Cape Peninsula
University of Technology

The effects of various drip fertigated water quantities on hydroponically cultivated *Cucumis sativa L.*

by

DONAVON MARK SONNENBERG

Thesis submitted in fulfilment of the requirements for the degree

Master of Technology: Horticulture

in the Faculty of Applied Sciences

at the Cape Peninsula University of Technology

Supervisor: Prof P Ndakidemi

Co-supervisor: Prof Charles Laubscher

Cape Town

June 2012

DECLARATION

I, Donavon Mark Sonnenberg, declare that the contents of this dissertation/thesis represent my own unaided work, and that the dissertation/thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed **Date**

ABSTRACT

The effects of various water quantities were assessed on Cucumber (*Cucumis sativa* L.) grown hydroponically in the greenhouse. The objectives of the study were to evaluate influence of water quantities on: i) photosynthesis and chlorophyll content of *Cucumis sativa* L.; ii) the nutrient uptake in *Cucumis sativa* L. iii) flavonoid and anthocyanin metabolism in *Cucumis sativa* L. and iv) growth and yield in *Cucumis sativa* L. The treatments included 8 various water regimes (2l/h, 4l/h, 6l/h, 8l/h, 10l/h, 12l/h, 14l/h and 16l/h. The plants received water five times a day, making it 10, 20, 30, 40, 50, 60, 70, and 80 litres per day.

Results showed that generally the Photosynthetic rate (A), intercellular CO_2 concentration (C_i) and stomata conductance (gs) and the transpiration rate of the cucumber plants were significantly increased by increasing water quantities compared with lower water quantities. Additionally, there were significant improvements in leaf colour in weeks 2, 3, 4, 5, 6, 7 and 8. Overall, the foliage colour was improved as water supply was increased. The greener leaves were documented in treatments supplied with higher water doses. Additionally, the chlorophyll content of cucumber plants was increased significantly with varying water quantities. The highest chlorophyll contents were found in plants treated with 16l/h.

The fresh and dry weights of roots, leaves and stems were significantly ($P \leq 0.001$) influenced by different water quantities supplied to *Cucumis sativa* L. The largest quantity of fresh roots was recorded in the control treatment (2l/h) in comparison with all other treatments. However, the best growth with regard to fresh and dry weights of leaves and stems were recorded by supplying the water quantities ranging from 10-16l/h. Altering water supply significantly ($P \leq 0.001$) affected the uptake of nitrogen, phosphorous, potassium, calcium, sodium, copper, zinc, aluminium and iron in roots of *Cucumis sativa* L. Irregular results were recorded in the uptake of these nutrients in the roots. However, leaf uptake of N, P, K, Ca, magnesium, sulphur, Cu, Zn, manganese, boron, and Al responded significantly ($P \leq 0.001$) to the different water quantities. The best result for each was observed at quantities involving 16l/h. In stems of cucumber water quantities significantly ($P \leq 0.001$) affected the uptake of N, P, K, Ca, Mg, Na, S, Cu, Zn, Mn and B. The highest uptake of N, P, Ca, Mg and S were found at the maximum supply of water (16l/h) compared with the control (2l/h). Sodium uptake showed irregular patterns, whereas K and Zinc uptake peaked at 14l/h.

The data from this study showed that flavonoid metabolism was not significantly affected by the different water quantities supplied to cucumber plants. However, the anthocyanin content in roots, leaves, and stem was significantly influenced by water levels. The lowest water quantity (2-6l/h) significantly increased the levels of anthocyanins in all tissues tested.

Increasing water quantities significantly decreased the anthocynanin metabolism in all tissues.

