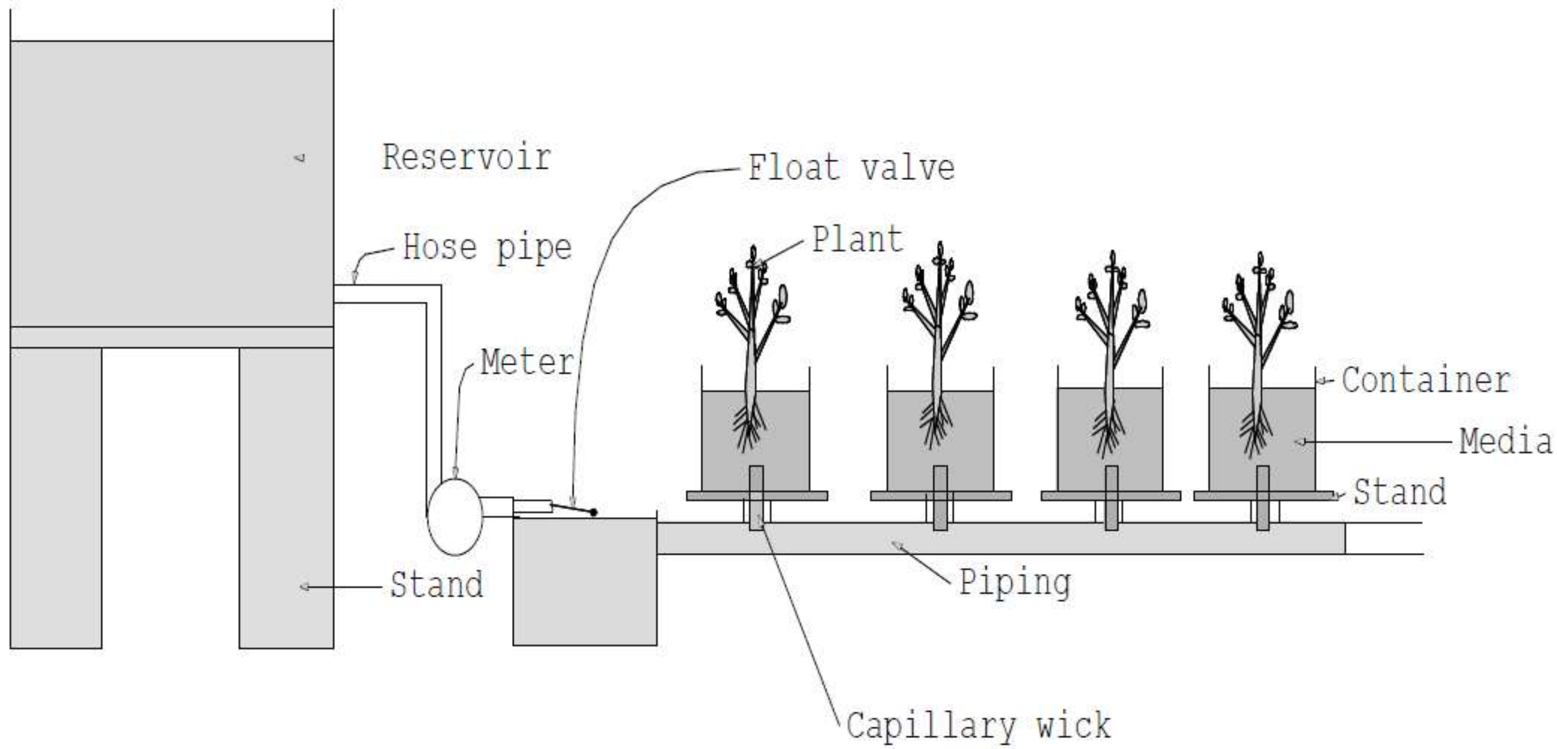

Figure 3. 2: **Schematic diagram of capillary wick irrigation system. Water is conducted from the piping system via the capillary wick to the plant growth media in the container for plant uptake**

3.4 Treatments and Experimental Layout

Performance of the selected potted ornamental plants was evaluated under two irrigation systems in pots of 4 litres capacity with established soil: sand: manure in a ratio of 3:2:1 media mix. The media type was selected based on results obtained from the previous laboratory experiments (Wesonga *et al.*, 2014). Each treatment contained ten pots. The experiment was carried out as a split-split plot in complete randomized design with three replications (Figure 3.3). Three methods of fertilization application namely top fertilization, side fertilization and fertigation formed the main plots while the two methods of irrigation were allocated to sub-plots.

3.5 Experimental Layout

The experiment was laid out as shown in Figure 3.3

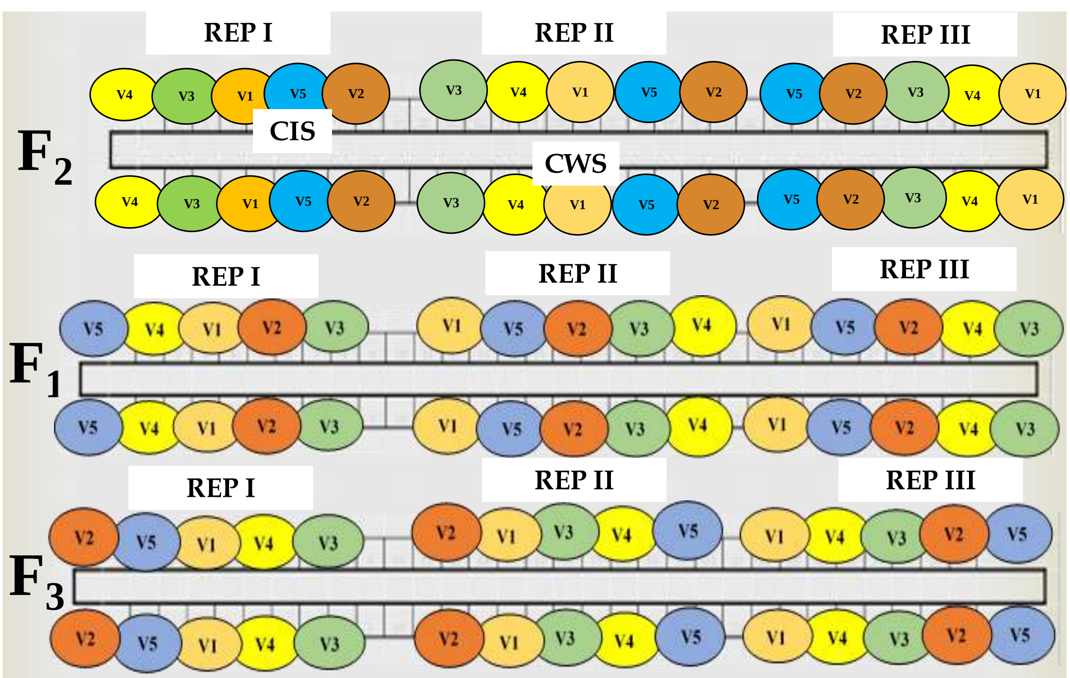

Figure 3. 3: Experimental layout in the greenhouse for the selected potted ornamental plants under CIS and CWS

3.6 Plant Establishment

The plant materials consisted of *Cordyline terminalis,* Red Dracaena; *Epipremnum aureus,* Money Plant; *Dracaena fragrans,* Corn Plant; *Spathiphyllum clevelandii,* White Anthurium and *Chlorophytum comosum,* Spider Plant. They were obtained from Farmline nursery, a commercial ornamental potted plant nursery, in Kasarani, Nairobi.

Cuttings *of Cordyline terminalis,* Red Dracaena; *Epipremnum aureus,* Money Plant; and *Dracaena fragrans,* Corn Plant; and divisions of *Spathiphyllum clevelandii,* White Anthurium and *Chlorophytum comosum,* Spider Plant; were propagated in the Department of Horticulture, JKUAT, nursery tunnels in sixty hole propagation trays, under coco-peat sand mixture while maintaining an EC of 1.2 (Digital EC Meter DEC-2, Atago Company Limited, Tokyo 105-0011, Japan) and pH of 5.5 (Digital pH Meter DPH-2, Atago Company Limited, Tokyo 105-0011, Japan). Cuttings used in this study appeared as shown in Plate 3.1.

Before insertion, cutting bases were treated with rooting powder containing 0.6% indole-3-butyric acid (Hormonil Rooting Powder T-6, Amiran Kenya Limited). After four weeks of growth, with plants at two leaf stage (Plate 3.8)**,** plants were transplanted in Polyvinyl Chloride (PVC) pots of four (4) litres capacity which were used to establish the plants in soil: sand: manure (3:2:1) media mix (Wesonga *et al.*, 2014). The system with plants in place appeared as shown in Plate 3.9.

Plate 3. 1: (a) Cuttings of *Cordyline terminalis,* Red Dracaena and (b) divisions of *Chlorophytum comosum,* Spider Plant, growing in JKUAT, Department of Horticulture tunnels

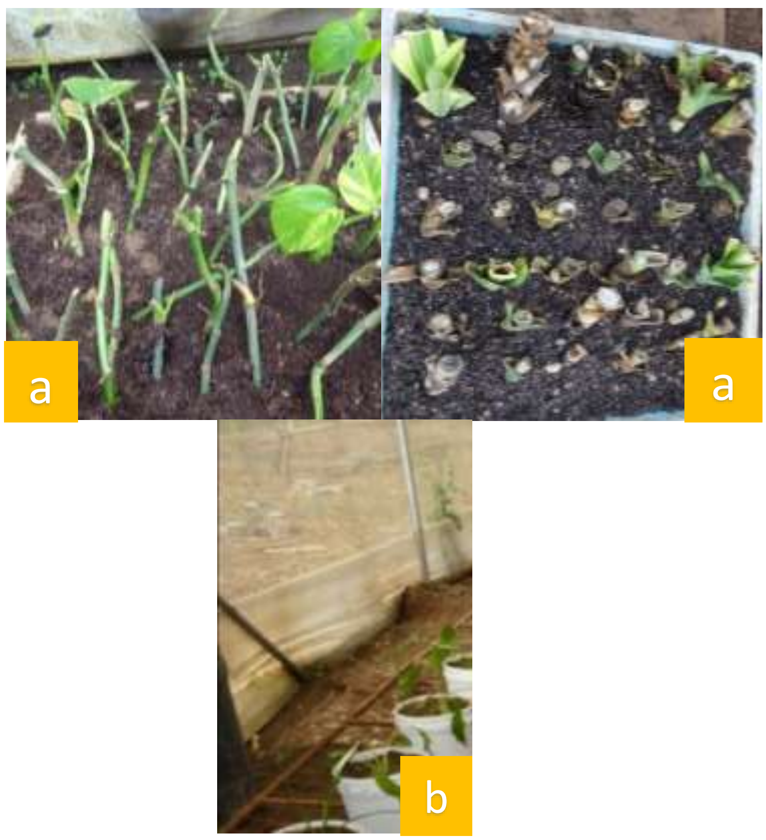

Plate 3. 2: (a) Cuttings of *Epipremnum aureus,* Money Plant; *Dracaena fragrans,* Corn Plant; and (b) divisions of *Spathiphyllum clevelandii,* White Anthurium, growing in JKUAT, Department of Horticulture tunnels

The system with Money Plants in place appeared as shown in plate 3.3.

Plate 3. 3: ***Epipremnum aureus,*** **Money Plant growing in the greenhouse during the experimental period**

The system with White Anthuriums in place appeared as shown in plate 3.4.

Plate 3. 4: ***Spathiphyllum clevelandii,*** **White Anthurium growing in the greenhouse during the experimental period**

The system with spider plants in place appeared as shown in plate 3.5.

Plate 3. 5: *Chlorophytum comosum,* Spider Plant growing in the greenhouse

during the experimental period

The system with corn plants in place appeared as shown in plate 3.6.

Plate 3. 6: ***Draceana fragrans,* Corn Plant growing in the greenhouse during the**

experimental period

The system with Red Dracaenas in place appeared as shown in plate 3.7.

Plate 3. 7: ***Cordyline terminalis,* Red Draceana growing in the greenhouse during the experimental period**

Plate 3. 8: The selected potted ornamental plants growing under conventional irrigation system and capillary wick irrigation system, at two leaf stage

Plate 3. 9: The selected potted ornamental plants growing under conventional irrigation system and capillary wick irrigation system at 12 months growth stage

3.7 Data Collection

3.7.1 Collection of Weather Data

Temperature during the growth period was recorded daily at 10.00 am using a maximum minimum thermometer (Hoogendoorn Growth Management, Vlaardingen, The Netherlands) in mercury. Daily values of minimum, average and maximum temperature were calculated for the experimental period (May, 2015-April, 2016).

3.7.2 Determination of Water Use and Plant Growth

Determination of Water Use under CWS and CIS.

The amount of water applied was assessed on a weekly basis.

Amounts of water applied by both irrigation methods were determined. Water was applied to the conventionally irrigated plants from the top using a calibrated watering can, which required the plants to be watered one by one, while for the plants in the capillary wick irrigation system, they were sub irrigated with wicks placed from the side of the pots. The excess water was collected into a saucer drain under each pot for CIS system. Gross water use was defined as the amount of water applied. Net water use for the CIS was determined as the difference between the amounts applied and drained. Net water use for the CWS was determined as the amount of water applied, as drain water was not experienced. Daily values were cumulated over the twelve-month experimental period.

Irrigation scheduling for ornamental plants irrigated through the CIS involved use of a plastic rod, 40 cm in length and 1 cm in diameter, which was dipped to the growing media at the side of pot. When the wetness of the media was found to be less than a quarter in the growing media from the bottom of the pot, then that indicated dryness of the media at the root zone level and this meant the plants were due for irrigation. This is as shown in Plate 3.10. Irrigation was then applied. For the ornamental plants grown under CWS, water content in the medium was recharged as soon as it was absorbed by plant roots.

Plate 3. 10: A plastic rod used to determine irrigation scheduling in plants grown under CIS

Water saved during the production of the ornamental plants by the CWS as compared with the CIS, was calculated using the below method:

Where;

$$W_{CWS=Water\ supplied\ by\ CWS}$$

$$W_{CIS\ =Water\ supplied\ by\ CIS}$$

$$W_{SV=Water\ saved}$$ ***Equation 3***

Plugging the figures into the formula;

$$W_{SV} = \frac{W_{CIS} - W_{CWS}}{W_{CIS}} X100$$

Equation 4

3.7.3 Determination of plant growth

Plant measurements were taken for all the ten plants in each replication. Plant growth was assessed both on daily basis and on weekly basis. Growth was assessed in terms of leaf length, plant height and number of leaves, as shown in plate 3.11. For leaf length, leaves of approximately equal size were sampled and tagged with a string. The length of each leaf was taken daily along the midrib until the leaves reached maximum length when no more increase in length was recorded. Plant height was measured using a meter rule at weekly intervals starting from the day of transplanting; number of leaves were counted using a leaf counter at weekly intervals starting from day of transplanting.

Plant height and leaf number were assessed weekly since the development of these parts was slower. The plants used were of approximately same initial height.

Plate 3. 11: Data collection on leaf expansion (a), plant height (b) and number of leaves (c) in the greenhouse as indicated

3.7.4 Assessment of Fertilizer Application Method on Plant Growth Under CWS

The selected potted ornamental plants were fertilized at planting and thereafter at three weeks with ten 10 grams (g)/plant of Multicote (15:7:25) slow release fertilizer (Amiran Kenya Limited) using three methods of fertilization namely surface, side and fertigation. A fertigation system was used to apply nutrient solution through capillary wicks to the media. The troughs in the CWS were held at a one percent slope. Irrigation water was contained in a 460 L reservoir tank raised 1.8 m above the ground. The flow of water from the tank into the piping system was automatically controlled using a float valve as shown in Figure 3.2. The leaves used for data collection were tagged for ease of identification for subsequent measurements as shown in Plate 3.12.

Plate 3. 12: A sample of tagged leaves of *Chlorophytum comosum* and *Cordyline terminalis* for data collection on leaf expansion

3.8 Data Analysis

Data was subjected to Analysis of Variance (ANOVA). Means separation was done by protected Fisher's least significant difference (Tukey's HSD) test at significance level of $p \leq 0.05$. Amounts of water applied by both irrigation methods were determined. Gross water use was defined as the amount of water applied. Net water use for the CIS was determined as the difference between the amounts applied and drained. Net water use for the CWS was determined as the amount of water applied, as drain water was not experienced. Daily values were cumulated over the twelve (12) month experimental period.

CHAPTER FOUR

RESULTS AND DISCUSSION

In this study, we sought to evaluate water use and performance of selected potted ornamental plants (*Epipremnum aureus,* Money Plant; *Spathiphyllum clevelandii,* White Anthurium; *Draceana fragrans,* Corn Plant; *Chlorophytum comosum,* Spider Plant; and *Cordyline terminalis*, Red Draceana) under CWS and CIS in Kenya. In addition, the effect of fertilization method on growth of the selected ornamental potted plants under CWS was also assessed.

Since the study involved a sub-irrigation system where water content in the medium is recharged as soon as it is absorbed by plant roots, a major factor which influenced effective growth of the selected potted ornamentals is air-water relationships of the two media and this relationship is directly influenced by the physical characteristics of the substrate. The relative balance of air and water within the pore spaces of a medium is critical to plant growth (Brückner, 1997; Caron & Nkongolo, 1999). This is in line with studies done by Wesonga *et al.* (2014) using Tomato (*Solanum lycopersicon* Mill. cv. Anna F1) as the test crop using CWS.

4.1 Soil Analysis

The forest soil pH and EC was slightly above the optimal ranges of 5.5-6.8 in the case of soil pH and <0.8 ds/m for EC respectively. The major nutrients required for plant growth, that is, Nitrogen, Phosphorus and Potassium were moderate in comparison to the optimal ranges (Table 4.1).

Table 4. 1: Soil Analysis results for the soil used in the experiment

SOIL SAMPLE	pH (H2O 1:2:5)	EC (1:2:5 ds/m)	% N	% K	% P
1	6.82	0.18	0.39	4.56	0.23
2	5.43	0.34	0.21	2.78	0.14
3	5.21	0.37	0.18	1.96	0.11
Optimal Ranges	5.5-6.8	< 0.8	0.3	2.5	0.3

Soil is a dynamic three-dimensional substance that covers some of the world's land surface. It varies from place to place, in response to the five factors that form it: climate, topography, organisms, the parent rock below surface and time. Soil medium assures rapid plants establishment by providing a favorable environment for the developing root system.

Most soils have at least some residual nutrients. Only a soil test can assess this. Wesonga *et al.* (2014) found out that the best media mix for growing plants under the capillary wick system was soil: sand: manure in the ratio 3:2:1 media mix. Thus, before using the media, a test was done so as to determine the fertility level to ensure the ornamental plants are supplied with the right nutrients in the right quantities (Table 4.1). Fertilizing without the results of a soil test leads to a waste of money and the product and can exacerbate an existing nutrient imbalance. In addition, sometimes nutrients are present in sufficient supply but are unavailable because of too high or too low pH.

Both acidity and high salinity affect plant growth negatively and reduced the rate of growth and survival of the plant species. Highly acidic soils (pH<4.0) frequently have low levels of phosphorus, calcium, and molybdenum and high concentrations of aluminum and manganese which are often toxic for plants (Bordeleau & Prévost, 1994). Our study revealed that when the pH was lower than the recommended levels, the available Nitrogen, Phosphorus and Potassium was in lower quantities as compared to when the media mix was having a soil pH in the recommended levels (Table 4.1).

Soil pH, is a description of the soil's acid/alkaline reaction, is affected by land use, land management and vegetation type in the original area of soil formation. The pH scale ranges from 0 (very acid) to 14 (very alkaline). Soils generally range from pH 4.0 to pH 8.0. pH is important because it regulates the availability of individual nutrients in the soil solution. The pH scale is logarithmic; each unit is 10 times more acid or alkaline than the next. For example, a soil with pH 4.0 is ten times more acid than a soil with pH 5.0, and 100 times more acid than a soil with pH 6.0. A soil's pH depends on the parent rock (limestone is alkaline, granite is acidic), rainfall, plant materials and other factors. Individual plants perform best within specific pH ranges. It is just as important to manage pH as fertility. Most garden plants perform well in a soil with pH 6.0 – 7.0.