Plant height displayed significant differences with water quantities from weeks 1-8. In week 1, the plant height was superior at supplying 4l/h in comparison with other treatments. In week 2 and 5 irregular trends were detected. At weeks 3 and 4, plants supplied with 8-12l/h displayed superior plant height performance. At weeks 7-8, significant and optimal results were observed at water quantities ranging from 4-16l/h compared with the control treatment. Water quantities significantly ($P \leq 0.001$) affected the number of leaves per plant from weeks 2-8. Irregular results were displayed in weeks 2 and 3. At weeks 4 and 5, the highest numbers of leaves were in water quantities of 12l/h and 10l/h, respectively. Generally, leaf numbers increased with increasing water levels from weeks 6-8. Plant vigour was significantly affected by the alteration of water quantities at weeks 1, 2, 4, 5, 6, 7 and 8. At weeks 1 and 4, more vigorous plants were found in the treatments that received from 10-16 l/h. At weeks 2 and 5, optimal results were found at treatments that received from 6-14l/h. At weeks 6, 7 and 8, the most vigorous plants were found at the highest water quantity of 16l/h. With fruit length, fruit width, rind colour, fruit quality (marketable fruit) and weight, results from the harvest done in the first, second and third week showed that water quantities significantly influenced these parameters. Optimal results were reported when the plants were supplied with water ranging between 14-16l/h. During harvesting at week 4, the fruit length, width, rind colour, were of marketable quality at 16l/h. Generally, the plants that received highest amount of water (16l/h) had the highest cucumber yields compared with all other treatments.

Higher water quantities in this study resulted in increased physiological responses such as photosynthesis and nutrient uptake which resulted in the higher fruit yields. In water-limited environments, results from this study could assist growers with reasonable cucumber yields while saving water for other farm uses.

ACKNOWLEDGEMENTS

It is with sincerity that I extend my gratitude to the following persons and institutions:

- **PROF PATRICK NDAKIDEMI,** Senior professor, The Nelson Mandela African Institute of Science and Technology, School of Life Sciences and Bio-engineering for his vast experience, knowledge, encouragement, guidance and friendship shown throughout the period of my studies.

- **PROF CHARLES LAUBSCHER,** Associate professor, Department of Horticultural Sciences, Cape Peninsula University of Technology for his professional approach, assistance shown, input of knowledge and experience.

- **CANDICE LIANA SONNENBERG,** my wife, for her love, patience, support, encouragement and assistance in collecting articles and data for my thesis.

- **MR D. & MRS S. SONNENBERG,** my parents, for their motivation, love and support throughout my academic career.

- **DENVER SONNENBERG,** my brother, for his assistance, love and encouragement when it was needed.

- **FRIENDS,** whom I had to neglect but still displayed their love, encouragement and patience throughout my studies.

- **THE CAPE PENINSULA UNIVERSITY OF TECHNOLOGY,** for providing me with all the useful resources that was required in order for me to complete my studies.

- **THE WESTERN CAPE DEPARTMENT OF AGRICULTURE,** for granting me financial assistance, time and support needed to undertake the research and to write the thesis.

- **THE NELSON MANDELA AFRICAN INSTITUTE OF SCIENCE AND TECHNOLOGY** for allowing me to complete my thesis at their campus and allowing me to spend valuable time with their senior lecturer.

BIOGRAPHICAL SKETCH

Donavon Mark Sonnenberg was born in Grassy Park, Cape Town, South Africa, on the 29th September 1985. He attended Plantation Primary School and matriculated at Fairmount Senior Secondary in 2002. He enrolled at the Peninsula Technikon in 2003 and obtained the ND Horticulture in 2007 and enrolled at the Cape Peninsula University of Technology in 2007 and obtained the BTech Horticulture in 2008. He is currently employed by the National Department of Agriculture as an agriculture food and quarantine technician.

DEDICATION

This thesis is dedicated to my:

Sister	Desireé Hartnick, whom is currently battling with breast cancer

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER THREE: THE EFFECTS OF VARIOUS DRIP FERTIGATED WATER QUANTITIES ON PHOTOSYNTHESIS AND CHLOROPHYLL CONTENT OF HYDROPONICALLY CULTIVATED *CUCUMIS SATIVA* L.

CHAPTER FOUR: THE EFFECTS OF VARIOUS DRIP FERTIGATED WATER QUANTITIES ON NUTRIENT UPTAKE OF HYDROPONICALLY CULTIVATED *CUCUMIS SATIVA* L.

CHAPTER FIVE: THE EFFECTS OF VARIOUS DRIP FERTIGATED WATER QUANTITIES ON FLAVONOID AND ANTHOCYANIN CONTENT OF HYDROPONICALLY CULTIVATED *CUCUMIS SATIVA* L.

CHAPTER SIX: THE EFFECTS OF VARIOUS DRIP FERTIGATED WATER QUANTITIES ON THE GROWTH OF HYDROPONICALLY CULTIVATED *CUCUMIS SATIVA* L.

LIST OF FIGURES

CHAPTER FIVE: THE EFFECTS OF VARIOUS DRIP FERTIGATED WATER QUANTITIES ON FLAVONOID AND ANTHOCYANIN CONTENT OF HYDROPONICALLY CULTIVATED *CUCUMIS SATIVA* L.

CHAPTER ONE

LITERATURE REVIEW AND INTRODUCTION

Review

Literature review and introduction of; possible effects of water quantities on photosynthesis, nutrient uptake, phenolic compounds metabolism and growth of plants.

Donavon Sonnenberg[1], Patrick A. Ndakidemi[2], and Charles Laubscher[1*]

[1]Faculty of Applied Science, Cape Peninsula University of Technology, Cape Town Campus, P.O. Box 652, Cape Town 8000, South Africa.
[2]The Nelson Mandela African Institute of Science and Technology, School of Life Sciences and Bio-engineering, Nelson Mandela Rd, P O Box 447, Arusha- Tanzania.

[*]Corresponding author

Tel: +27 21 4603198. Fax: +27 4603193

Email: laubscherc@cput.ac.za

1.1 Abstract

In Africa, yield losses in vegetable production to farmers are exacerbated by water management practices such as those used in the hydroponic systems. As opposed to surface irrigation, controlling water supply to plants through drip irrigation may help growers to use water more resourcefully hence facilitate various physiological processes in plants such as photosynthesis, nutrient uptake and assimilation of metabolites. This review focuses on the need of supplying optimum quantities of water to obtain exceptional yields of high quality. This will help growers in reducing extra expenditure on water and thereafter recording good profits.

Key words: anthocyanin, chlorophyll, flavonoids, growth, nutrient uptake, photosynthesis.

1.1 INTRODUCTION

Originating from the *Cucurbitaceae* family, *Cucumis sativus* L. (cucumber) has become one of the most well-liked vegetable produce (Ahmad and Aniz, 2005). In intensified systems,

cucumbers may be produced hydroponically in sterilized media such as perlite, sawdust or rockwool (Shaw et al., 2000; Heuvelink and Körner, 2001). In these systems, each cucumber plant is trained with twine hung from a cable harnessed on top of each plant with its side shoots removed in between each node (Shetty and Wehner, 1998; Shaw et al., 2000). In the controlled environments, the optimum temperature for cucumber crops is 24-26^{o}C throughout the day and 18^{o}C at night. Chung and Staub (2003) stated that cold damage can occur when temperatures drop below 12^{o}C.

Water is an essential component when growing vegetable crops and other plants. Cucumber crops need great quantities of water for optimal plant development and fruit production (Combrink, 2005). As a result of drought and water becoming very rare all over in the world including South Africa, it is commanding to utilize less water and still get the best out of the vegetable crops (Bajracharya and Sharma, 2005). The use of drip irrigation is one of the best options for optimizing this scarce resource as less water is used and increased crop yields may be achieved. This method is good because under controlled conditions such as those of hydroponic cultivation, it is possible to establish the exact quantity of water that is necessary to cultivate plants effectively.

One of the major difficulties experienced by vegetables producers in South Africa, is the water management and water use efficiency. As opposed to surface irrigation, the drip irrigation may help growers to use water more resourcefully and prevent plants from coming into contact with water and hence preventing disease development (Shock, 2006). To solve the water crisis problem it is imperative to establish the optimum quantities to be supplied to obtain exceptional yields of high quality. This will help growers in reducing extra expenditure on water and thereafter recording good profits.