For example, areas of forestland tend to be more acidic than areas of grass land. Also, conversion of land from forestland or grassland to cropland can result in drastic pH changes after a few years. This explains why the soil pH of our soil sample tended to be more acidic, that is, closer to pH 4, since the forest soil had been transported from Kyeni forest by lorry, around Kamwangi area, in Mangu Sub county, a forest land. It is a distance of about 30 km from JKUAT.

Sand was incorporated to the media mix due to its high porosity and thus better drainage and aeration to the root environment allowing the ornamental plants to access water, nutrients and oxygen easily. Sand also has low Cation exchange capacity (CEC), which is an expression of the soil's ability to hold and exchange cations. Ions are constantly exchanged among the soil solution, CEC sites on clay and humus particles, and plant roots. This is not a random process, but is dependent on electron charge. Clay and humus have high CECs because they are tiny particles with very large surface area-to-volume ratio, with many negative sites that can attract cations. Sand has very low CEC because sand particles are large, with low surface area-to-volume ratio and hence fewer negative sites. Thus, combining the two (Soil and Sand) into the media mix ensures that the ornamental plants are supplied with the required nutrients maximumly (Table 4.1).

Since containerized plants grow at a shallow depth and limited volume of a container, the growing media must provide the appropriate physical and chemical properties necessary for plant growth (Sahin *et al.*, 2005). Similar results by So *et al.* (2003) have shown that medium mixture containing cocopeat is best suited for CWS due to its high capillary action and high gas phase. It is therefore clear that physical properties of a root substrate are the most important characteristics in production of horticultural crops especially under sub-irrigations systems. However, for this study, the media was selected according to Wesonga *et al.* (2014) due to its availability and achieving the same results as that which is amended with cocopeat. This would mean, the poor resource growers, who are the majority ornamental potted plant growers, would easily access it and adopt it in their production units.

4.2 Weather During the Growing Period

The Greenhouse temperature values were recorded daily for period of study (May, 2015-April, 2016). To achieve this, a minimum-maximum thermometer was mounted in the greenhouse to monitor temperature. These values were then used to compute the average for the period of study (Table 4.2). The two treatments were placed in the same greenhouse, which led to selected potted ornamental plants in both treatments to grow under the same air temperature conditions.

For detailed daily maximum, minimum and average temperature values, please refer to the appendix 3.

The mean monthly temperatures during the study period are as presented in Table 4.2.

Table 4. 2: Greenhouse average monthly temperature during the experimental period of May, 2015 to April, 2016

Month	Average temperature (°C)
MAY	32
JUNE	30
JULY	25
AUG	30
SEP	30
OCT	32
NOV	29
DEC	28
JAN	29
FEB	30
MAR	35
APR	36

The mean monthly temperature inside the greenhouse was 30.5 ^{o}C as shown in Figure 4.1. The annual mean of daily greenhouse temperatures ranged from 25 ^{o}C–36 ^{o}C during the growing period. This can be summarized as in Figure 4.1.

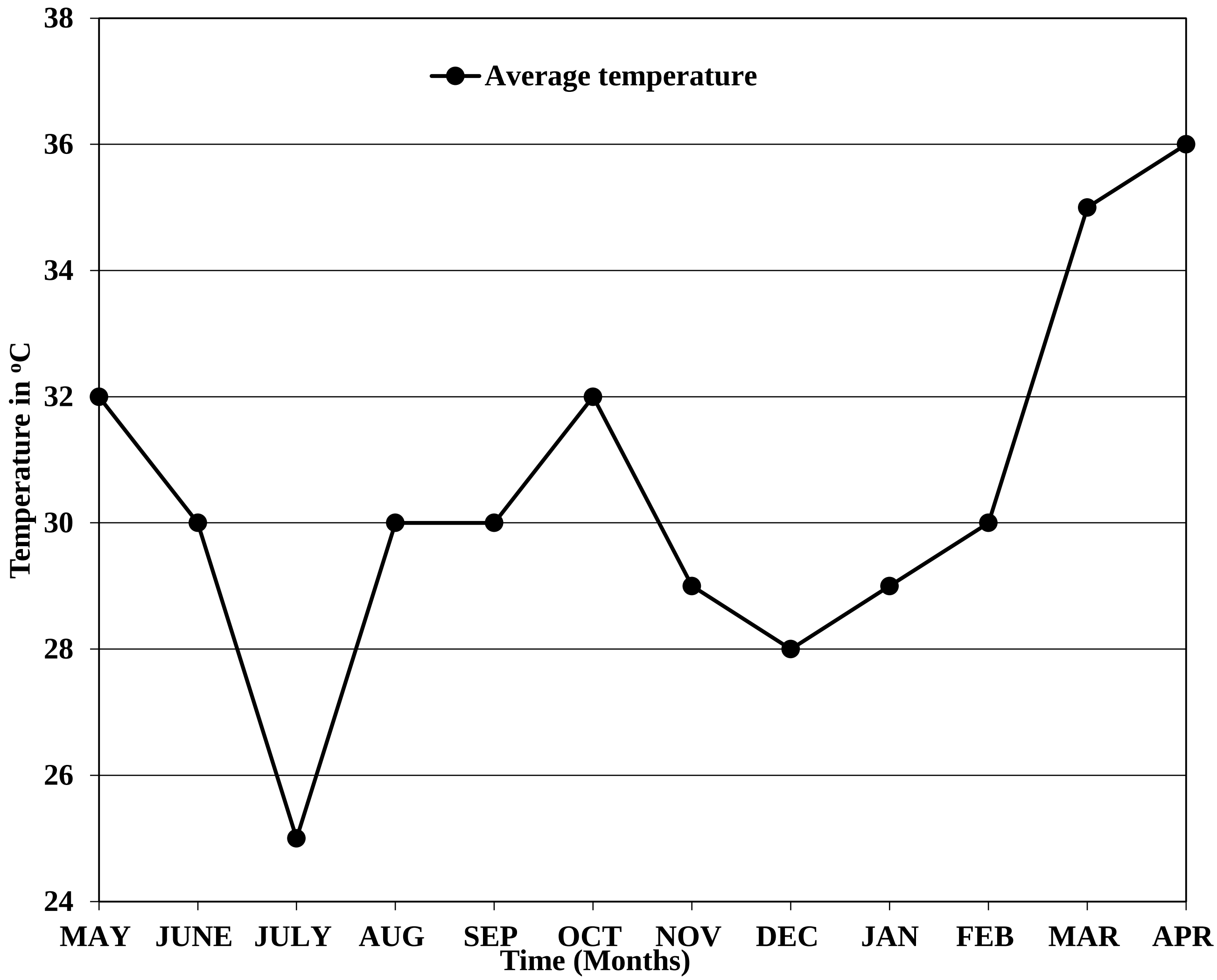

Figure 4. 1: Average monthly temperature in the greenhouse during the growth period (May, 2015-April, 2016)

From this study, it is clear that there was variation in temperature in the greenhouse during a cool month as compared to a warmer month (Figure 4.1), throughout during the growth period, with July, 2015 been the coolest month with an average temperature of 25^{o}C while

April, 2016 was the hottest month with an average temperature of 36^{o}C, which were within the expected range for Juja. This was due to the difference in seasons during the year (Figure 4.1).

4.3 Water use for the selected potted ornamental plants

4.3.1 Plant Water Use

The cumulative plant water use for CWS and CIS is presented in Figure 4.2.

The study revealed gross water use of the CIS system was higher as compared to the gross water use by the CWS system. Over the twelve months growing period, gross water use for the CIS and CWS were 9725 and 3529 litres respectively (Table 4.3). Therefore, water consumption per day per plant for the month of May, 2015 was 0.60 litres/day/plant for the CIS as compared to 0.22 litres/day/plant for CWS; for the month of June, 2015 was 0.59 litres/day/plant for the CIS as compared to 0.21 litres/day/plant for CWS; for the month of July, 2015 was 0.49 litres/day/plant for the CIS as compared to 0.17 litres/day/plant for CWS; for the month of August, 2015 was 0.58 litres/day/plant for the CIS as compared to 0.21 litres/day/plant for CWS; for the month of September, 2015 was 0.57 litres/day/plant for the CIS as compared to 0.21 litres/day/plant for CWS; for the month of October, 2015 was 0.61 litres/day/plant for the CIS as compared to 0.22 litres/day/plant for CWS; for the month of November, 2015 was 0.57 litres/day/plant for the CIS as compared to 0.21 litres/day/plant for CWS; for the month of December, 2015 was 0.53 litres/day/plant for the CIS as compared to 0.19 litres/day/plant for CWS; for the month of January, 2016 was 0.54 litres/day/plant for the CIS as compared to 0.20 litres/day/plant for CWS; for the month of February, 2016 was 0.63 litres/day/plant for the CIS as compared to 0.22 litres/day/plant for CWS; for the month of March, 2016 was 0.66 litres/day/plant for the CIS as compared to 0.24 litres/day/plant for CWS and for the month of April, 2016 was 0.70 litres/day/plant for CIS as compared to 0.26 litres/day/plant for CWS. For the CWS system, the net water use was equal to the gross water use as there was no drainage. The total gross monthly water use for the CIS varied between 690 (July) and 950 (April) litres while for the CWS it varied between 242 (July) and 349 litres (April) (Table 4.3).

Table 4. 3: Water use in litres under CIS and CWS between May, 2015 and April, 2016

MONTH	CIS	CWS	% WATER SAVING
MAY	840 (±18.26)	307 (±8.35)	63.5
JUNE	800 (±31.62)	290 (±6.50)	63.8
JULY	690 (±35.94)	242 (±7.37)	65
AUG	812 (±11.22)	293 (±8.01)	64
SEP	770 (±15.55)	281 (±4.76)	63.5
OCT	847 (±27.55)	310 (±7.02)	63.4
NOV	771 (±13.07)	280 (±11.29)	63.7
DEC	740 (±11.52)	270 (±4.50)	63.5
JAN	750 (±12.69)	275 (±4.15)	63.3
FEB	825 (±16.07)	292 (±3.39)	64.6
MAR	930 (±13.48)	340 (±3.74)	63.4
APR	950 (±7.85)	349 (±3.49)	63.3
TOTAL	9725	3529	
Average (±SD)	(±75.45)	(±29.53)	63.75

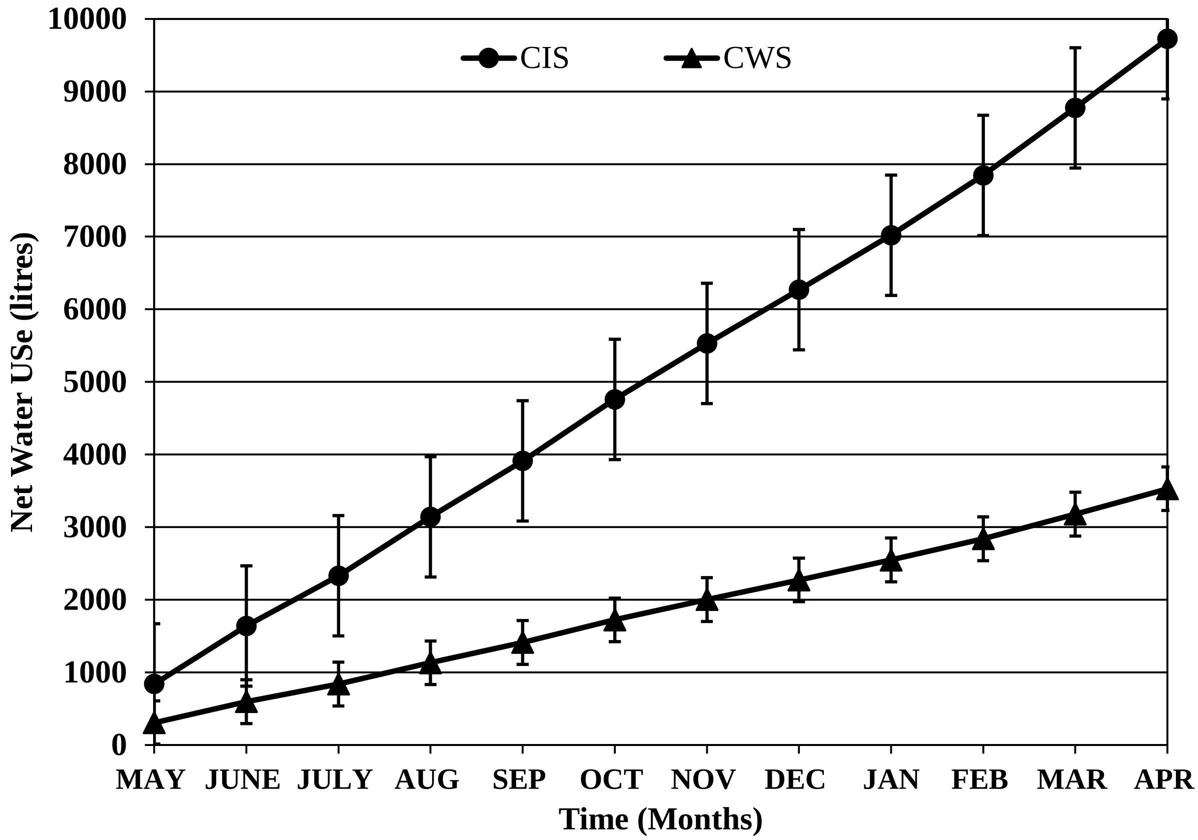

Figure 4. 2: Cumulative amount of water use under CIS and CWS between May, 2015 and April, 2016.

Vertical lines represent ± standard error

4.3.2 Water Use Under CIS and CWS

Confirming our hypothesis regarding water use for the selected potted ornamental potted plants, this study revealed that CWS saved water averagely by 63.75% as compared to CIS.

Therefore, for this experiment, % water saving under the CWS can be summarized in the table 4.3.

The results revealed that CWS saved water averagely by 63.75% as compared to CIS. This is in line with other previous research that also reported that sub irrigation systems reduced total water use as compared to overhead irrigation systems and produced plants of similar or better quality to those grown using overhead irrigation systems (Dole *et al.*, 1994; Holcomb *et al.*, 1992; Klock-Moore & Broschat, 1999).

Our study revealed gross water use of the CIS system was higher as compared to the gross water use by the CWS system. Over the twelve months growing period, gross water use for the CIS and CWS was 9725 and 3529 litres respectively (Table 4.3). For the CWS system, the net water use was equal to the gross water use as there was no drain. The total gross water use for the CIS varied between 690 (July) and 950 litres (April) (Table 4.3) while for the CWS it varied between 242 (July) and 349 (April) litres (Table 4.3).

These variations were due to the differences in weather (temperature) in the said months, with July been the coolest month with an average temperature of 25^oC in the period of growth while April was the hottest month with an average temperature of 36^oC (Figure 4.1). The annual difference of 6196 litres (Table 4.3) in gross water use between the CIS and the CWS implies 63.75% water savings by the CWS.

4.4 EC and pH of the Water Throughout the Season

Average EC and pH of supply water by CIS and CWS differed slightly. This difference was not significant ($P<0.05$). For the CIS system, the EC and pH was 1.3 mS cm^{-1} and 7.7 respectively while for CWS system it was 1.2 mS cm^{-1} and 6.7 respectively. The average EC and pH of drainage water from CIS system were 0.1 mS cm^{-1} and 6.1 respectively. EC ranged between 1.0 mS cm^{-1} and 1.6 mS cm^{-1} while pH ranged between 5.0 and 10.3 (Table 4.4).

Table 4. 4: Average EC and pH values for water supplied to CWS and CIS and drainage from CIS

MONTHS	CIS		CWS		DRAIN CIS	
	EC	pH	EC	pH	EC	pH
May	1.1	10.3	1	6.6	0.1	6.9
June	1.2	8.4	1.2	6	0.1	7.1
July	1.1	8.8	1.1	6.3	0.1	6.8
August	1.6	9.7	1.1	7.7	0.2	7.2
September	1.2	8.2	1.1	7.7	0.1	6.6
October	1.4	7.5	1.3	7.3	0.3	5.9
November	1.4	6	1.2	6.1	0.1	5.5
December	1	6.6	1.1	6.4	0.2	5.4
January	1.1	6.3	1	6.7	0.2	5
February	1.4	6.8	1.4	6	0.1	5.3
March	1.2	6.7	1.2	6.2	0.1	5.5
April	1.5	7	1.3	7	0.1	5.8
Daily Maximum	**1.6**	**10.3**	**1.4**	**7.7**	**0.3**	**7.2**
Daily Minimum	**1**	**6**	**1**	**6**	**0.1**	**5**
Average	**1.3**	**7.7**	**1.2**	**6.7**	**0.1**	**6.1**
(±SD)	**(±0.10)**	**(±0.12)**	**(±0.06)**	**(±0.16)**	**(±0.14)**	**(±0.90)**

Average EC and pH of supply water by CIS and CWS differed slightly. This difference was not significant ($P<0.05$). For the CIS system, the EC and pH was 1.3 mS cm^{-1} and 7.7 respectively while for CWS system it was 1.2 mS cm^{-1} and 6.7 respectively. The average EC and pH of drainage water from CIS system was 0.1 mS cm^{-1} and 6.1 respectively. EC ranged between 1.0 mS cm^{-1} and 1.6 mS cm^{-1} while pH ranged between 5.0 and 10.3

The maximum EC of the irrigation water supplied to CWS was 0.2 higher than that of the CIS 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 CIS (9725 l m^{-2} yr^{-1}) compared to the CWS (3529 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 for the CIS 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 (E. James & Van Iersel, 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 (Crettaz *et al.*, 1999). The pH of the drainage water in our study was lower than the CIS, probably due to accumulation of fertilizers which have been shown to decrease pH of leachate in *petunia* and *begonia* grown in soilless media metromix (James & Van Iersel, 2001). The quality of drainage water from the CIS 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 revealed from the study.

4.5 pH of Drainage Water

The excess drain water was collected in a saucer beneath the CIS pots. Days in the month of August 2015 recorded highest average pH values of drainage water while January had the lowest average drainage pH of drainage water (table 4.4).

4.6 Plant Growth and Development

Suitability of Capillary Wick Irrigation System (CWS) was evaluated using greenhouse grown selected potted ornamental plants as test crops. A root substrate with high water absorption characteristics (Klock-Moore & Broschat, 2001) and at the same time good air-water ratio (Gruda & Schnitzler, 2004) is best suited for sub-irrigation systems. The type of root substrate is thus important for better performance of capillary wick system (So *et al.*, 2003) for growth and development.

A mixture of 1-part coconut coir: 2 parts perlite (v/v) has been shown to give better growth in *cyclamen* under capillary wick irrigation system (So *et al.*, 2003). Therefore, producing on suitable and less amount of medium is a better alternative for increasing land productivity since less land area is required for production. The choice of a suitable medium depends on availability, cost, requirements of the plants, ability to grow the best plants and give greatest return on the investment. Therefore, the medium should have high water and nutrient retention capacity with relatively low weight and good aeration for better plant growth. Water management is essential for the survival and growth of crops and is better achieved in limited soil volumes such as in containerized plants (Pershey, 2014).

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; Steininger & Pasian, 1994), there was no significant difference between the two treatments in terms of number of leaves ($p \leq 0.05$).

4.6.1 Leaf expansion

Leaves of *Chlorophytum comosum, Draceana fragrans* and *Cordyline terminalis* expanded faster in the CWS than in the CIS, while for *Spathiphyllum clevelandii* and *Epipremnum aureus*, the leaves expanded faster in the CIS than in the CWS. However, the difference was not significant ($p \leq 0.05$). For *Spathiphyllum clevelandii*, for example, for an average of the fifteen plants in each system, maximum leaf length reached was 228 mm for plants grown under CIS and 206 mm for plants grown under CWS (Figure 4.3). This was an average of fifteen plants in each system. Leaf length expansion was characterized by initial slow expansion rate followed by a fast expansion rate before levelling off. For *Epipremnum aureus*, averagely for the fifteen plants in each system, maximum leaf length reached was 132 mm and 114 mm for plants under CIS and CWS respectively. The difference was not significant ($p \leq 0.05$). The leaf length expansion was also characterised with initial slow expansion rate followed by a fast expansion rate before levelling off (Figure 4.4).

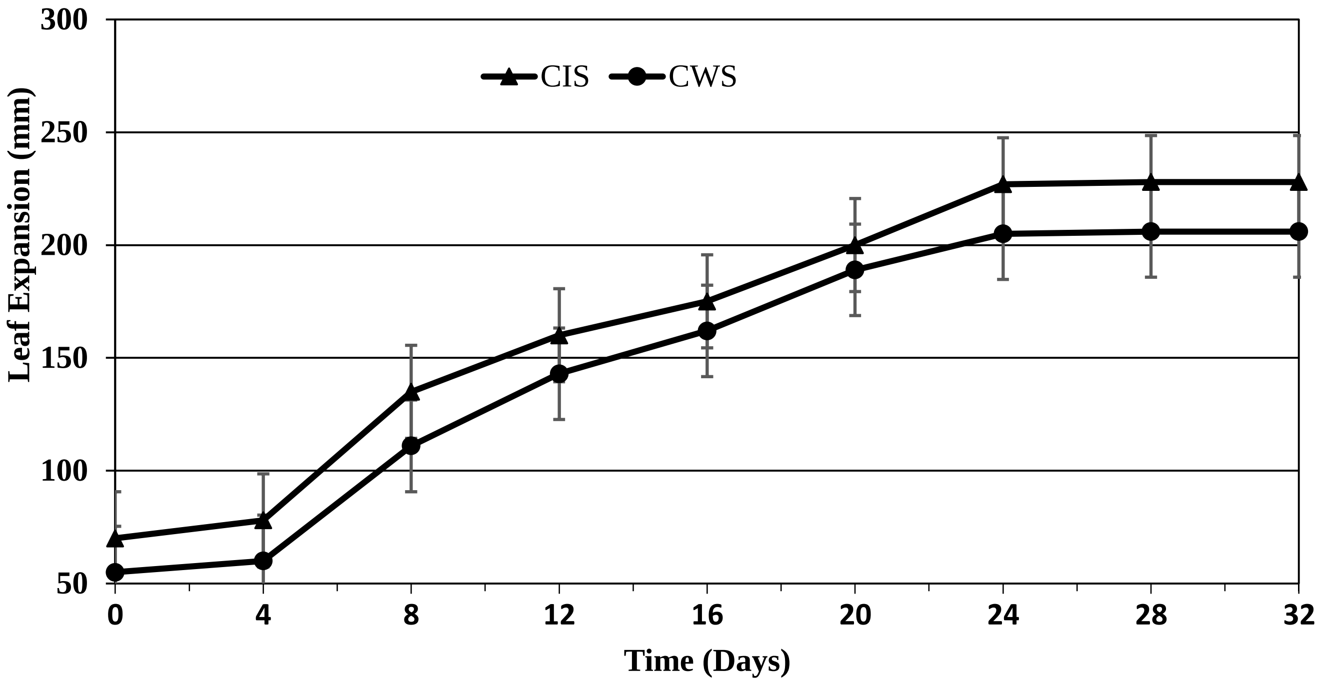

Figure 4. 3: Expansion of *Spathiphyllum clevelandii* leaves grown under CIS and CWS

Vertical lines represent ± standard error

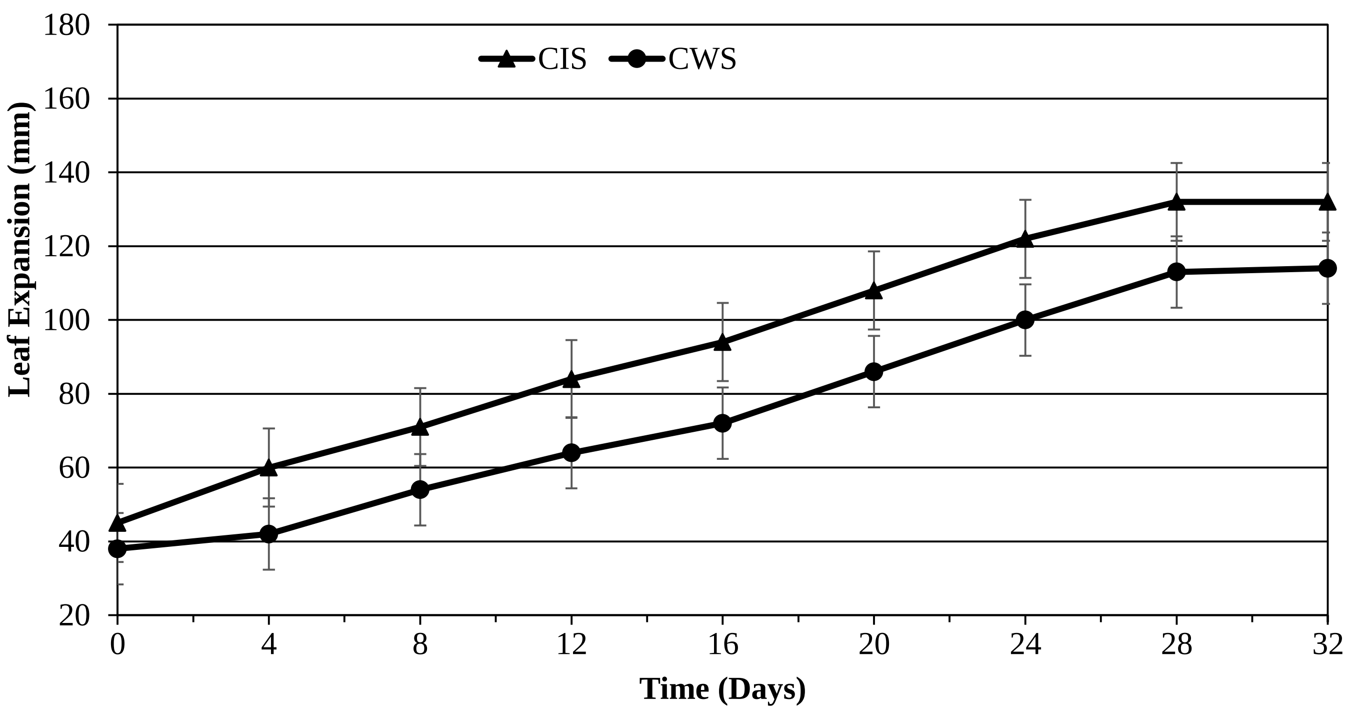

Figure 4. 4: Expansion of *Epiprepnum aureus* leaves grown under CIS and CWS

Vertical lines represent ± standard error

For *Chlorophytm comosum,* the average of fifteen plants in each system, maximum leaf length reached was 154 mm and 172 mm under CIS and CWS respectively (Figure 4.5). For *Dracaena fragra*ns, an average of the fifteen plants in each system, maximum leaf length reached was 233 mm and 241 mm under CIS and CWS respectively (Figure 4.6). For *Cordyline terminalis,* the average of the fifteen plants in each system, maximum leaf length reached was 222 mm and 238 mm under CIS and CWS respectively (Figure 4.7). Leaf length expansion was characterized by initial slow expansion rate followed by a fast expansion rate before levelling off. The difference in leaf length expansion was not significant ($p \leq 0.05$).

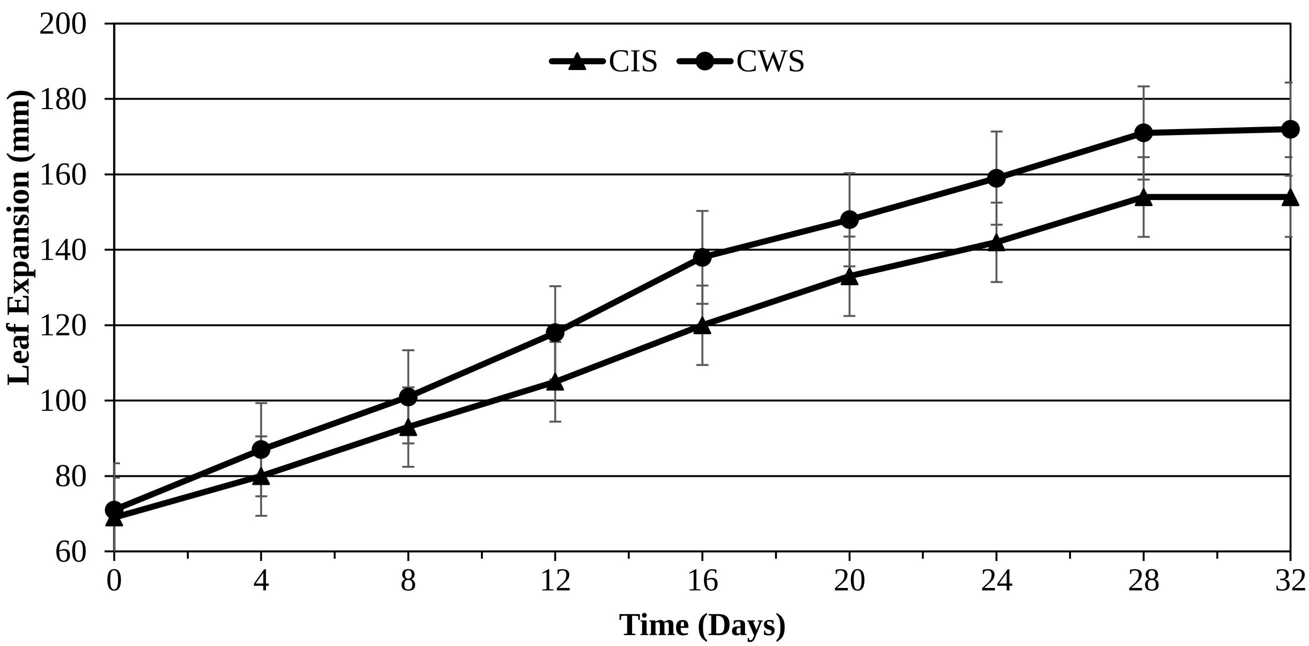

Figure 4. 5: Expansion of *Chlorophytum comosum* leaves grown under CIS and CWS

Vertical lines represent ± standard error

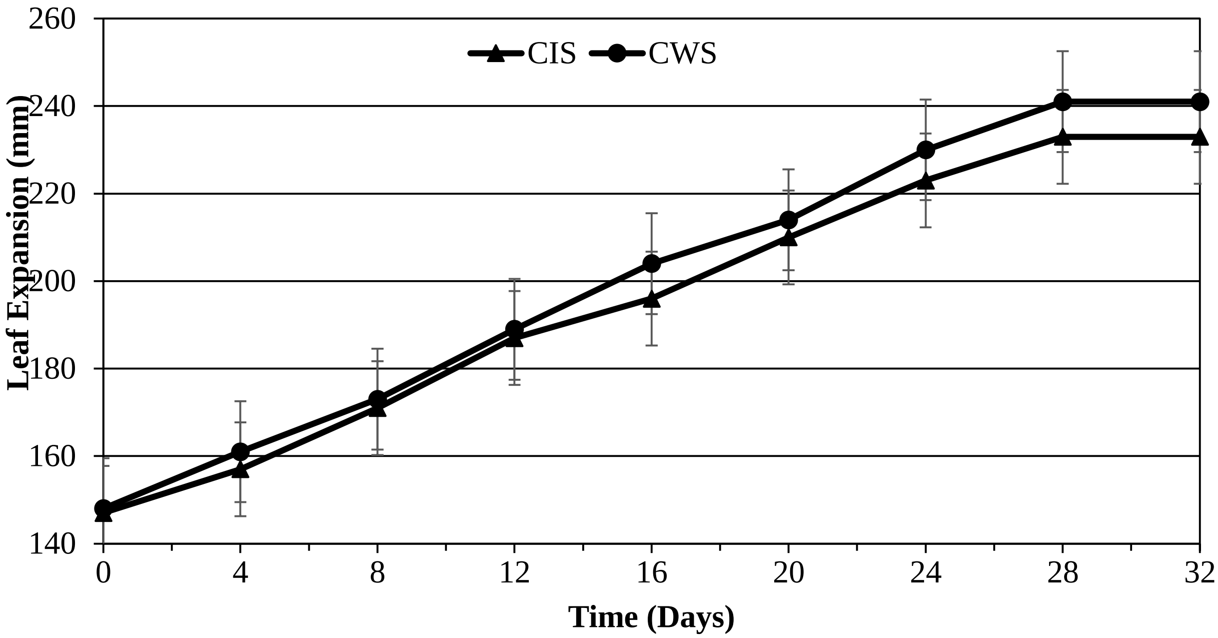

Figure 4. 6: Expansion of *Draceana fragrans* leaves grown under CIS and CWS

Vertical lines represent ± standard error

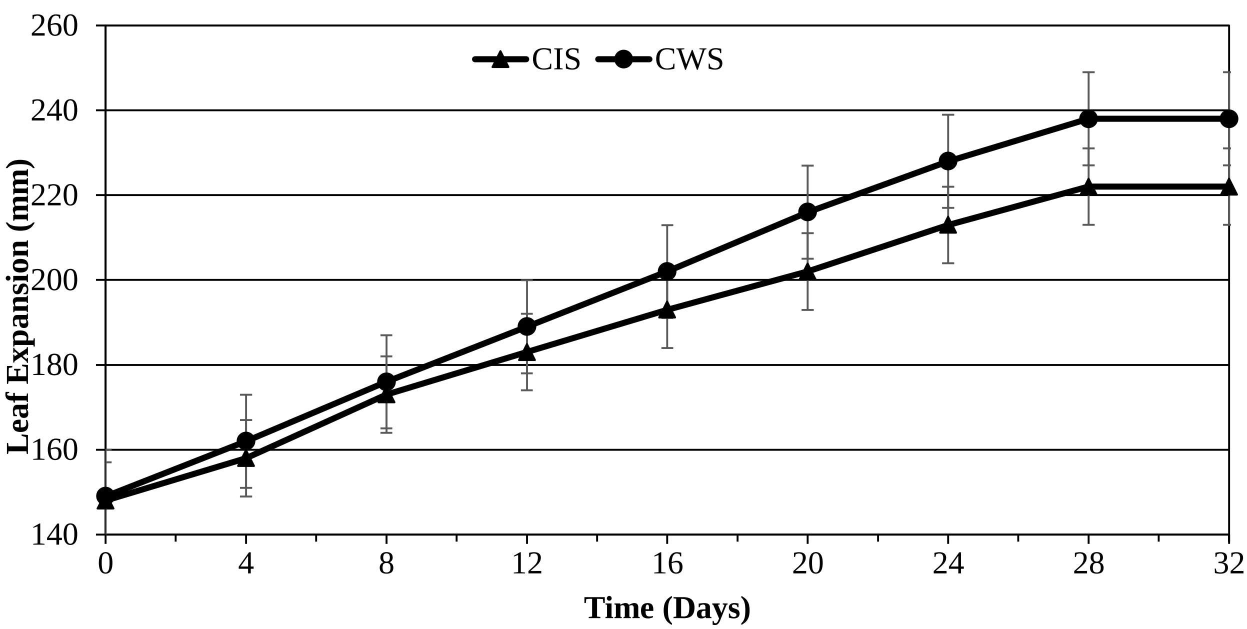

Figure 4. 7: Expansion of *Cordyline terminalis* leaves grown under CIS and CWS

Vertical lines represent ± standard error

4.6.2 Number of leaves per plant

The number of leaves did not differ significantly under the CIS and CWS systems. For *Spathiphyllum clevelandii* plants, the maximum number of leaves recorded was 31 for CIS and 27 for CWS which was not significantly different ($p \leq 0.05$) (Figure 4.8).

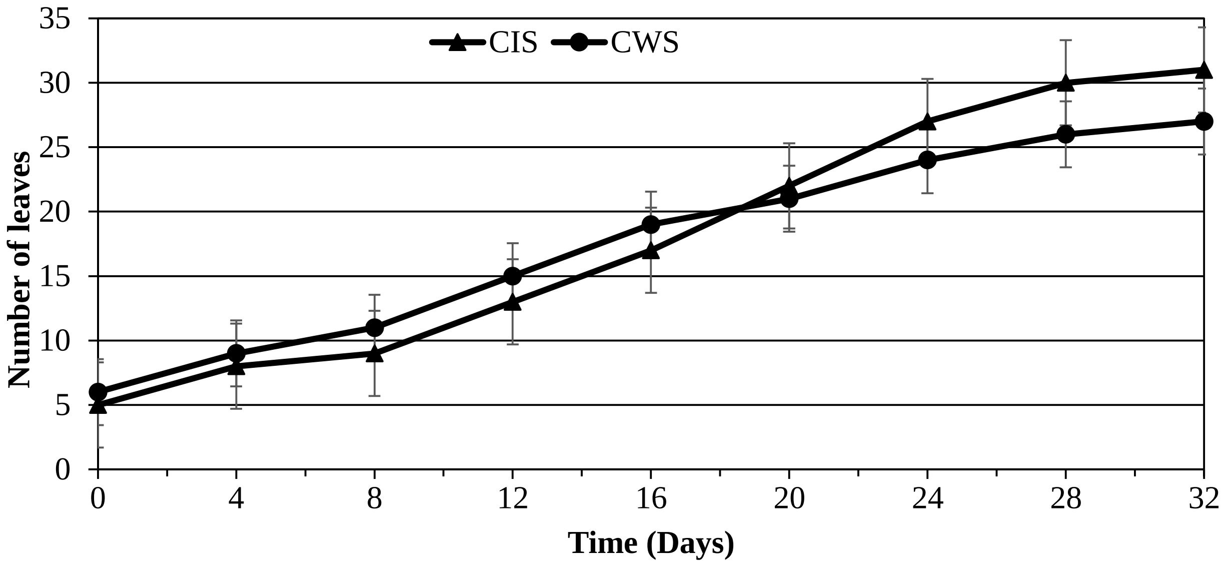

Figure 4. 8: Number of leaves in *Spathiphyllum clevelandii* plants grown under CIS and CWS

Vertical lines represent ± standard error

For *Epipremnum aureus* plants, the maximum number of leaves recorded was 30 for CIS and 26 for CWS which was not significantly different ($p \leq 0.05$) (Figure 4.9). For *Chlorophytum comosum* plants, the maximum number of leaves recorded was 32 for CIS and 33 for CWS which was not significantly different ($p \leq 0.05$) (Figure 4.10).