1.3 EFFECTS OF VARIOUS QUANTITIES OF DRIP IRRIGATED WATER ON PHOTOSYNTHESIS AND WATER USE EFFICIENCY

Photosynthesis is a process whereby energy of the photosynthetically active radiation (within the wavelength range 400–700 nm) is used to segregate gaseous carbon dioxide and liquid water furthermore recombining them into gaseous oxygen and a sugar called glucose (Petela, 2007). Photosynthesis, transpiration and dry matter production of plants are closely connected procedures. In the photosynthesis procedure, water plays an important aspect by controlling the

stomatal opening and the effects it has on plants that do not receive sufficient water (Leopald, 1964). Photosynthesis is accountable for build-up of most of the dry mass of plants, and dry matter yield is reduced when plants are exposed to low leaf water potentials (Boyer, 1976).

Photosynthesis is proportional to stomatal opening under various conditions and is therefore sensitive to adjustments in water relations which have an influence on the stomatal function. The decrease in photosynthesis accumulation during midday is partially due to the fact that there is a shortage of water and this leads to the stomata being to some extent closed. Ashton (1956) confirmed a significant decrease in photosynthesis in sugarcane when soil tensions were near the permanent wilting point. Generally, plants that are exposed to limited water have a decrease in photosynthetic activities (Schapendonk et al., 1989; Pezeshki, 2001; Blanco et al., 2008). Li et al. (2003) have shown that plants receiving excessive amounts of water go into a temporary photosynthesis reduction, but near the end of the investigation the photosynthetic rate increased. Similarly, Schneider and Childers (1941) reported a 15% drop in photosynthesis in apple leaves due to limited water conditions, a situation caused by low leaf water potentials.

Stomata conductance regulates the photosynthetic activities in the plant. For example, stomatal closure is associated with reduction in photosynthesis through reduction of internal CO_2 concentration in the foliage. In crops, water stress can reduce the photosynthetic rate indirectly by stomata closing or directly by reducing the photosynthetic capacity of leaves by inhibiting the Calvin cycle or the rate of electron transport above the chloroplast membranes (Kaiser, 1987). Research by Bradford and Hsiao (1982); Ceccarelli (1984) have shown that larger resistance of the stomata to CO_2 diffusion leads to a decrease in the CO_2 concentration within the foliage and as a result lessened the rate of photosynthesis. As stated before, stomatal closure results to decreases in CO_2 assimilation (Chaves, 1991) and furthermore in growth and yield. Studies have suggested that when plants are exposed to mild limited water conditions the stoma plays a primary function in directing the decrease of the net CO_2 uptake by leading to reduction in leaf internal CO_2 concentrations (Kaiser, 1987; Cornic and Briantais 1991; Cornic 2000; Souza et al. 2003). However, CO_2 build-up controlled by stomatal closure encourages unevenness among activity and electron necessity for photosynthesis (Krause 1988; Long et al. 1994). In cowpea, crops exposed to drought stress experienced decreases in CO_2 assimilation rates by relying on stomatal closure, hence reducing accessible internal CO_2 and limited the water loss via transpiration.

Flexas et al. (2007) recommended that limited water conditions can affect photosynthesis directly or indirectly by reducing the CO_2 availability due to gas diffusion limitations and alterations in photosynthetic metabolism (Lawlor and Cornic, 2002). To ascertain this, Silva et al. (2010) indicated that after plants were exposed to limited water conditions, the CO_2 assimilation rate was reduced drastically in comparison with the control treatments.

The intercellular CO_2 concentration (C_i) is another important aspect which can affect the photosynthesis processes. When there is a deficiency of water in plants, a low concentration of CO_2 will be supplied for photosynthesis and as a result the intercellular CO_2 concentration (C_i) will decrease (Farquhar and Sharkey, 1982). Smith and Osmond, (1987); Hubick et al., (1988); Ehleringer et al., (1992); Donovan and Ehleringer, (1994) revealed that intercellular CO_2 concentration (C_i) decreased when plants were exposed to limited water conditions (Smith and Osmond, 1987; Hubick et al., 1988; Donovan and Ehleringer, 1994).This difference between gas exchange data and additional measures of intercellular CO_2 concentration (C_i) is a result of patchy stomatal closure when exposed to water stress (Brodribb, 1996; Lawlor, 2002; Flexas et al., 2004). Limited water conditions in plants may perhaps enhance photorespiration and deplete intercellular CO_2 due to stomatal closure restricting CO_2 concentration into intercellular air spaces (Ben et al., 1987; Kaiser, 1987; Cannon and Roberts, 1994; Wingler et al., 1999; Cornic and Fresneau, 2002; Noctor et al., 2002).

Water use efficiency refers to the yield per unit of water consumed (Hsiao and Acevedo, 1974). Water use efficiency is a significant issue with regards to irrigation systems and water management will definitely become even more essential in the future as water becomes scarcer (Cetin and Uygon, 2008). Studies have proved that various irrigation regimes affect water use efficiency in crops as plants supplied with less water had higher water use efficiency than those with higher amounts (Cetin and Uygon, 2008).

Hence, it is vital to study the impact of water availability on photosynthetic parameters such as photosynthetic rate (A), intercellular CO_2 concentration (C_i), stomatal conductance (gs) and water use efficiency in vegetables exposed to different water quantities under green house conditions.

1.4 EFFECTS OF VARIOUS QUANTITIES OF DRIP IRRIGATED WATER ON CHLOROPHYLL FORMATION

The chlorophyll content in plants is highly sensitive to environmental stresses such as limited moisture availability (Younis et al., 2000) which can significantly lower the chlorophyll content (Guerfel et al., 2008). Lower water content in plant tissues affects the chlorophyll content by reducing the photosynthetic electron - chain activity in plant chloroplasts and ultimately affecting the photosynthetic content (Keck and Boyer, 1974). In plants, the chlorophyll is stored in the chloroplast and during moisture stress periods molecular damages take place on chloroplasts and hence, affect chlorophyll synthesis (Alberte et al., 1975; Thornber 1975). A study by Alberte et al. (1975) revealed that chlorophyll synthesis was inhibited to a minimum of 50% when leaves were exposed to mild water drought situations.

The reduction of chlorophyll in plants, when exposed to water stress, is due to its sensitivity to water scarcity. Therefore, there is a need to study the influence of various water quantities on the chlorophyll content in plants grown under intensively managed systems such as those found in the glasshouse.

1.5 EFFECTS OF VARIOUS QUANTITIES OF DRIP IRRIGATED WATER ON NUTRIENT UPTAKE

Nutrient availability (i.e. macro-and micronutrients) for plant growth and development in hydroponics systems is very important for vegetable production. However, crop nutrient uptake is affected by various quantities of water and transpiration rates. It was previously reported that the higher the transpiration rate, the greater the nutrient uptake (Tanguilig et al., 1987). For example, when a small amount of water is supplied to the crop, nutrient uptake by the roots is reduced and so does their transport to the shoots. The reduced nutrient uptake has been reported to be due to restriction in the transpiration rates leading to impaired active transport and membrane permeability (Greenway and Klepper, 1969; Viets, 1972; Hsiao, 1973; O`Toole and Baldia, 1982; Yamboa and O`Toole, 1984; Pinkerton and Simpson, 1986; Tanguilig et al., 1987; Kramer and Boyer, 1995; Alam, 1999). Reduction in nutrient accessibility by roots is also one of the crucial factors that restrict plant growth under limited water conditions (Hu et al., 2006). For example, it was reported that when plant roots were exposed to limited water, nutrient uptake was generally reduced (Viets, 1972; Pinkerton and Simpson, 1986). The

reduced nutrient uptake was related to a reduced rate of diffusion of nutrients to the plant roots due to low soil moisture (Viets, 1972; Pinkerton and Simpson, 1986).