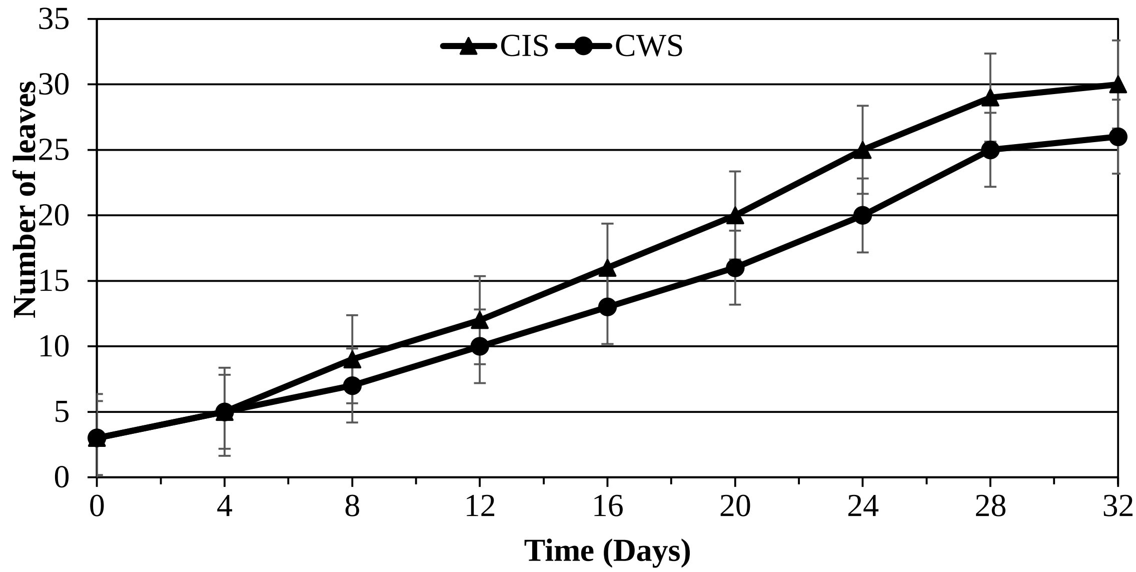

Figure 4. 9: Number of leaves in *Epipremnum aureus* plants grown under CIS and CWS

Vertical lines represent ± standard error

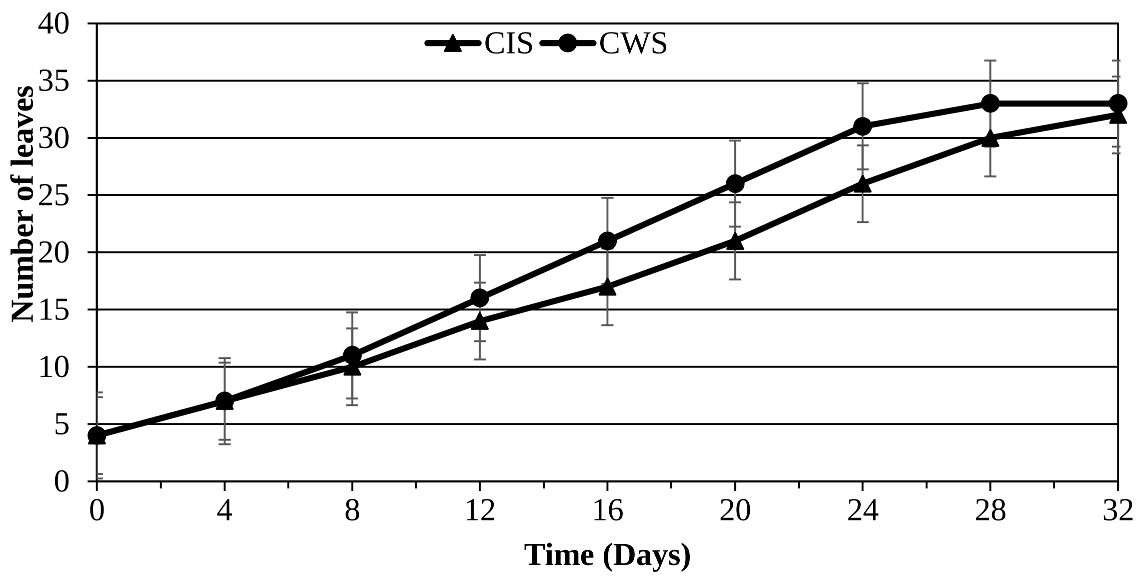

Figure 4. 10: **Number of leaves in *Chlorophytum comosum* plants grown under CIS and CWS**

Vertical lines represent ± standard error

For *Dracaena fragrans* plants, the maximum number of leaves recorded was 25 for CIS and 26 for CWS which was not significantly different (p≤0.05) (Figure 4.11). For *Cordyline terminalis* plants, the maximum number of leaves recorded was 22 for CIS and 24 for CWS which was not significantly different (p≤0.05) (Figure 4.12).

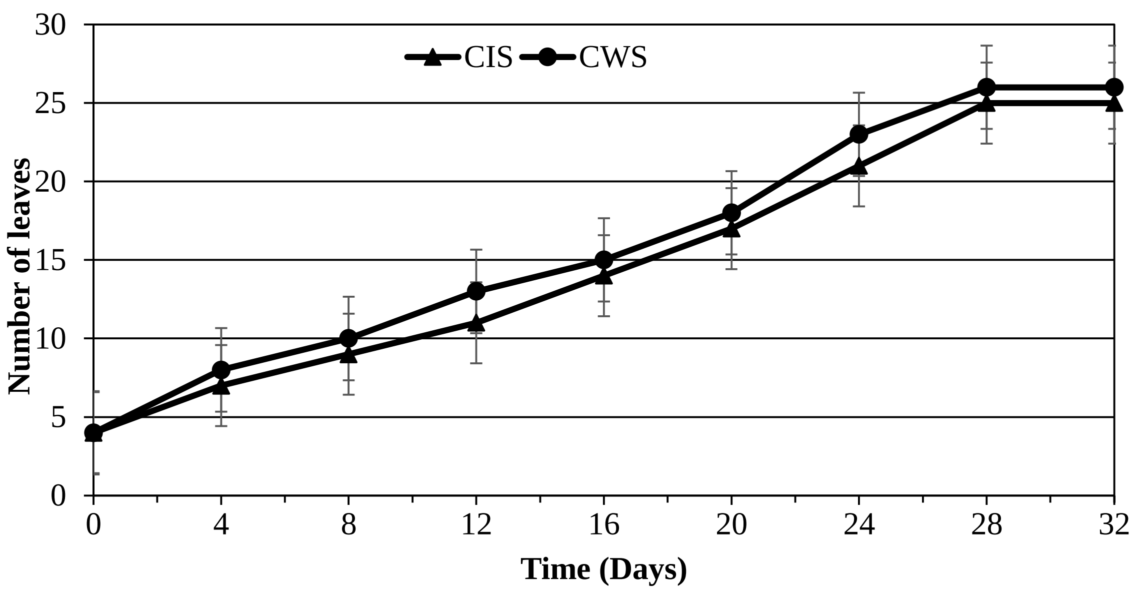

Figure 4. 11: **Number of leaves in *Dracaena fragrans* plants grown under CIS and CWS**

Vertical lines represent ± standard error

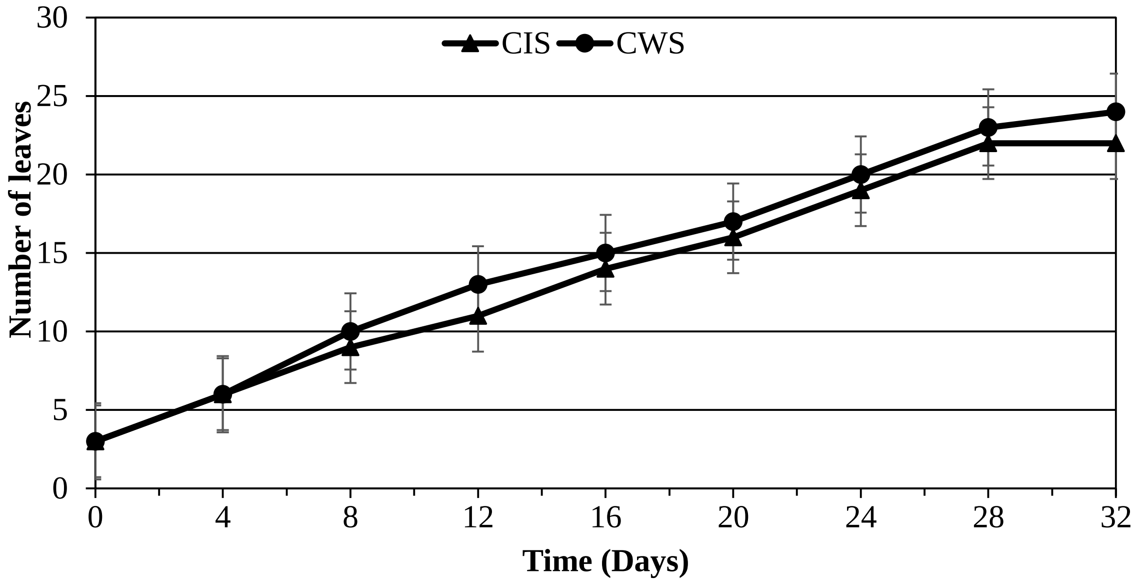

Figure 4. 12: **Number of leaves in *Cordyline terminalis* plants grown under CIS and CWS**

Vertical lines represent ± standard error

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; Steininger & Pasian, 1994), there was no difference between the two treatments in number of leaves ($p \leq 0.05$). Consequently, number of leaves did not differ significantly between CIS and CWS.

4.6.3 Plant Height

Plants were longer under CIS as compared to CWS for two varieties namely *Spathiphyllum clevelandii* and *Epipremnum aureus*. For *Spathiphyllum clevelandii*, the maximum height reached was 247 mm and 245 mm under CIS and CWS respectively (Figure 4.13). The difference was however not significant ($p \leq 0.05$). For *Epipremnum aureus*, the maximum length reached for was 700 mm and 690 mm under CIS and CWS respectively which was not significant (Figure 4.14). This was for an average of fifteen plants in each system.

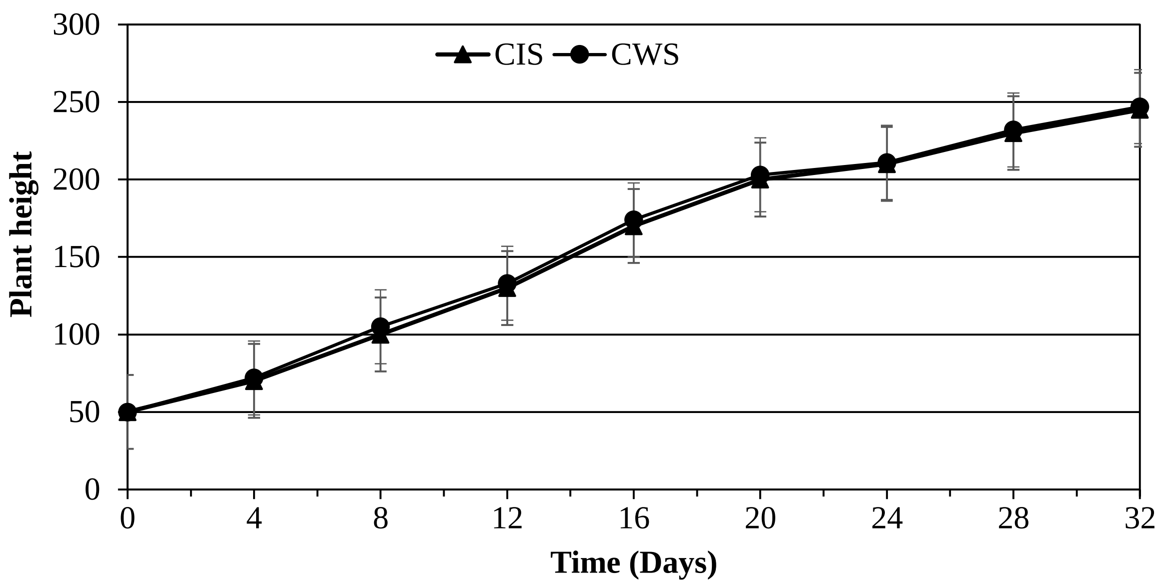

Figure 4. 13: Stem length expansion of *Spathiphyllum clevelandii* plants grown under CIS and CWS

Vertical lines represent ± standard error

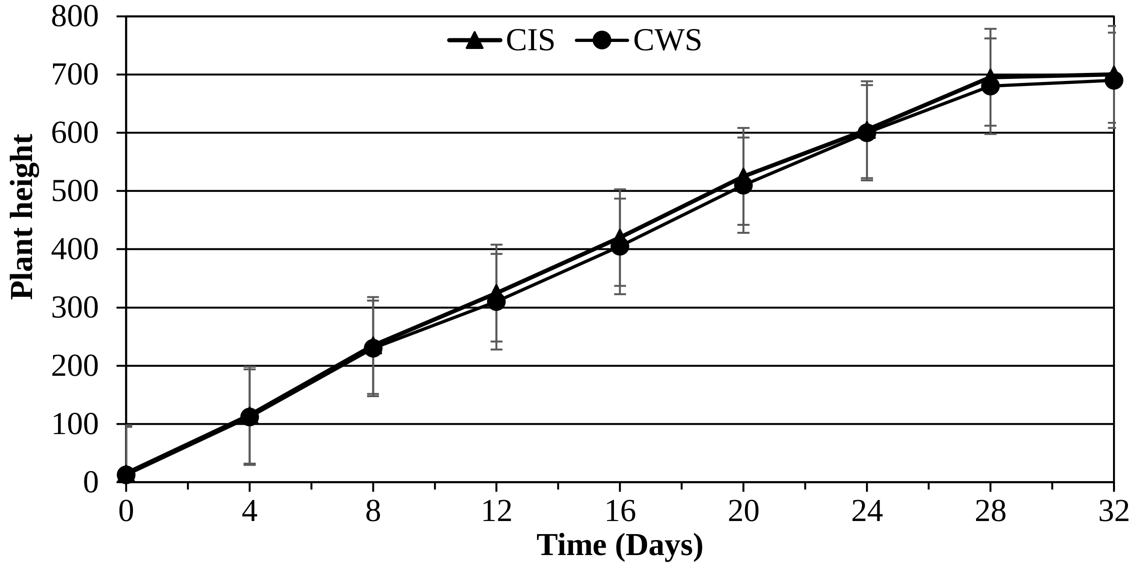

Figure 4. 14: Stem length expansion of *Epipremnum aureus* plants grown under CIS and CWS

Vertical lines represent ± standard error

Plants were longer under CWS as compared to CIS for three varieties namely *Chlorophytum comosum, Dracaena fragrans* and *Cordyline terminalis.* For *Chlorophytum comosum*, for an average of fifteen plants in each system, the maximum height reached was 310 mm and 315 mm under CIS and CWS respectively (Figure 4.15). The difference was however not significant ($p \leq 0.05$). For *Dracaena fragrans*, the maximum height reached for was 780 mm and 790 mm under CIS and CWS respectively which was not significant ($p \leq 0.05$). This was for an average of fifteen plants in each system. (Figure 4.16). For *Cordyline terminalis,* for an average of fifteen plants in each system, the maximum height reached was 740 mm and 755 mm under CIS and CWS respectively (Figure 4.17).

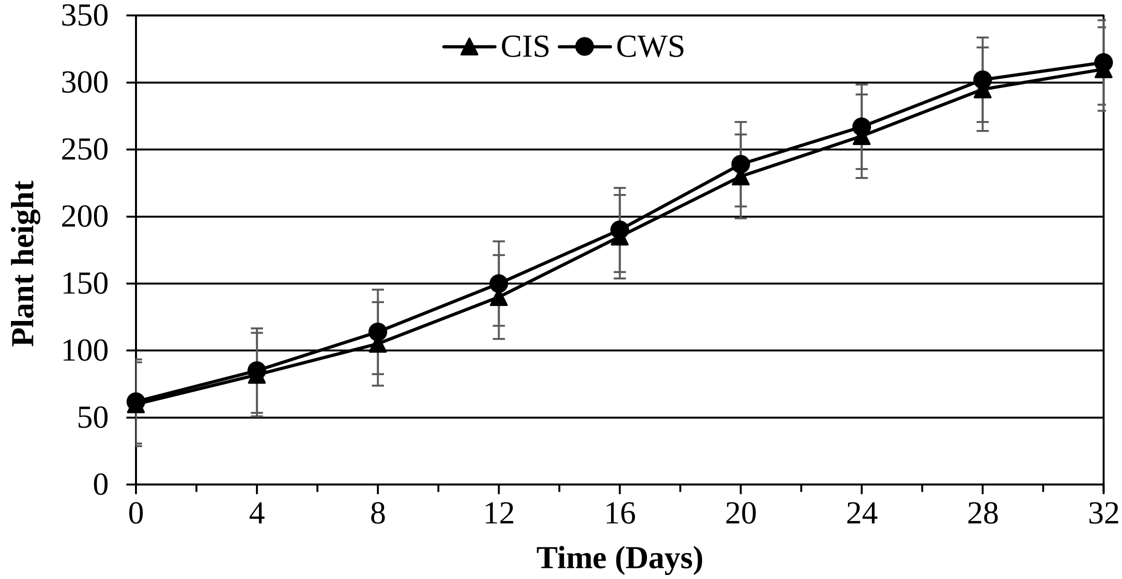

Figure 4. 15: Stem length expansion of *Chlorophytum comosum* plants grown under CIS and CWS

Vertical lines represent ± standard error

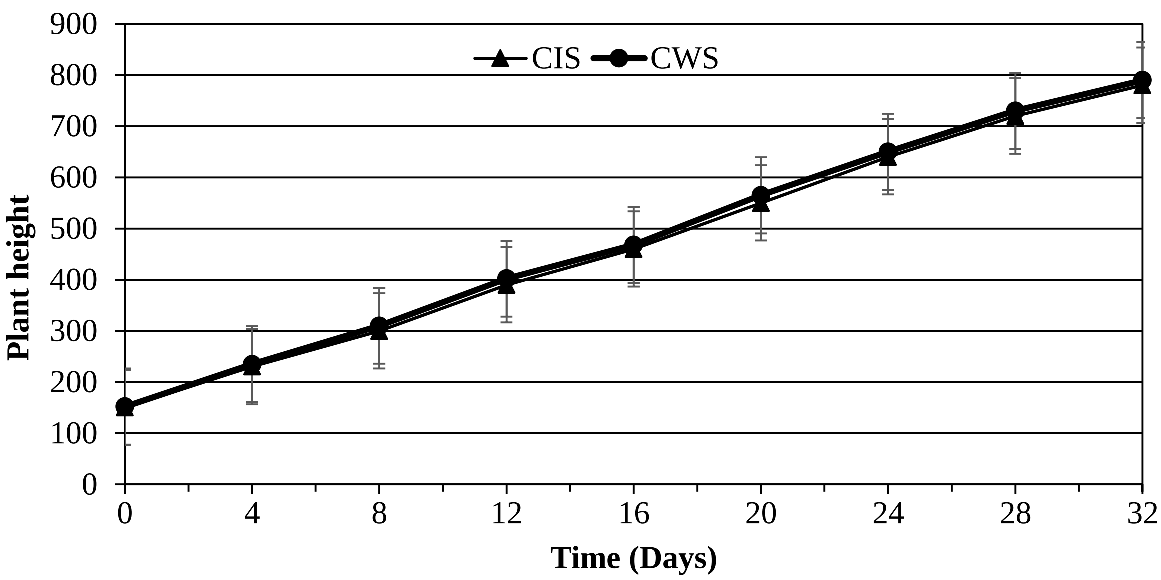

Figure 4. 16: Stem length expansion in *Dracaena fragrans* plants grown under CIS and CWS

Vertical lines represent ± standard error

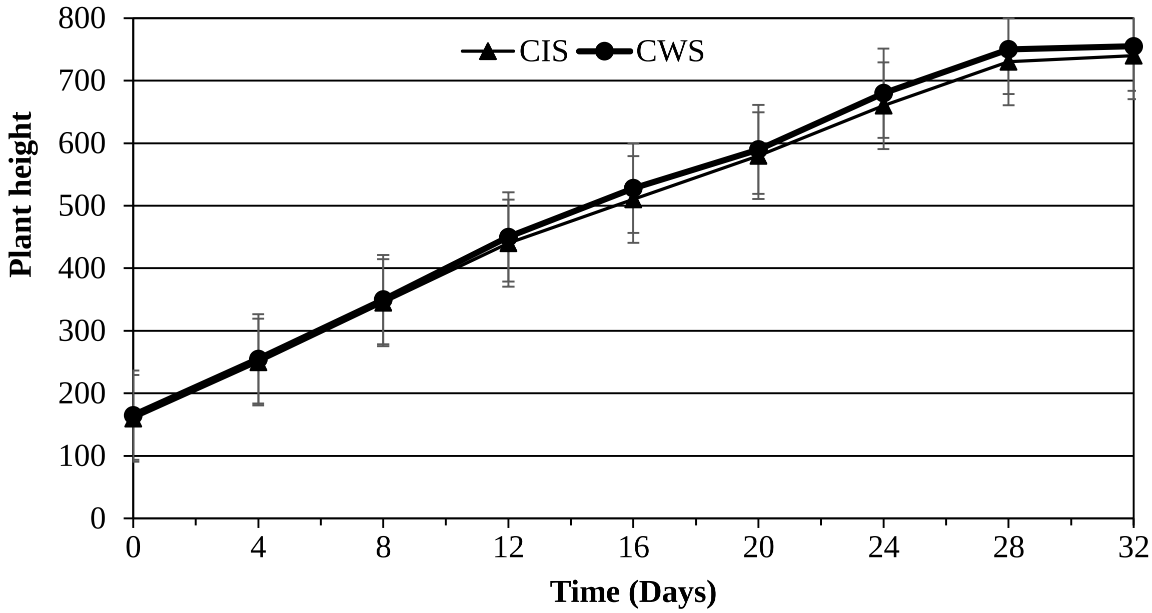

Figure 4. 17: **Stem length expansion in *Cordyline terminalis* plants grown under CIS and CWS**

Vertical lines represent ± standard error

4.6.4 Leaf length as Influenced by Irrigation System

These study findings indicate that *Chlorophytum comosum*, Spider Plant; *Dracaena fragrans,* Corn Plant and *Cordyline terminalis,* Red Dracaena; had better growth under the CWS as compared to the other two species *Spathiphyllum clevelandii*, White Anthurium; and *Epipremnum aureus,* Money Plant; which performed better in CIS, although the differences were not significant ($p \leq 0.05$) (Figure 4.18).