Water stress has also been reported to decrease nutrient uptake and their transportation process in plants (Wardlaw, 1967). Smika et al. (1965) studied the associations between water accessibility and nitrogen (n) fertilizer, and reported that enhanced crop yield was achieved only when fertilizer was dissolved in a sufficient amount of soil solution. Like nitrogen (n), the mobility of potassium (k) also declines when the soil water content decreases under limited water conditions. Studies done by Beringer and Trolldenier (1978) and Scherer (2001) showed that when onion plants were exposed to low soil moisture conditions, crops wilted due to k, magnesium (mg) and sulphur (s) deficiency. In a research project conducted by Huluka et al. (1994) on cotton plants to test the effect of water stress on plant nutrition status, it was identified that the n and protein content of leaves, stems and roots decreased in plants exposed to low quantities of water, suggesting that low amounts of water affects a crops` nutrient levels.

Water stress can cause damage to the plant as a result of impaired ion uptake. However, the damage will depend on the severity of the water stress. Although decreasing of the water potential does not lower the build-up of anions in the cells and xylem sap of the roots, it decreases the sum of the ions that are transported to the shoots as a result of reduced water flow (Greenway, 1967). For example, Erlandsson (1975) showed that a change in the water potential of plants caused by water stress has an effect on the active ion uptake mechanism. So, decreased uptake of plant mineral elements under limited water conditions is due to low moisture and reduced transpiration flow (Marschner, 1995; Baligar et al., 2001).

The amount of water a plant receives has a direct effect on the amount of nutrients it will contain. Water will therefore determine if a plant will have a lot of nutrients or not. This will be a useful tool for growers to obtain the optimum amount of water required that will lead to optimum nutrient absorption in plants for optimum crop production.

1.6 EFFECTS OF VARIOUS QUANTITIES OF DRIP IRRIGATED WATER ON PHENOLIC COMPOUNDS

The word Flavonoid a phenolic compound, is a word that is universally used to describe a broad collection of natural products of which the chemical strucuture consist of a carbon framework

(Marais et al., 2006). Flavonoids are polyphenolic plant secondary metabolites which are synthesized along the polypropanoid pathway with phenylalanine as its activation molecule. Flavonoids have attracted a lot of attention because of its influence on green, red, blue and purple pigmentation found in plants and its association with the health benefits of wine, chocolate and commonly with diets rich in fruits and vegetables (Winkel, 2006). Benefits for instance, the blue colour is indication of the presence of anthocyanins (delphinidin-based) in petals. Various plant flavonoids play a role in defence against microbes, insects and mammalian herbivory. A few of them namely; isoflavones, flavons and flavanones are acknowledged as constitutive antifungal plant agents (Harborne and Williams, 2000; Ndakidemi and Dakora, 2003; Makoi and Ndakidemi, 2007; Makoi et al., 2010; Makoi and Ndakidemi, 2012). Flavonoids are capable of modifying enzymatic and chemical reactions, which can have a positive or negative impact on human health (Beecher, 2003). Flavonoids are commonly acknowledged for their antioxidant activity. Antioxidants are compounds that guard cells against the harmful effects of reactive oxygen species (Kukić et al., 2006). Epidemiological research has identified beneficial effects of dietary flavonoids in reducing chronic diseases such as cancer (Chung et al., 2005; Ramos, 2007).

Anthocyanins also play a role in the autumn colours in numerous plant species and photo-protection in leaf cells. Their capability of being a natural UV filter comes from their absorption of light in the 280 - 315 nm regions. The production of these phenolic compounds in plants is facilitated by stress conditions (Chalker-Scott, 1999; Ndakidemi, 2006). Mattivi et al. (2006); Castellarin et al. (2007b) stated that limited water conditions increase anthocyanin accumulation via the stimulation of anthocyanin hydroxylation, by up-regulating the gene encoding the enzyme. Castellarin et al. (2007b) stated that early exposure to limited water conditions in grape berries led to increased sugar accumulation, which hastens anthocyanin synthesis. Given the induction of anthocyanins by osmotic stress, it is not astonishing to learn that plant tissues containing anthocyanins are commonly resistant to limited water conditions. Decades ago, anthocyanin accumulation in *Populus* shoots was linked with limited water conditions (Wettstein-Westersheim, 1962). Drought tolerant plants which illustrates great tolerance to drought, accumulates three to four times more anthocyanins throughout dehydration, compared with their fully hydrated state (Sherwin and Farrant, 1998).

Even though the concentration of anthocyanins and other phenolic compounds have constantly increased in reaction to limited water conditions, it is important to assess the effects of various

quantities of drip irrigated water on the flavonoid and anthocyanin metabolism in *Cucumis sativa* L. grown in hydroponic culture. The presence of phenolic compounds may affect the quality and taste of cucumber fruits and can alter its digestibility, or even cause undesirable browning and structural modifications which could adversely alter the functional properties of the proteins and their behaviour.

1.7 EFFECTS OF VARIOUS QUANTITIES OF DRIP IRRIGATED WATER ON VEGETATIVE GROWTH

Growth can be defined as an unalterable growth or increase of cells in size. Cell enlargement cannot be maintained without simultaneous synthesis of membranes (Hsiao and Acevedo, 1974) which is the process involving complex reactions supported by water and other metabolites. Water is essential for every plants` growth, flower and fruit formation (Smittle et al., 1994). The growth of any organism depends on the growth of its individual cells. Most of a cell's content consists of water and hence, for a cell to enlarge its volume it requires water (Hopkins and Hüner, 2004).

Water transport is an essential component of the growing process. It plays role in cell expansion and is responsible for most of the increase in cell volume, characterizing growth (Hsiao, 1973; Westgate and Boyer, 1985). Plant response to water shortage depends on the amount of water lost, the speed of water loss from the plants and how long the plants are exposed to limited water conditions. Cellular water deficit can result in a concentration of solutes, changes in cell volume and membrane shape, disrupting membrane integrity and denaturation of protein and finally hindering growth (Bray, 1997). Water stress can also limit meristematic cells from expanding to the maximum size and hence lowering the general enlargement of the plant organ (Hsiao, 1973). Therefore, for cell volume to increase to initiate growth, plants requires adequate water uptake.

Water has an important role to play in the production of dry or fresh matter for the plant. The end product of leaf photosynthesis is starch. Starch build up in leaves undergoes the following process: $6\ CO_2 + 12\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$. In the presence of carbon dioxide and water, the starch builds up in leaves. The starch is the primary element of dry weight accumulation in plants (Huber et al., 1984). When plants are exposed to limited quantities of water, photosynthesis is hindered, and plant biomass can decrease (De Herralde et al., 1998).

Plant growth is highly sensitive to limited water conditions. As soon as a limited water condition develops, water potential in plant tissue is altered and drops. A decrease in water potential reduces the growth of plants (Davies and Zhang, 1987, 1991; Zhang and Davies, 1989; Davies et al., 1994). As water potential drops to zero, plant growth will come to an end (Green, 1968). It is nevertheless known that alterations in turgor can directly influence changes in growth that could lead to a number of changes through biological regulatory mechanisms. As soon as the turgor pressure in plants has changed, it affects critical physiological processes. In numerous instances any reduction in tissue pressure, lowered growth and led to a complete stop in growth when the water potential was lessened (Boyer, 1968; Acevedo et al., 1971).

Various researchers have concluded that root growth is generally privileged compared with shoot growth under limited water conditions. For example, El Nadi et al. (1969); Hoffman et. al. (1971); Pearson (1966) reported increased root to shoot ratio in plants under limited water conditions. The reason for roots outgrowing the shoots of the plant under limited water conditions was due to their greater ability to adjust osmotically when the amounts of water supplied are less (Green, 1968). Therefore, leaf growth is recognized to be very sensitive to limited water conditions while root growth is much more resistant (Boyer, 1968; Westgate and Boyer, 1985). The mechanism involved suggests that only when the roots own growth requirement for water has been achieved; it will then supply water to the shoots (Westgate and Boyer, 1985). Álvarez et al. (2009) showed that the root/shoot ratio of *Dianthus* plants exposed to drought, was superior to those supplied with large amounts of water. In this study, a hormonal signal was sent from the root to the shoot of the plant to close the stomata and slow down the growth.