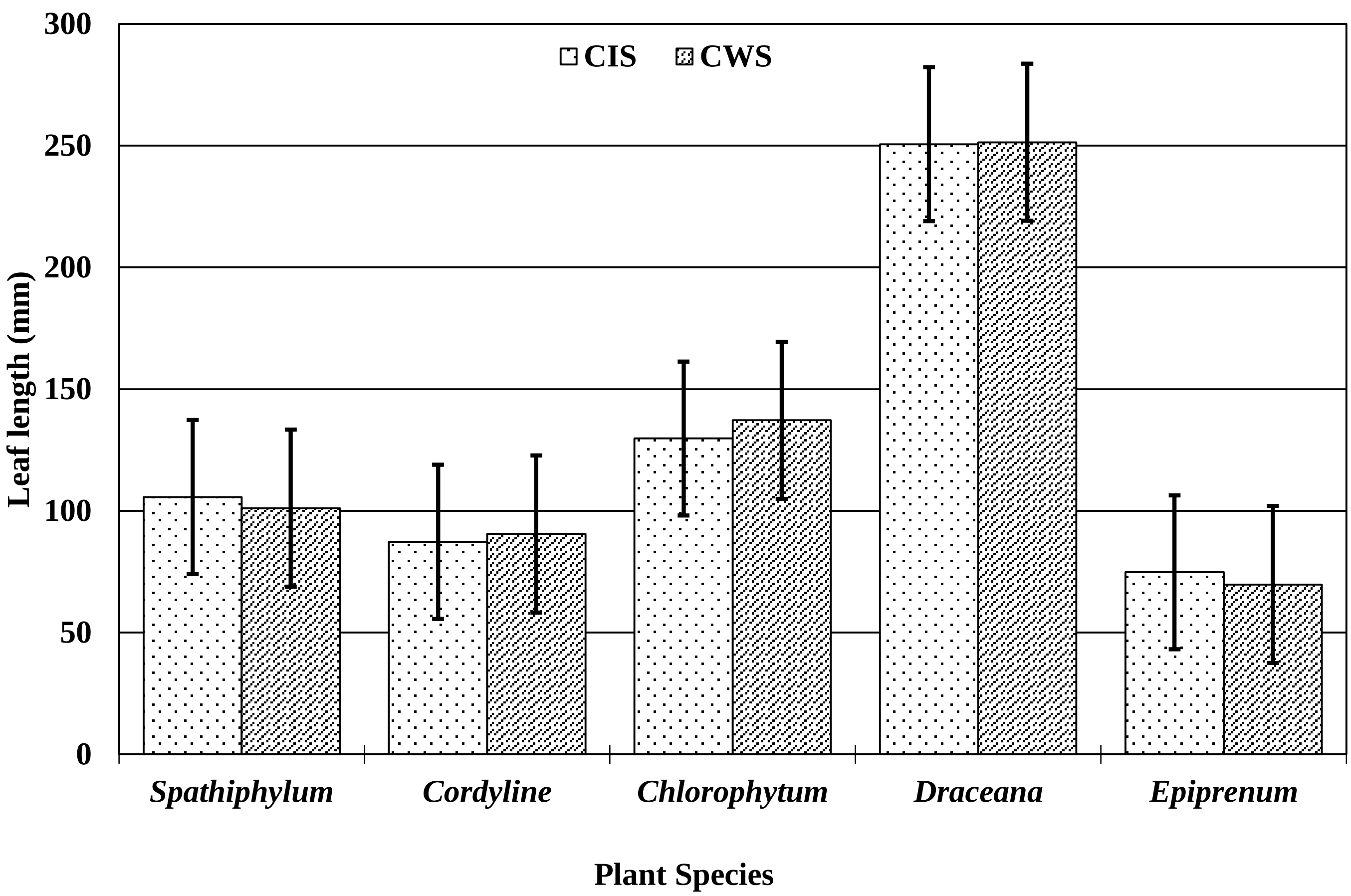

Figure 4. 18: Leaf length as influenced by irrigation system

Vertical lines represent ± standard error

It is necessary to note that CIS, overhead watering, was apt to splash soil and water from the selected potted ornamental plants pots during the process of watering. When this happened in the early stages of the experiment, it usually took thirty minutes to water all the plants in the experiment. So as to take care of this water loss, the researchers adopted very specialized attention and care while watering using CIS so as to make sure such losses are completely avoided. This meant that the researchers had to increase the watering hours to one and a half hours to water all the CIS potted ornamental plants. For potted plants grown under the CWS system, the only time spent during the watering process was while refilling the reservoir tank that supplies water to the CWS pipes where the researchers had inserted the capillary wicks that delivered water to the media in the pots. Thus, in our study, CWS helped reduce remarkably the working hours for watering to just 10 minutes. Lee *et al.* (2010) reported that CWS helped reduce remarkably the working hours for watering from four hours in overhead irrigation system to just five minutes for *cyclamen* grown in pots.

From this study, it was observed that application of CWS and the specialized attention while watering using CIS, overhead watering, the researchers were able to effectively reduce incidences of pests and diseases throughout the growing period. Throughout the period of growth, pesticides or chemicals were never applied to control pests and diseases. This is very good practice in production of ornamental plants as it ensures a high-quality plant and at the same time that which is free of pests and diseases, has the right foliage colour, quality leaves and stems and ultimately high aesthetic value for sale in the market. This ensured that the leaves were free from leaf chlorosis and necrosis. It is very clear from this study that the CWS system was highly beneficial to get uniform potted products with high quality. These are the desired qualities when purchasing ornamental plants as described in chapter two (Table 2.1). Capillary action of the wick is a very important factor in wick culture systems since they are self-watering sub-irrigation systems using wick to absorb water.

Capillarity and durability of the wick material were attributes for success of this study's capillary wick irrigation system. This, the researchers believe, is due to the uniformity of watering, which is one of the greatest benefits of sub irrigation, because it creates uniform media moisture. In summary, sub irrigation through the Capillary wick system used in this study, it was found to be an effective alternative to produce the selected potted ornamental plants. Compared with CIS, this study suggests that sub irrigation through the Capillary wick system, is a viable irrigation system, yielding equal or better plant growth and nutrition with much less water (Table 4.3) and with zero leaching losses. Overall, it is significant to note that capillary wicks were able to support the selected potted ornamental plants growth effectively throughout the growing period (Figure 4.18).

Ornamental potted plant growers aim to produce high-quality, high-value plants. In general, quality can be broadly defined in terms of plant compactness, enhanced foliar and floral characteristics (e.g. pigment composition), rooting characteristics and/or enhanced shelf life, although this will vary between species (Demotes-mainard, 2014; Fustec & Beaujard, 2000; Macfarlane *et al.*, 2005). Historically, growers have manipulated many of these characteristics by applying chemical growth regulators (Morel *et al.*, 2012), but increased costs and awareness of environmental and health effects (along with pressure from consumers) may reduce the long-term viability of this approach (Lütken *et al.*, 2012). The environmental impact of plant production is now a major consideration for consumers (Yue *et al.*, 2011).

In this study, ornamental potted plants that were grown in both irrigation systems were saleable and of high quality (based on colour and lack of blemishes); however, our findings indicate that *Chlorophytum comosum,* Spider Plant; *Dracaena fragrans,* Corn Plant and *Cordyline terminalis,* Red Dracaena; had better growth under the CWS as compared to *Spathiphyllum clevelandii,* White Anthurium; *Epipremnum aureus,* Money Plant; which performed better in CIS, although the differences were not significant ($p \leq 0.05$). The researchers therefore suggest that the selected ornamental potted plants performance could be improved over time by fine tuning the nutrition and irrigation management of crops produced under the CWS system with the added benefits of water conservation.

Producing equal or better-quality ornamental potted plants under reduced water consumption is of great interest for ornamental potted plant growers. The similarity in the selected potted plant growth performance throughout the growing season was not surprising. For example, Davis *et al.* (2008) observed no significant differences in growth of sub irrigated versus overhead irrigated northern red oak *(Quercus rubra L.)* seedlings. In koa *(Acacia koa Gray),* sub irrigated and overhead-irrigated plants had similar gas exchange, height and root collar diameter (Davis *et al.*, 2011; Dumroese *et al.*, 2011). Consequently, growers will have to look for other ways to manipulate other aspects of plant production, such as regulating water availability, which often has positive results controlling growth and quality.

Inconsistent results were also found in bell pepper, which showed either minimal change (Assouline, 2002) or larger decreases (Sezen *et al.*, 2007) in water productivity, due to higher irrigation frequency in the former study. Authors of the studies in which water productivity increased as irrigation frequency decreased suggest that this is a consequence of optimal soil moisture conditions being achieved, that is, the plants were not over-watered. A decrease in water productivity may be attributed to plants being subject to too severe a period of stress. Ultimately, this variation highlights that limiting irrigation frequency can affect species differently, and in some situations, may not be suitable. Improved physiological understanding may provide more insight for applying this sort of a strategy on a wider basis. Therefore, the Capillary Wick Irrigation System comes in handy as demonstrated in this study since quality was not compromised in the Capillary wick irrigation system. The use of water in this system was controlled by the crop water demand and therefore improved crop water productivity meaning more crop per drop of water used.

4.6.5 Leaf length as Influenced by Fertilization Method

This study revealed that the selected potted ornamental plants performed better under fertigation, followed by top fertilization and then side fertilization (Figure 4.19).

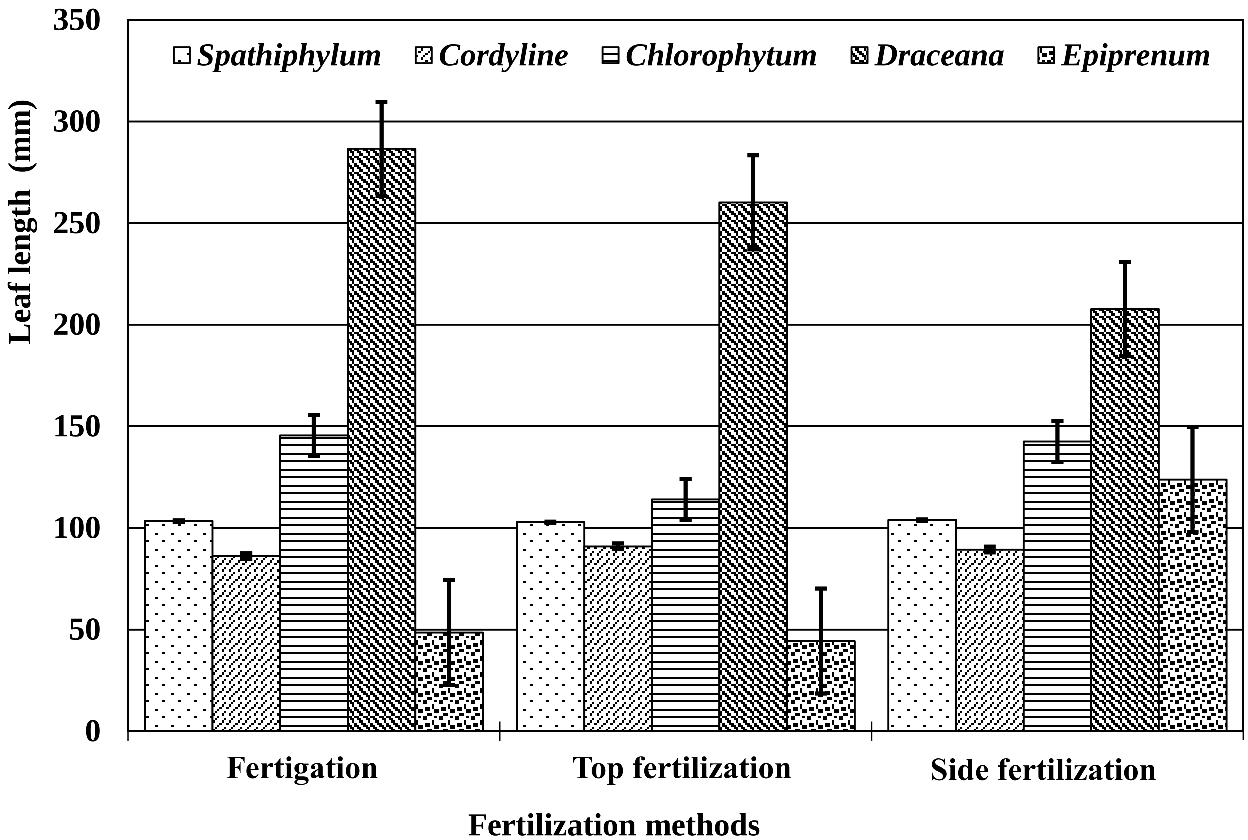

Figure 4. 19: Leaf length as influenced by fertilizer application method

Vertical lines represent ± standard error

In this study, fertilizer was applied in the selected potted ornamental plants so as to maintain and achieve maximum growth. Inefficient fertilizer application methods do not supply the much-needed nutrients required by the plants. Therefore, efficient fertilizer application methods must be adopted urgently in greenhouse production of ornamental potted plants since minimizing fertilizer and water requirements for greenhouse production has become increasingly important to growers, because many are faced with higher water and fertilizer costs, decreasing availability of quality water and government regulations provide for protecting surface and groundwater (James & Van Iersel, 2001; Uva *et al.*, 2001).

The study findings also indicate that the selected potted ornamental plants performed better under fertigation, followed by top fertilization and then side fertilization (Figure 4.19). Fertigation, is the incorporation of soluble fertilizers into irrigation water. This the researchers believe is due to the harmonization and integration between application of water and plants nutrients. The dissolved fertilizer often moves with applied water through the wick as the water is delivered to the plants. This enables the media to be supplied with uniform moisture and thus could explain why the plants performed better under fertigation (Figure 4.19).

Klock-moore *et al.* (2001) also found out that for overhead irrigated pots of *Dypsis lutescens*, Areca Palm; *Crossandra infundibuliformis*, Crossandra; *Pentas lanceolate*, Pentas; and *Philodendron*, Philodendron 'Hope' plants, the water leached from the pots contained fertilizer salts. For top fertilization, even though nutrients are leached beyond the root zone, the excess water was collected through the underside saucers and re-used in the next watering cycle. This may explain why there is no significant difference between fertigation and top fertilization in our experiment. For side fertilization, the absorbability of the fertilizer on the wicks may have played a role in its uptake by the plant. These results show that it is possible to optimize fertilization and keep environmental contamination under control, using this Capillary wick irrigation system for ornamental potted plants production. Thus, the study recommends that nursery growers producing potted ornamental plants adopt cultivation systems that collect and reuse the excess irrigation water.

4.7 Relevance to Landscape Planning and Conservation: Water Conservation

The world's supply of fresh water is finite and is threatened by pollution. Rising demands for water supply for agriculture, industry, and cities are leading to competition in the allocation of limited fresh water resources. Increasing demand for food production has led to ceaseless and intensive use of agrochemicals in agriculture. The increasing use of chemical fertilizer has caused environmental problems generally manifested in soil and groundwater contamination. The increasing scarcity of fresh water resources world-wide makes the development of sustainable irrigation practices a key challenge for agriculture.

Landscapes and gardens, which are components of Ornamental Horticulture industry, are one of the primary factors contributing to the quality of life of people worldwide. They beautify our surroundings, cleanse our environment, provide natural cooling, sustain wildlife, and provide many other important benefits. Their value is extensive and they are without question a worthwhile use for the country’s water resources. Because landscapes are often over-irrigated, there is a great potential for significant water conservation without negative effects (Labour, 2007).

The quality and quantity of water used, along with the leachate leaving container nurseries, is of great concern for nurseries all over the world (Fare *et al.*, 1992). With increasing emphasis on water quality, commercial nurseries are being targeted as potential sources of ground and surface water contamination (Evans & Stamps, 1996). Although overhead irrigation is inefficient, many container grown landscape plants are still irrigated with overhead sprinklers, especially larger plants (Beeson & Knox, 1991).

Over the last three decades, closed-loop soilless systems have become more and more popular among horticultural growers, since this high-tech practice represents an effective tool to face recent and upcoming changes in legislation concerning water and nutrient management in Europe (Katsoulas *et al.*, 2015; Rouphael & Colla, 2004; Savvas *et al.*, 2007). In fact, subirrigation delivers nutrients in a uniform manner, offers greater flexibility in pot spacing and sizing, reduces the run-off of nutrients, simplifies the nutrient solution management, and increases the nutrient and water use efficiencies (Montesano *et al.*, 2010).

The results of this study come in handy to indicate the importance of subirrigation for sustainability and efficient use of resources, for example water and nutrients, in agreement with a previous report of Rouphael and Colla (2005b), which is crucial for Kenya, where water supplies are limited. In Kenya, most landscapes if not all, are irrigated by sprinkler, furrow or flood irrigation, all of which are relatively inefficient. Vegetable producers are very concerned about the potential water shortages for irrigation (Lawlor, 2002). The days of unlimited water are rapidly passing, and more efficient irrigation methods must be evaluated and implemented so as to conserve this limited resource.

Water conservation and water reuse programs result in substantial environmental benefits, arising from reductions in water diversions and reductions in the impacts of wastewater discharges on environmental water quality (Anderson, 2003). Improved water conservation in landscapes, mainly in dry landscapes, may be achieved using plant species with low water requirements. Selecting plants, however, demands information on water needs of different species (García-Navarro *et al.*, 2004).

Capillary wick irrigation which involves the use of a device that delivers water by capillary movement from a reservoir to the plant growing medium (Figure 3.2) has potential to enhance crop production and contribute to food security. This innovative method is easy and cheap to install and operate (Bainbridge, 2002), making it particularly suitable for resource poor farmers in Kenya. With Kenya is classified as a water scarce nation and agriculture consuming 70% of the available water, using the capillary wick system, this study has demonstrated that the water savings can be achieved up to 63.75%, making water available for other uses such as domestic, industrial, environmental, recreational and energy production uses. This effective and efficient irrigation system should also be considered for much wider use in restoration, forestry, agroforestry, agriculture, gardening, landscaping because they work well and save water. Water conservation and water reuse produces substantial environmental benefits, arising from reductions in water diversions and reductions in the impacts of wastewater discharges on environmental water quality (Anderson, 2003).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study was aimed at evaluating water use and the performance selected potted ornamental plants grown under CIS and CWS. The results show that capillary wick irrigation system can be used effectively in ornamental potted plants production and fertigation is the most suitable fertilizer application method under Capillary Wick Irrigation System.

The following conclusions can be derived from the study:

1. Production of the selected potted ornamental plants under CWS, is a water saving irrigation method which reduced water use on an average of 63.75 % as compared to CIS.
2. *Chlorophytum comosum,* Spider Plant; *Dracaena fragrans*, Corn Plant and *Cordyline terminalis,* Red Dracaena; had better growth (in terms of leaf length expansion, plant height and leaf number) under the CWS as compared to *Spathiphyllum clevelandii,* White Anthurium; *Epipremnum aureus,* Money Plant; which performed better in CIS.
3. The selected potted ornamental plants performed better under fertigation, followed by top fertilization and then side fertilization.

5.2 Recommendations

From our study, we have the following further research suggestions:

This study was carried out for one year with five different types of ornamental potted plants produced in a greenhouse in JKUAT, Juja main campus, Kenya, in one substrate of a media mix of soil sand and manure in the ratio of 3:2:1. It is therefore recommended that;

1. Studies be done for a longer period of two or three years since better results can be achieved when data is collected for a longer period.
2. Studies should be done with more ornamental potted plant species and this should include many varieties from different ornamental potted plant families so as to determine their suitability for CWS.
3. Further research be carried out with different media so as to determine their suitability for growing potted ornamental plants in the CWS.
4. This study was done in one location, JKUAT farm Block A, Juja main campus, Kenya. More research can be carried out in different areas so as to have data of ornamental potted plants grown in different locations of Kenya.
5. In this study, two of the ornamental potted plants varieties, that is, *Chlorophytum comosum* and *Dracaena fragrans* were found to be susceptible to the water quality used for watering. Therefore, it is recommended that the two ornamental potted plants varieties, that is, *Chlorophytum comosum* and *Dracaena fragrans,* be used in future to investigate the water quality used for irrigating ornamental plants.

6. Studies should be done with more susceptible fluoride and chloride ornamental potted plant species, to determine water quality, for growth of ornamental potted plants under CWS.

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APPENDICES

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Water use and plant growth of selected container grown ornamental plants under capillary wick based irrigation system and conventional irrigation system in Kenya

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Key words: Capillary wick, Conventional irrigation, Ornamental horticulture, Subirrigation, Sustainability

Abstract

The Ornamental Horticulture industry is a major industry in the world, comprising a complex group of enterprises which consume a lot of water. The current irrigation production system of potted ornamental plants in Kenya involves the use of hosepipes and watering cans, methods which are inefficient as water and nutrients are lost through drainage. A study was carried out from May 2015 to April 2016, in Jomo Kenyatta University of Agriculture and Technology (JKUAT) farm, Kenya, to evaluate a sub irrigation system, the Capillary Wick based Irrigation System, CWS, for selected potted ornamental plants (*Spathiphyllum clevelandii*, white anthurium; *Cordyline terminalis*, red dracaena; *Chlorophytum comosum*, spider plant; *Dracaena fragrans*, corn plant and *Epiprenum aureus*, money plant) production, as compared to the Conventional Irrigation System, CIS, overhead irrigation. The experiment was laid out in a split plot design replicated three times. The amount of water applied in the two systems was determined weekly throughout the growing period. Vegetative growth in both systems was assessed in terms of leaf expansion and plant height. The growth data was subjected to Analysis of Variance (ANOVA) and means separation done by Turkey at $p \leq 0.05$. CWS resulted in an average of 63.75% reduction in net water use compared with CIS. Thus, CWS offers promising potential for potted ornamental plants production when compared with CIS, given the added benefits of water conservation, reduced labour cost and nutrient runoff. Studies should be done with more ornamental plant species so as to determine their suitability for growing in the CWS.

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Introduction

The Ornamental Horticulture industry produces all kinds of plants – trees and shrubs, perennials and annuals, cut flowers and pot plants. It is a major industry in the world comprising a complex group of enterprises involved in the production and sales of plants in nurseries and florist crops, design of interior and exterior landscapes and the development of recreational areas for enjoyment, which consume a lot of water. Usually, generally, in Kenya, irrigation of potted ornamental plants is done using overhead irrigation systems such as watering cans and hose pipes, methods which can be very inefficient in water use, using large quantities of water and fertilizer. Irrigation systems that water directly into the containers apply less water than overhead application irrigation systems, thus conserving water. An example of such a type of irrigation system is the CWS (Bainbridge, 2002).

Effective management of water for ornamental potted plants production in water-scarce areas requires efficient approaches. Kenya is classified as a water scarce nation and Agriculture consumes 70% of the available water limiting access to water for domestic, industrial, environmental, recreational and energy production uses. Overhead irrigation is the most practical and the most commonly used irrigation system for potted ornamental plants. In practise, in the field, many nursery growers use drip or microjet irrigation for crops grown in containers >20 (twenty) litres (Beeson & Knox, 1991).

A number of approaches are being used by nursery growers to improve irrigation management, enhance efficient water use and to minimize the detrimental effect of water stress in plants. The CIS, overhead watering, results in lots of water loss and runoff (Klock-moore & Broschat, 2001). CWS, a subirrigation system, is a new innovative technique of irrigation that is simple to install, operate, and uses minimal amount of water and fertilizer (Bainbridge, 2002). It involves the use of a device that delivers water by capillary movement from a reservoir to the plant growing medium and has potential to enhance crop production and can therefore contribute to food security. This system is not currently commercially used in Kenya and is therefore necessary to evaluate its performance in order to determine its suitability for greenhouse ornamental potted plants production.

Generally, the current production system of potted ornamental potted plants in Kenya involves the use of overhead irrigation systems which often employs hose pipes and use of watering cans. This type of production is especially common for 15 litres container sizes or smaller. However, these methods are inefficient since the amount of water that actually reaches the plants is in the range of 12 to 50% (Beeson & Knox, 1991) More efficient systems are needed to be adopted for the production of potted ornamental plants especially with the increasing concern over environmental pollution by water arising from plants production systems. Greenhouse cultural production systems must pace up with environmental regulations aimed at protecting water resources. Sub irrigation systems can improve efficiency of water used throughout the production period, since water and nutrients are re-used.

Recently, there has been ongoing research to develop a CWS for use under Kenyan conditions which has identified a locally available wick material, that is, polyester cloth material, commonly used as shoulder shawl. It had the best performance in terms of water absorption pattern and maximum capillary height but had slightly lower water holding capacity, out of the five wick materials tested (Wesonga *et al.*, 2014). The use of this locally available material can ensure that the system is affordable to the majority resource poor growers in Kenya, who make a majority of the ornamental potted plant nurseries production units. So far, the study focus of CWS under the Kenyan conditions had been focusing on vegetable production (Wesonga *et al.*, 2014), but the system could be utilized in other areas such as potted ornamental plants whose management is challenging. This method has been used in mesquites, *Prosopis grandulosa* (Bainbridge, 2002), Palo verde, *Cercidium floridium* (Bainbridge, 2002), Kalanchoe, *Kalanchoe blossfeldiana* (Son *et al.*, 2006) and white anthurium, *Spathiphylum clevelandii* (Bryant and Yeager, 2002; Yeagar and Henley, 2004) among others in various countries.

Our objective was to evaluate efficient irrigation system for selected potted ornamental plants (*Epiprenum aureus*, money plant; *Spathiphyllum Clevelandii*, white anthurium; *Draceana fragrans*, corn plant; *Chlorophytum comosum*, spider plant; and *Cordyline terminalis*, red draceana) under CWS and CIS in Kenya.

Materials and methods

Experimental site

The experiment was conducted at JKUAT farm, Block A, Juja-Kenya (latitudes 3°35"S and Longitudes of 36°35"E, altitude 1525 meters above sea level) during the period from May, 2015 to April, 2016 (GoK, 1997). Juja is located 36km North-East of Nairobi along the Thika-Nairobi highway and is located in the Upper Midland Zone four which is semi-humid to semi-arid. It has a mean annual temperature of 20°C and mean maximum temperature of 30°C (Muchena *et al.* 1978; Wanjogu and Kamoni, 1986). The area receives an average rainfall of 856 mm with a bimodal distribution (Kaluli *et al.*, 2011).

Plant materials and Experimental Design

The plant materials consisted of *Cordyline terminalis*, red dracaena; *Epiprenum aureus*, money plant; *Dracaena fragrans*, corn plant; *Spathiphyllum clevelandii*, white anthurium and *Chlorophytum comosum*, spider plant. They were obtained from Farmline nursery, a commercial ornamental potted plant nursery, in Kasarani, Nairobi, for propagation purposes. The experiment was carried out as a split plot in complete randomized design with three replications. Three methods of fertilization application of top fertilization, side fertilization and fertigation formed the main plots while the two methods of irrigation were allocated to sub-plots.

Cuttings of *Cordyline terminalis*, red dracaena; *Epiprenum aureus*, money plant; and *Dracaena fragrans*, corn plant; and divisions of *Spathiphyllum clevelandii*, white anthurium and *Chlorophytum comosum*, spider plant; were propagated in the Department of Horticulture, JKUAT, nursery tunnels in sixty hole propagation trays, under coco-peat sand mixture while maintaining an EC of 1.2 (Digital EC Meter DEC-2, Atago Company Limited, Tokyo 105-0011, Japan) and pH of 5.5 (Digital pH Meter DPH-2, Atago Company Limited, Tokyo 105-0011, Japan). Before insertion, cutting bases were treated with rooting powder containing 0.6% indole-3-butyric acid (Hormoril Rooting Powder T-6, Amiran Kenya Ltd). After four weeks of growth, with plants at two leaf stage, plants were transplanted in Polyvinyl Chloride (PVC) pots of four (4) litres capacity which were used to establish the plants in soil: sand: manure (3:2:1) media mix (Wesonga *et al.*, 2014).

Source: Authors, 2015

Fig. 1. (a) Cuttings of *Cordyline terminalis*, red dracaena and (b) divisions of *Chlorophytum comosum*, spider plant, growing in JKUAT, Department of Horticulture tunnels.

The capillary wick irrigation system was laid out in a polythene covered greenhouse using six (6)-inch diameter reservoir plastic pipes, raised thirty (30)cm above the ground on a metal framework while the conventional irrigation system containers were placed directly opposite beside them on the same metal framework. The metal framework was used as a raised stand on which the potted plants were placed. The distance between the pipes was one (1) meter.

The CWS pots were first drilled with three drainage holes of five (5)mm circumference at the bottom of the pots, and then on each pipe, holes four (4)cm by five tenths (0.5)cm were drilled with a spacing of forty (40)cm through which capillary wicks were inserted into the piping system. Capillary wicks, four (4)cm in width and forty-five (45)cm in length were then dipped in water to saturate them and then inserted to the inside of the pot through the hole and aligned to the pot's inner wall perpendicularly to the media's surface. Media was then added into the pots as per the treatments.

The treatment pots were then transferred to the CWS in the greenhouse and the wicks inserted into the piping system. The part of wick material exposed to the outside was maintained at four (4)cm. Plants were fertilized at planting and thereafter at three weeks with ten (10) grams (g)/plant of Multicote (15:7:25) slow release fertilizer (Amiran Kenya Limited).

The troughs in the CWS were held at a one (1) percent slope. Irrigation water was contained in a four hundred sixty (460) litre (L) tank raised 1.8 metres above the ground. The flow of water from the tank into the piping system was automatically controlled using a float valve as shown in Fig. three (3) below (See Fig. 3).

Water was applied to the conventionally irrigated plants from the top using a watering can, which required the plants to be watered one by one, while for the plants in the capillary wick irrigation system, they were sub irrigated with wicks placed from the side of the pots. The excess water was collected into a saucer drain under each pot for CIS system.

Data Collection and Analysis

All ten plants in each replication were used for measurements on stem length and leaf length elongation from the petiole along the midrib. Leaf length was recorded daily over a period of three weeks. Stem length and leaf number were assessed weekly for a period of six weeks since the development of these parts was slower.

Source: Authors, 2015

Fig. 2. A Research Assistant waters plants in the greenhouse with the selected potted ornamental potted plants using a watering can.

The Greenhouse temperature values were recorded daily and the average computed for the period of study (May, 2015-April, 2016) (See Fig. 5).

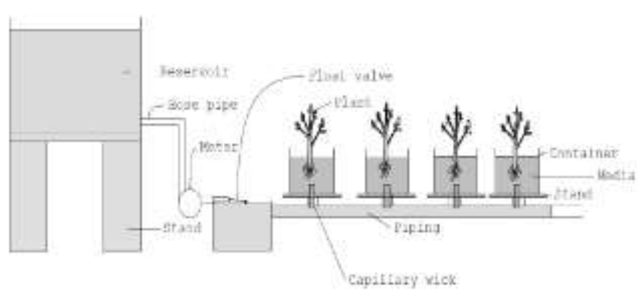

Fig. 3. Schematic diagram of capillary wick irrigation system. Water is conducted from the piping system via the capillary wick to the plant growth media in the container for plant uptake.

Fig. 4. Capillary wick irrigation system layout.

A total of ten cohorts were analyzed and averaged. Data was subjected to Analysis of Variance (ANOVA). Means separation was done by protected Fisher's least significant difference (Tukey's HSD) test at significance level of $p \leq 0.05$. Amounts of water applied by both irrigation methods were determined. Gross water use was defined as the amount of water applied. Net water use for the CIS was determined as the difference between the amounts applied and drained. Net water use for the CWS was determined as the amount of water applied, as drain water was not experienced. Daily values were cumulated over the twelve (12) month experimental period.

Results and discussion

In this study, we sought to evaluate efficient irrigation system for selected potted ornamental plants (*Epiprenum aureus*, money plant; *Spathiphyllum Clevelandii*, white anthurium; *Draceana fragrans*, corn plant; *Chlorophytum comosum*, spider plant; and *Cordyline terminalis*, red draceana) under CWS and CIS in Kenya. Specifically, we were to determine the amount of water used under CWS and CIS for the selected ornamental potted plants production, to determine the effect of CWS and CIS on growth of the selected ornamental potted plants and to evaluate the effect of fertilization method on growth of the selected ornamental potted plants under CWS.

Weather

The two treatments were placed in the same greenhouse, which led to selected potted ornamental plants in both treatments growing under the same air temperature conditions. There was variation in temperature in the greenhouse during a cool month as compared to a warmer month (Fig. 5), throughout during the growth period, with July, 2015 been the coolest month with an average temperature of 25°C while April was the hottest month with an average temperature of 36°C. This was due to the difference in seasons during the year. This can be summarized as in Fig. 5 below.

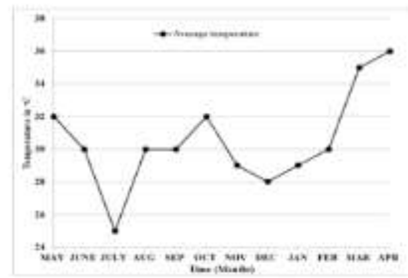

Fig. 5. Average temperatures in the greenhouse during the growth period.

Water use under CIS and CWS

Confirming our hypothesis regarding water use for the selected ornamental potted plants, our study revealed that CWS saved water averagely by 63.75% as compared to CIS. This is in line with other previous research that also reported that sub irrigation systems reduced total water use as compared to overhead irrigation systems and produced plants of similar or better quality to those grown using overhead irrigation systems (Klock-Moore & Broschat, 1999; Dole *et al*., 1994; Holcomb *et al*., 1992).

Where; W_{CWS} = water supplied by CWS

W_{CIS} = water supplied by CIS

W_{SV} = water saved

Plugging the values into the formula;

$$W_{SV} = \frac{W_{CIS} - W_{CWS}}{W_{CIS}} \times 100$$

Therefore, for our experiment, % water saving under the CWS can be summarized in the table below;

Table 1. Water use under CIS and CWS and the resultant percentage water saving.

MONTH	CIS	CWS	% WATER SAVING
MAY	840	307	63.5
JUNE	800	290	63.8
JULY	690	242	65
AUG	812	293	64
SEP	770	281	63.5
OCT	847	310	63.4
NOV	771	280	63.7
DEC	740	270	63.5
JAN	750	275	63.3
FEB	825	292	64.6
MAR	930	340	63.4
APR	950	349	63.3
TOTAL	9725	3529	

Our study revealed that gross water use of the CIS system was higher as compared to the gross water use by the CWS system. Over the 12 months growing period, gross water use for the CIS and CWS was 9725 and 3529 litres respectively (Fig. 6). For the CWS system, the net water use was equal to the gross water use as there was no drain.

The total gross water use for the CIS varied between 690 (July) and 950 (April) litres (Table 1) while for the CWS it varied between 242 (July) and 349 (April) litres (Table 1). These variations are due to the differences in weather (temperature) in the said months, with July been the coolest month with an average temperature of 25°C in the period of growth while April was the hottest month with an average temperature of 36 °C (Fig. 5). The annual difference of 6196 litres (Table 1) in gross water use between the CIS and the CWS implies 63.75% water savings by the CWS.

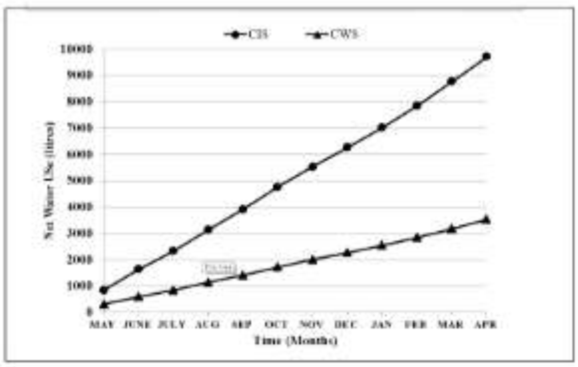

Fig. 6. Cumulative amount of water use under CIS and CWS between May, 2015 and April, 2016.

It is worth noting that CIS, overhead watering, was apt to splash soil and water from the selected potted ornamental plants pots during the process of watering. When this happened in the early stages of the experiment, we usually took thirty minutes to water all the plants in the experiment. So as to take care of this water loss, we adopted very specialized attention and care while watering using CIS so as to make sure such losses are completely avoided. This meant that we had to increase the watering hours to one and a half hours to water all the CIS potted ornamental plants. For potted plants grown under the CWS system, the only time we spent during the watering process was while refilling the reservoir tank that supplies water to the CWS pipes where we had inserted the capillary wicks that delivered water to the media in the pots. Thus, in our study, CWS helped reduce remarkably the working hours for watering to just ten (10) minutes. Lee *et al.*, reported that CWS helped reduce remarkably the working hours for watering from 4 hours in overhead irrigation system to just five (5) minutes for cyclamen grown in pots.

From our study, it was observed that application of CWS and the specialized attention while watering using CIS, overhead watering, we were able to effectively reduce incidences of pests and diseases throughout the growing period.

Throughout the period of growth, we never applied any pesticides or chemicals to control the pests and diseases. This is very good practice in production of ornamental plants as it ensures a high-quality plant and at the same time that which is free of pests and diseases, has the right foliage colour, quality leaves and stems and ultimately high aesthetic value for sale in the market. This ensured that the leaves were free from leaf chlorosis and necrosis. It is very clear from our study that our CWS system was highly beneficial to get uniform potted products with high quality. Capillarity action of the wick is a very important factor in wick culture systems since they are self-watering sub-irrigation systems using wick to absorb water.

Capillarity and durability of the wick material were attributes for success of our capillary wick irrigation system. This, we believe, is due to the uniformity of watering, which is one of the greatest benefits of sub irrigation, because it creates uniform media moisture. In summary, sub irrigation through our CWS was an effective alternative to produce the selected potted ornamental plants. Compared with CIS, our study suggests that sub irrigation through CWS, is a viable irrigation system, yielding equal or better plant growth and nutrition with much less water (Fig. 6) and with zero leaching losses. Overall, it is significant to note that capillary wicks were able to support the selected potted ornamental plants growth effectively throughout the growing period (Fig. 7).

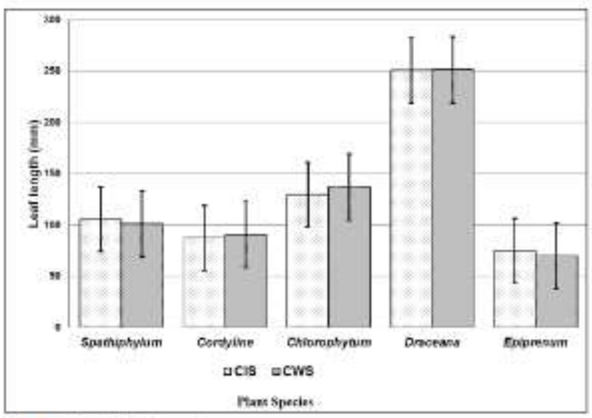

Fig. 7. Growth as influenced by irrigation system.

Ornamental potted plants that were grown in both irrigation systems were saleable and of high quality (based on colour and lack of blemishes) although our findings indicate that *Chlorophytum comosum*, spider plant; *Dracaena fragrans*, corn plant and *Cordyline terminalis*, red dracaena; had better growth under the CWS as compared to the other two species *Spathiphyllum clevelandii*, white anthurium; *Epipremum aureus*, money plant; which performed better in CIS, although the differences were not significant. We suggest that the selected ornamental potted plants performance could be improved over time by fine tuning the nutrition and irrigation management of crops produced under these the CWS system with the added benefits of water conservation. Producing equal or better-quality ornamental potted plants under reduced water consumption is of great interest for ornamental potted plant growers. The similarity in the selected potted plant growth performance throughout the growing season was not surprising. For example, (Davis *et al.*, 2008) Observed no significant differences in growth of sub irrigated versus overhead irrigated northern red oak (*Quercus rubra* L.) seedlings. In koa (*Acacia koa* Gray), sub irrigated and overhead-irrigated plants had similar gas exchange, height, and root collar diameter (Dumroese *et al.*, 2011; Davis *et al.*, 2011).

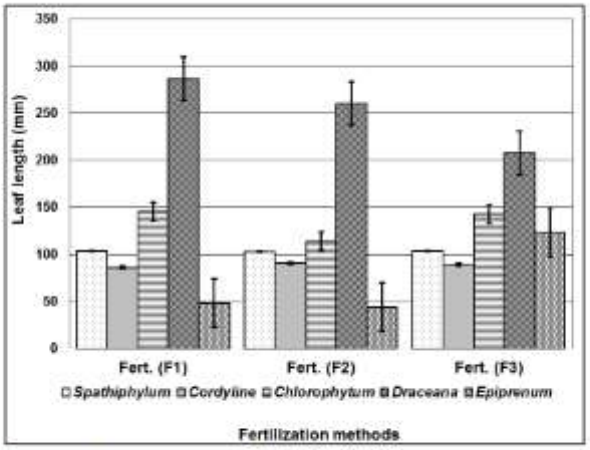

Fig. 8. Growth as influenced by fertilization method.

We applied fertilizer in our selected potted ornamental plants so as to maintain and achieve maximum growth. Inefficient fertilizer application methods do not supply the much-needed nutrients by the plants. Therefore, efficient fertilizer application methods must be adopted urgently in greenhouse for the selected ornamental potted plants production since minimizing fertilizer and water requirements for greenhouse production has become increasingly important to growers, because many are faced with higher water and fertilizer costs, decreasing availability of quality water, and government regulations provide for protecting surface and groundwater (Uva *et al*, 2001; Van Iersel, 1999).

Our findings indicate that the selected potted ornamental plants performed better under fertigation, followed by top fertilization and then side fertilization (Fig. 8). Fertigation, is the incorporation of soluble fertilizers into irrigation water. This we believe is due to the harmonization and integration between application of water and plants nutrients. The dissolved fertilizer often moves with applied water through the wick as the water is delivered to the plants. This enables the media to be supplied with uniform moisture and thus could explain why the plants performed better under fertigation (Fig. 8). Klock-moore *et al*, 2001 also found out that for overhead irrigated pots of areca palm (*Dypsis lutescens*), crossandra (*Crossandra infund ibuliformis*), pentas (*Pentas lanceolat*), and philodendron (*Philodendron*) 'Hope' plants, the water leached from the pots contained fertilizer salts. For top fertilization, even though nutrients are leached beyond the root zone, the excess water was collected through the underside saucers and re-used in the next watering cycle. This may explain why there is no significant difference between fertigation and top fertilization in our experiment. For side fertilization, the absorbability of the fertilizer on the wicks may have played a role in its uptake by the plant. Our results show that it is possible to optimize fertilization and keep environmental contamination under control, using our CWS for ornamental potted plants production. Thus, we propose that nursery growers producing potted ornamental plants adopt cultivation systems that collect and reuse the excess irrigation water.

Conclusion and recommendations

From the results of this study we conclude that production of the selected potted ornamental plants under CWS, an example of a sub irrigation system, is a water saving method by 63.75 % as compared to CIS. *Chlorophytum comosum*, spider plant; *Dracaena fragrans*, corn plant and *Epiprenum aureus*, money plant; had better growth under the CWS as compared to the other two species *Spathiphyllum clevelandii*, white anthurium;

Cordyline terminalis, red dracaena; which performed better in CIS, although the difference was not significant. Fertigation was the best fertilization method for the selected potted ornamental plants under CWS. CWS can be suited for effectively growing potted ornamental plants without lowering their quality. Our findings pave way for testing the system with a wider range of ornamental potted plants, other crops and ultimately commercialization of the system for the Kenyan conditions. CWS should be adopted for potted ornamental plants production since it conserves water, minimizes runoff, reduces need for irrigation equipment, is time efficient and economical. This will benefit our society and protect natural resources and the environment from pollution resulting from the application of excess fertilizer.

Acknowledgment

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Appendix 2: Data analysis

Leaf length					
Source	s.s	d.f.	m.s.	F	Sig.
Between Groups	7155.800	2	3577.900	1.570	0.214
Within Groups	198209.800	87	2278.274		
Total	205365.600	89			

ANOVA of leaf length as influenced by irrigation and fertilization method under CWS and CIS

Plant height					
Source	s.s.	d.f.	m.s.	F	Sig.
Between Groups	8792.067	2	4396.033	0.612	0.545
Within Groups	624980.833	87	7183.688		
Total	633772.900	89			

ANOVA of plant height as influenced by irrigation and fertilization method under CWS and CIS

Leaf number					
Source	s.s	d.f.	m.s.	F	Sig.
Between Groups	15.022	2	7.511	0.121	0.886
Within Groups	5390.267	87	61.957		
Total	5405.289	89			

ANOVA of number of leaves as influenced by irrigation and fertilization method under CWS and CIS t-Test: Equality of Means: Leaf length

		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Lower	Upper
Leaf_length	Equal variances assumed	0.11	0.74	0.71	88.00	0.48	7.20	10.16	-12.98	27.38
	Equal variances not assumed			0.71	87.88	0.48	7.20	10.16	-12.98	27.38

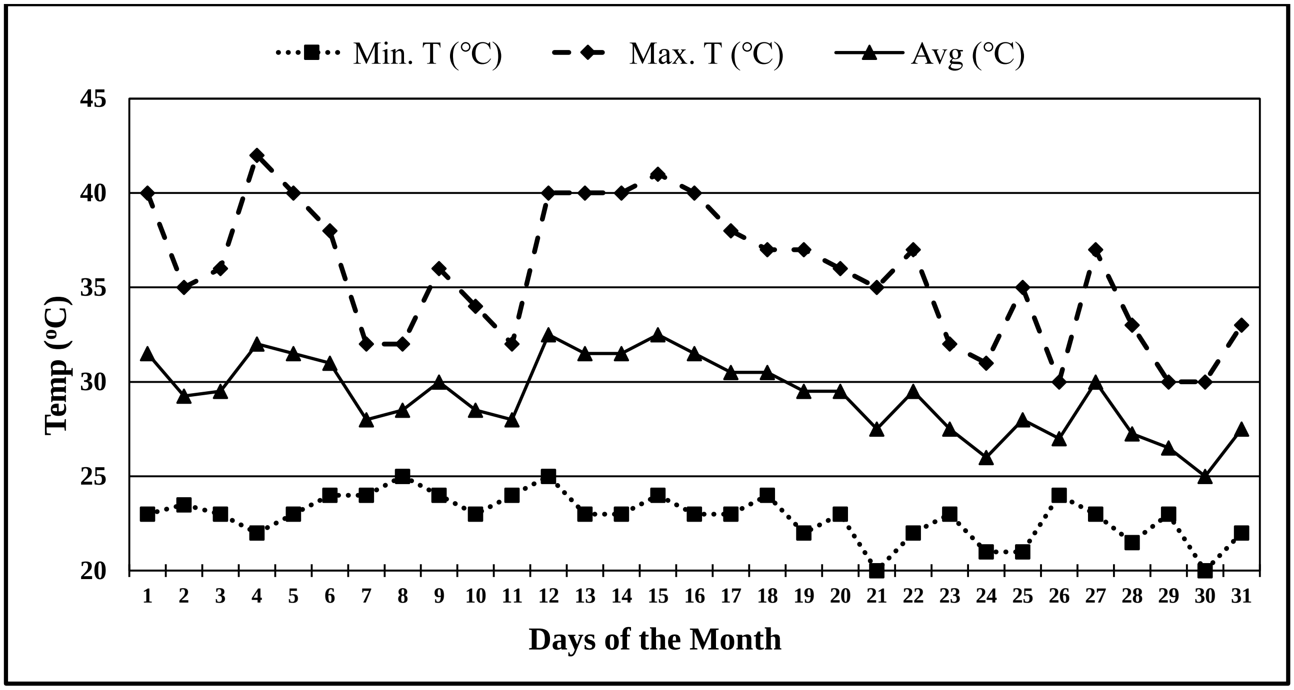
t-Test: Equality of Means: Plant Height

		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Lower	Upper
Plant_height	Equal variances assumed	1.65	0.20	1.61	88.00	0.11	28.47	17.63	-6.57	63.51
	Equal variances not assumed			1.61	85.65	0.11	28.47	17.63	-6.59	63.52

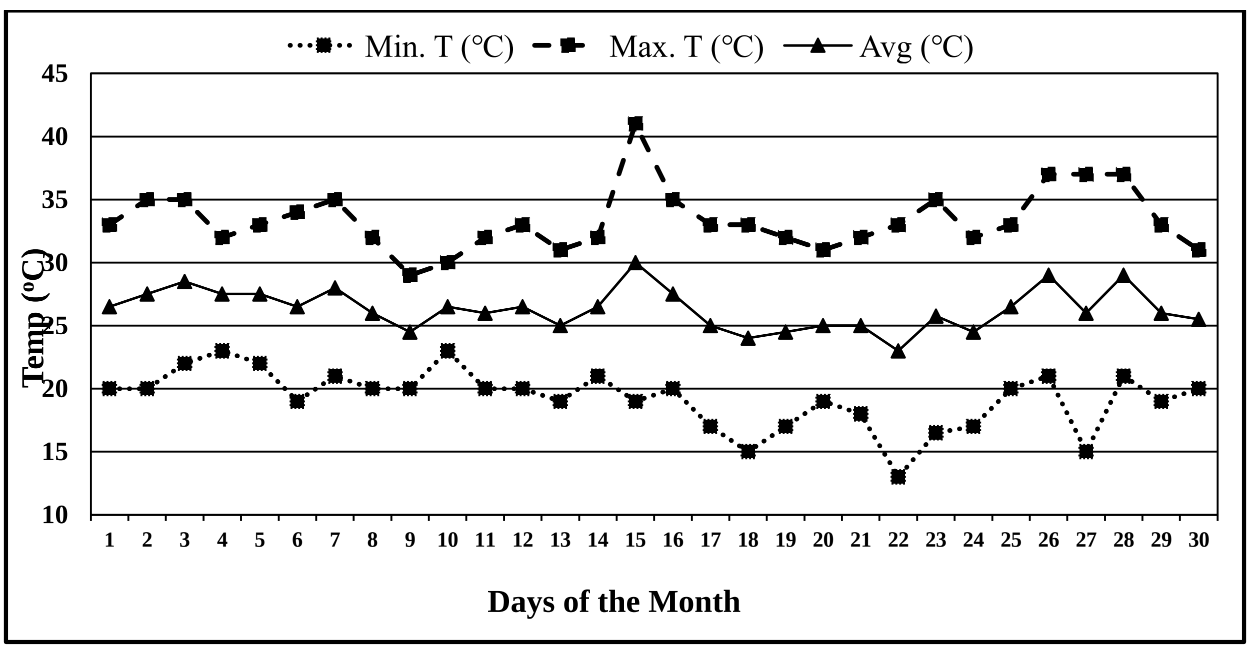
t-Test: Equality of Means: Leaf number

		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Lower	Upper
Leaf number	Equal variances assumed	0.091	0.764	1.865	88	0.066	3.022	1.621	-0.198	6.243
	Equal variances not assumed			1.865	74.323	0.066	3.022	1.621	-0.207	6.251

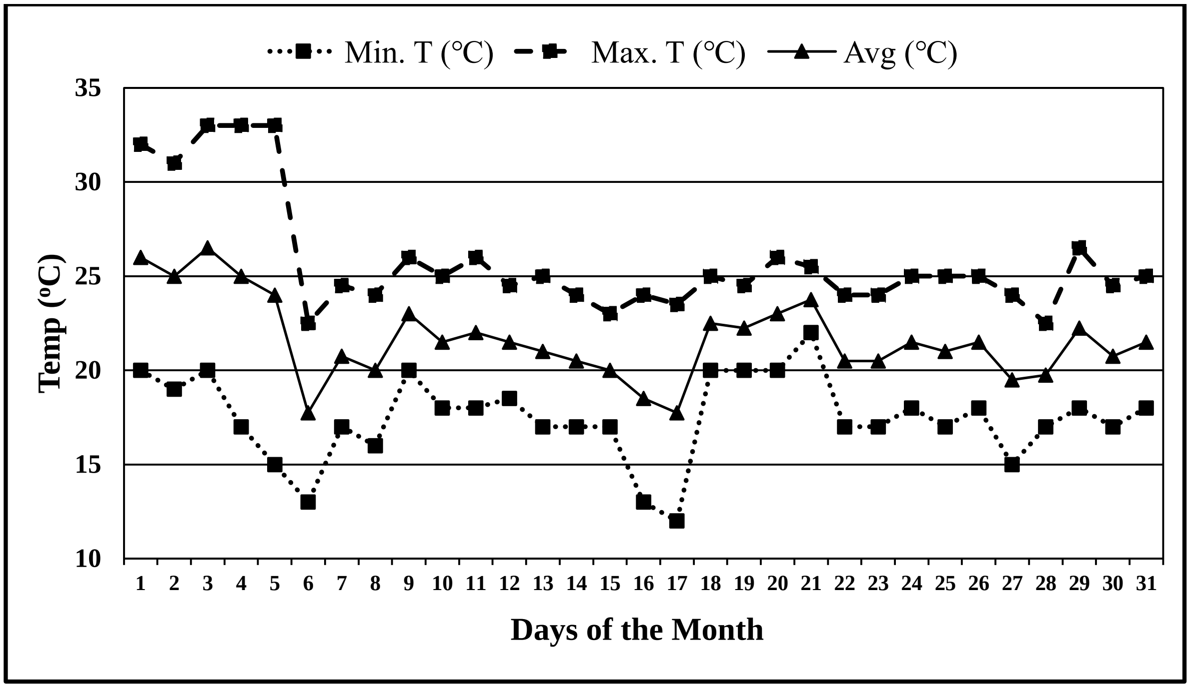
Appendix 3: Daily temperature in the greenhouse



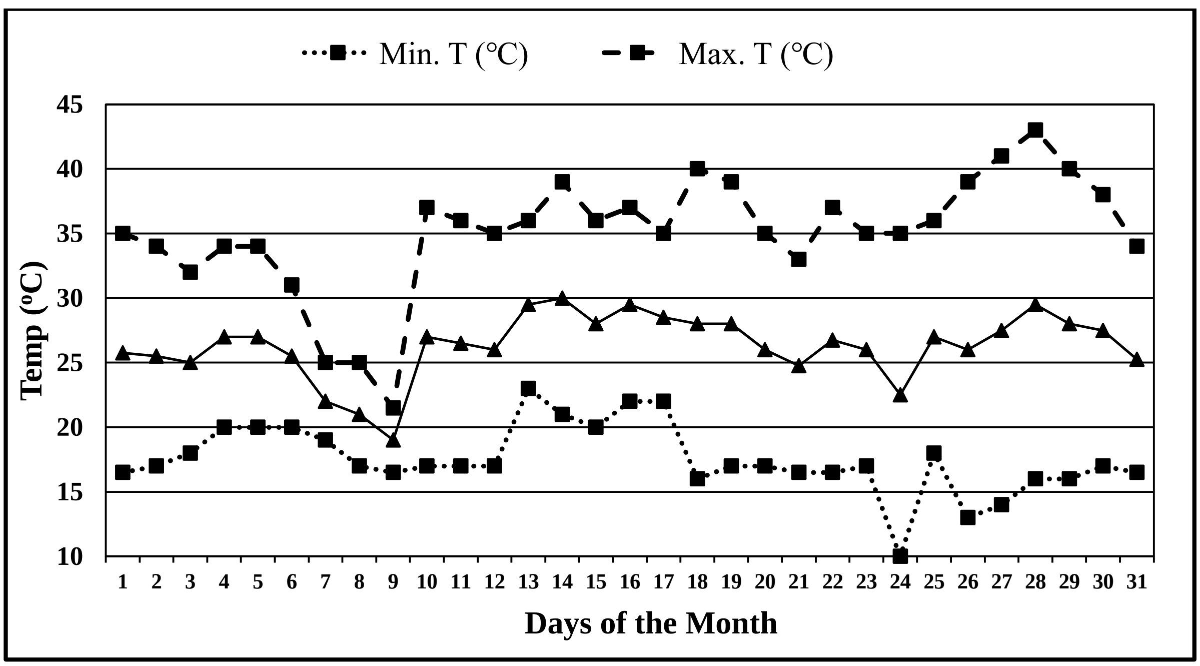
Daily temperature in the greenhouse (May, 2015)



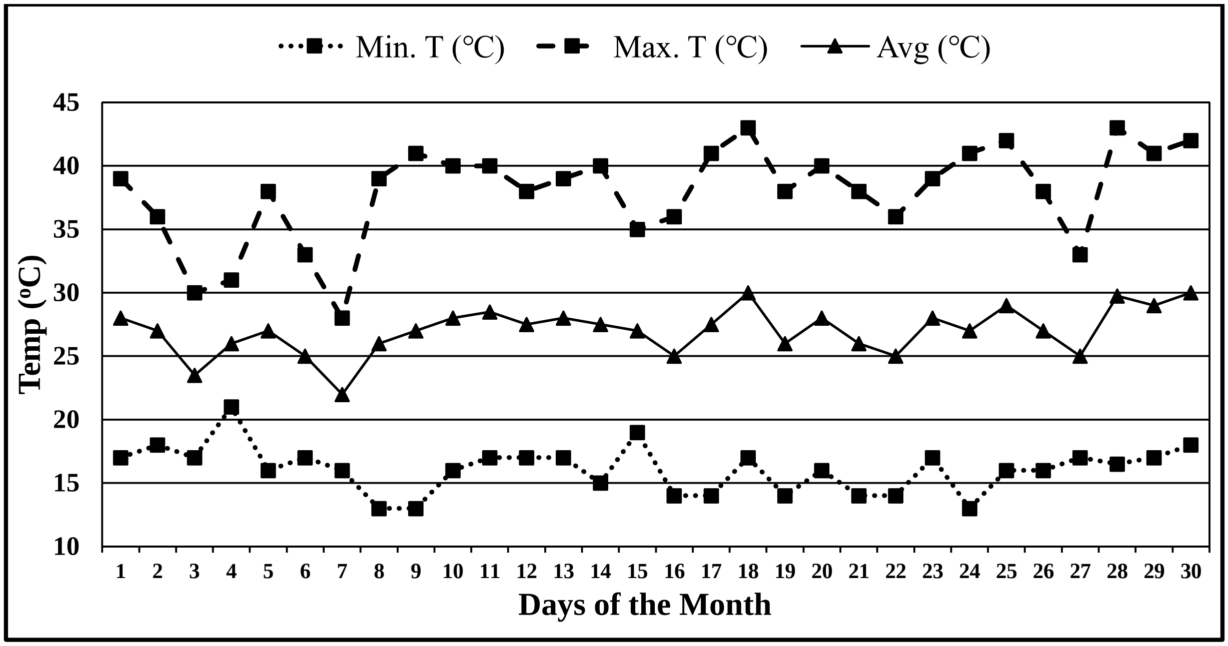
Daily temperature in the greenhouse (June, 2015)



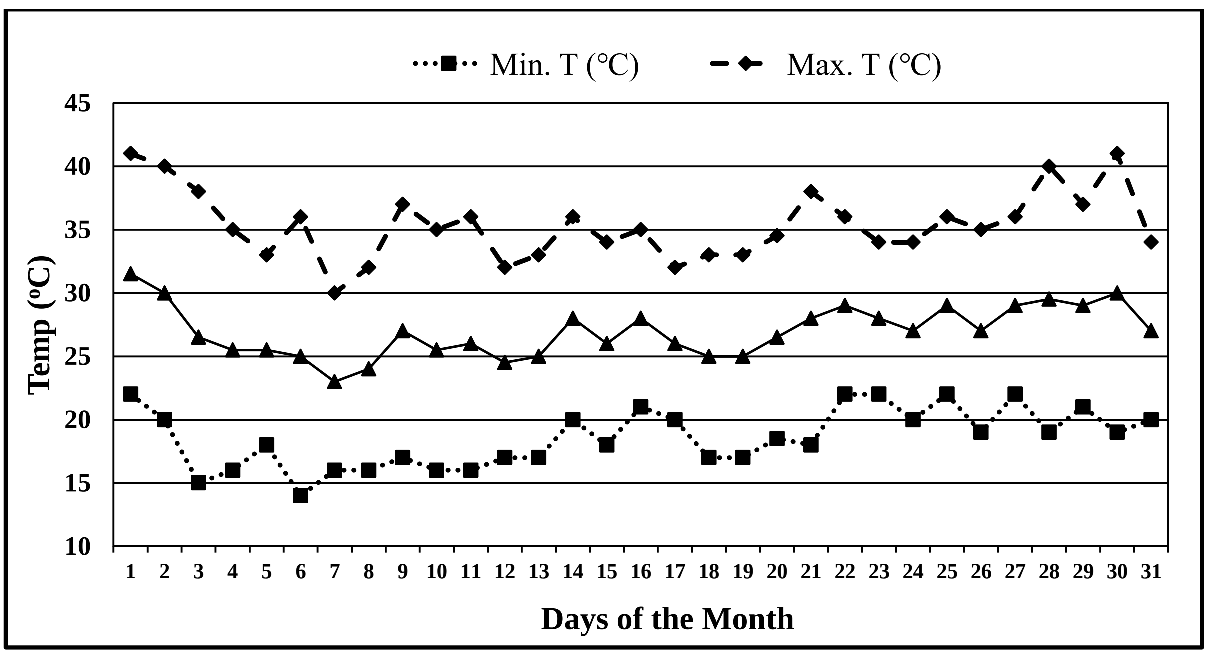
Daily temperature in the greenhouse (July, 2015)



Daily temperature in the greenhouse (August, 2015)



Daily temperature in the greenhouse (September, 2015)



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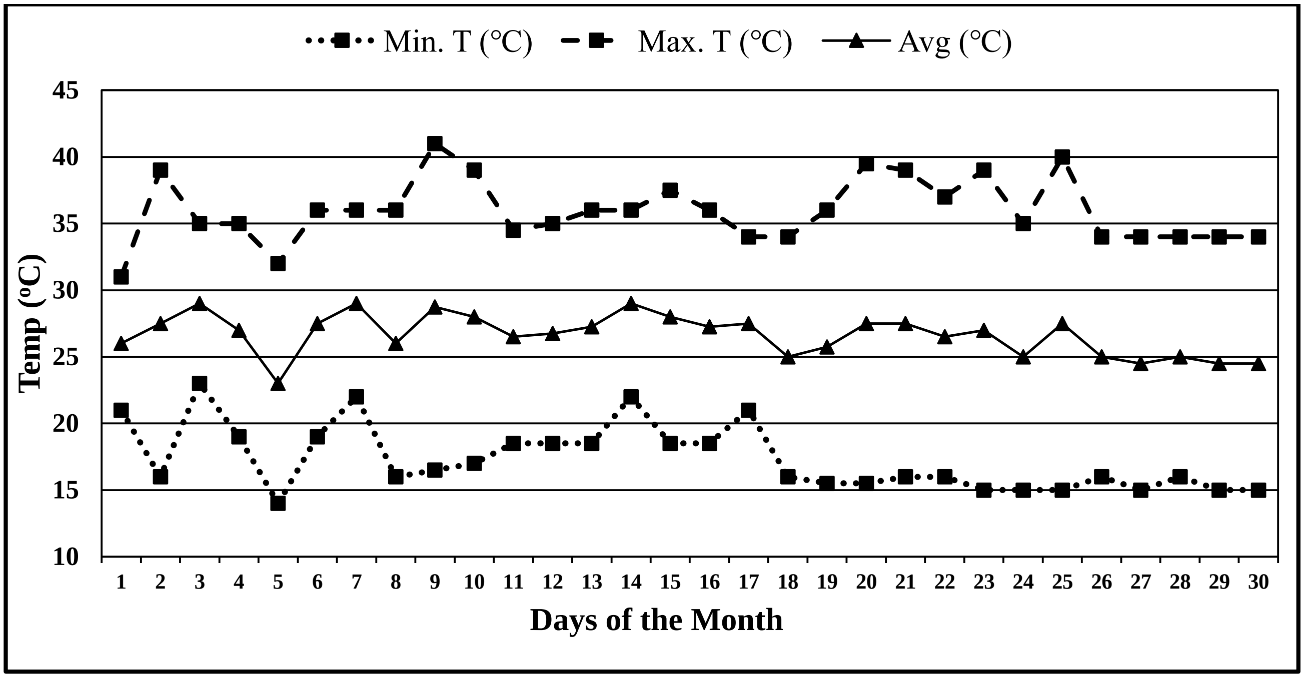
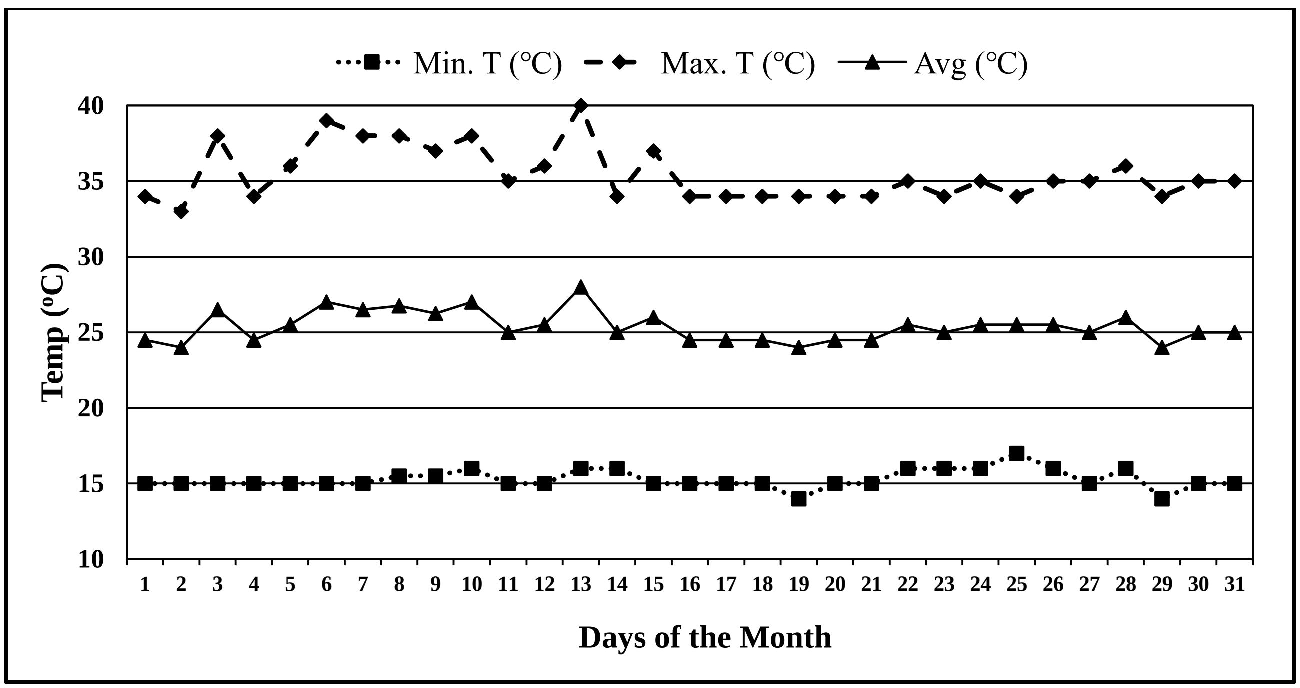
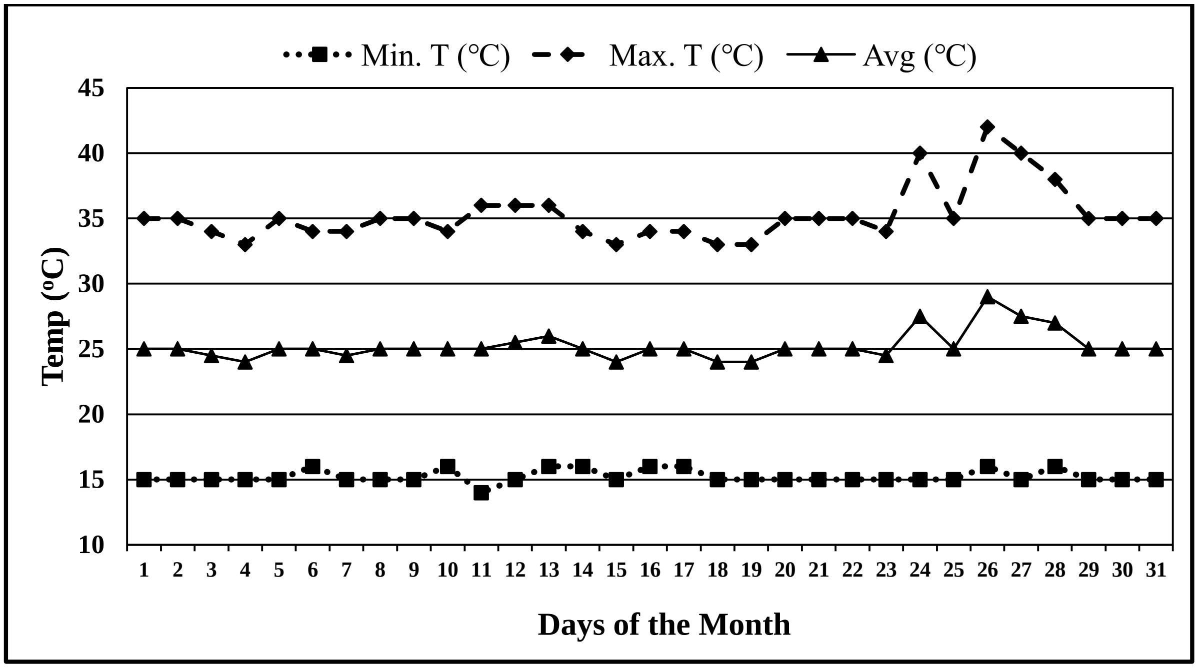


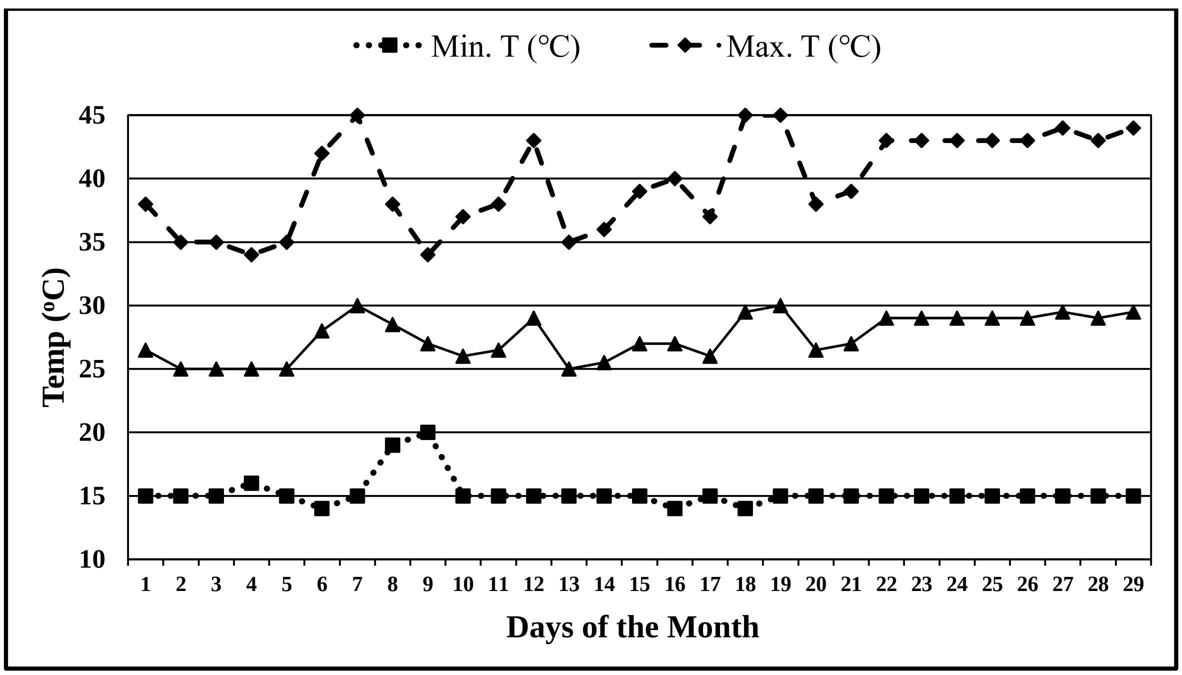
Daily temperature in the greenhouse (November, 2015)



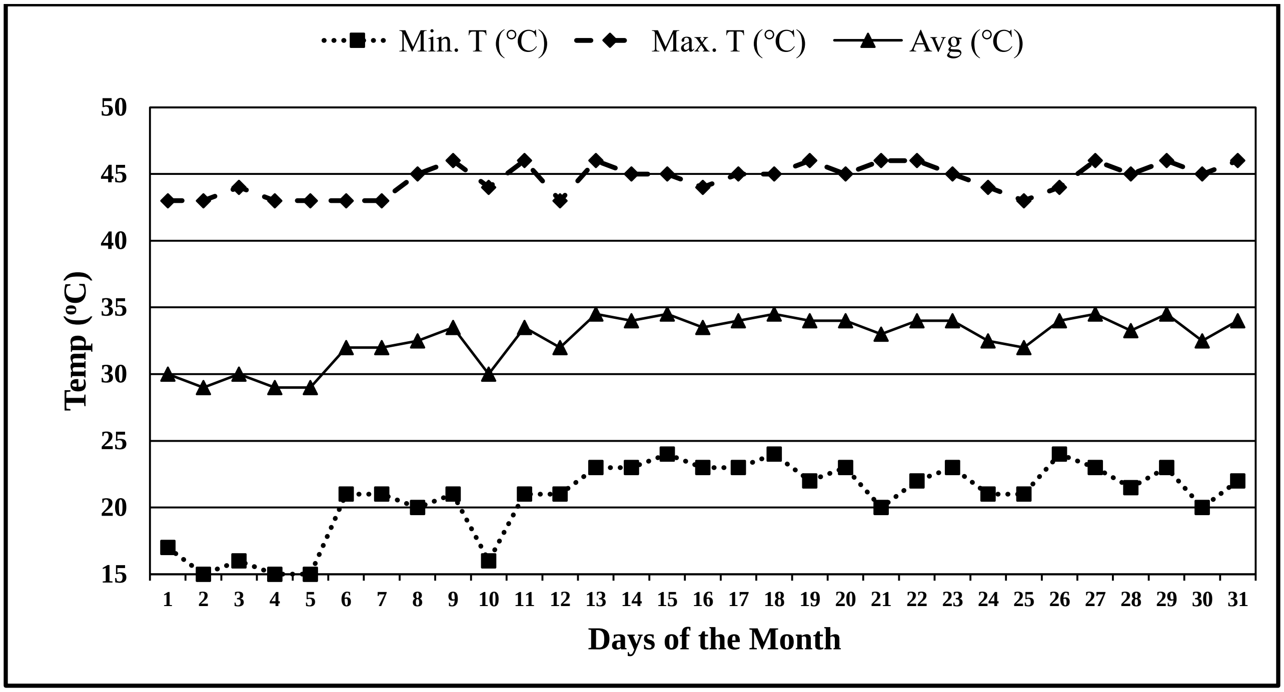
Daily temperature in the greenhouse (December, 2015)



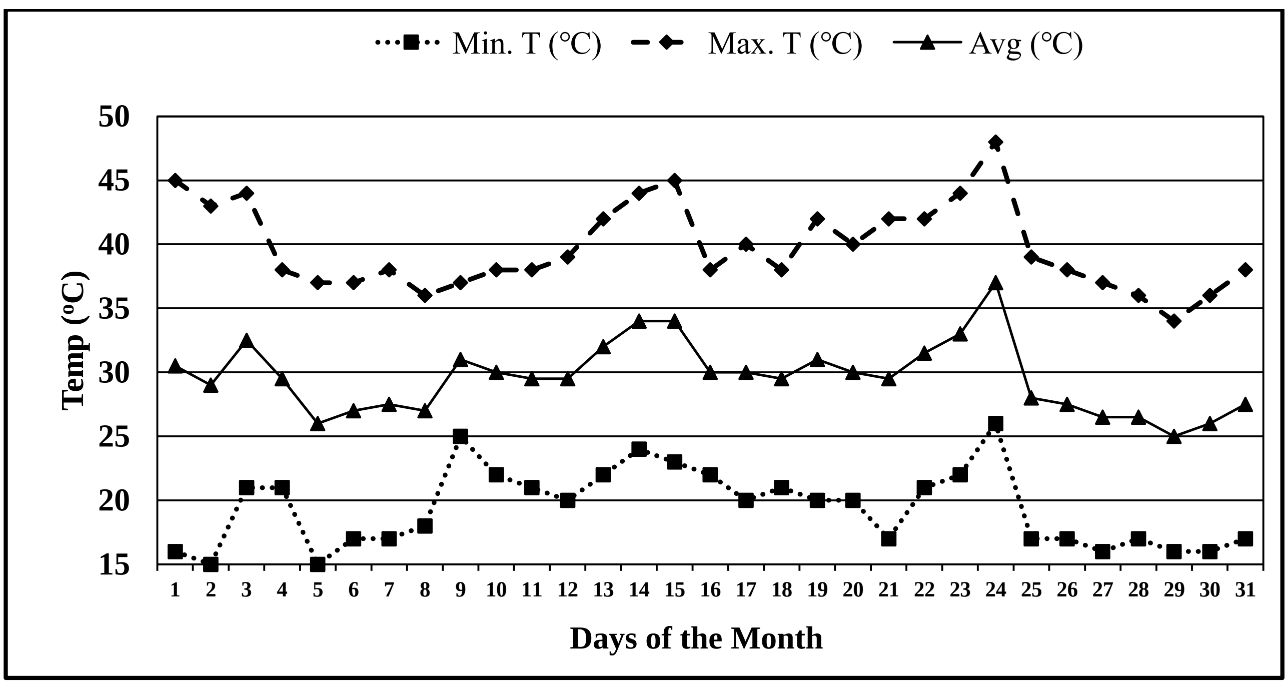
Daily temperature in the greenhouse (January, 2016)



Daily temperature in the greenhouse (February, 2016)



Daily temperature in the greenhouse (March, 2016)



Daily temperature in the greenhouse (April, 2016)