Guehl et al. (1994) revealed that when tree species were exposed to frequent watering conditions, both the stem height and root collar diameter increased significantly in size. On the other hand when trees were exposed to drought conditions the stem elongation and diameter growth were reduced in size (Guehl et al., 1994). Research by Zeng et al. (2009) showed that growth of *Cucumis melo* L. (stem diameter, number of leaves and plants height) increased when plants were subjected to more water. In banana trees, researchers have learned that when trees were exposed to drought there was a reduction in growth rate, stem girth, plant height, stem circumference and leaf length (Robinson and Alberts, 1986). This was attributed to reduced cell division and or cell expansion and hence, decreased plant physique. In other

studies, exposing plants to drier regimes resulted in the production of smaller leaves, shorter internodes sections, reduced flower numbers, size and quality (Cameron et al., 1999; Sánchez-Blanco et al., 2002; Cabello et al., 2008). In tuber crops such as potatoes, a reduction in water supply caused a decrease of yield by reducing growth of the crop canopy and biomass and thus lowering the tuber yields (Yuan et al., 2003). In fruit crops, plants that received large amounts of water produced larger fruits and plants that were treated to less water had small size fruits (Begg and Turner, 1976; Mao et al., 2002; Kumar et al., 2007; Zeng, 2009).

1.8 CONCLUSION

In conclusion, growth plays a major role in crops as it affects yield. Therefore, understanding the optimum quantities of water required by plants to achieve maximum growth in hydroponic systems is essential.

1.9 ACKNOWLEDGEMENTS

This study was supported by the Western Cape Department of Agriculture and Cape Peninsula University of Technology.

1.10 REFERENCES

Acevedo E, Hsiao TC, Henderson DW (1971). Immediate and subsequent growth responses of maize leaves to changes in water status. Plant Physiology, 48: 631-636.

Ahmad N, Aniz M (2005). In Vitro mass propagation of *Cucumis sativus* L. from nodal segments. Turkey Botany Journal, 29: 237.

Alam SM (1999). Nutrient uptake by plants under stress conditions. New York, Handbook of Plant and Crop Stress, Marcel Dekker: 285-314.

Alberte RS, Fiscus EL, Naylor AW (1975). The effects of water stress on the development of the photosynthetic apparatus in greening leaves. Plant physiology, 55: 317-321.

Álvarez S, Navarro A, Banón S, Sánchez-Blanco MJ (2009). Regulated deficit irrigation in potted *Dianthus* plants: Effects of severe and moderate water stress on growth and physiological responses. Scientia Horticulturae, 122: 579-585.

Ashton FM (1956). Effects of a series of cycles of low and high soil water on the rate of apparent photosynthesis in sugar cane. Plant Physiology, 31: 266-274.

Baligar VC, Fageria NK, He ZL (2001). Nutrient use efficiency in plants. Soil Science 32: 921-950.

Bajracharya RM, Sharma S (2005). Influence of drip irrigation method on performance and yields of cucumber and tomato. Kathmandu University Journal of Science, Engineering and Technology, 1(1): 1-7.

Beecher G (2003). Overview of dietary flavonoids: Nomenclature, occurance and intake. Journal of Nutrition, 133: 3248-3254.

Begg JE, Turner NC (1976). Crop water deficits. Advances in Agronomy, 28: 161-217.

Ben GY, Osmond CB, Sharkey TD (1987). Comparisons of photosynthetic responses of *Xanthium strumarium* and *Helianthus annus* to chronic and acute water stress in sun shade. Plant Physiology, 84: 476-482.

Beringer H, Trolldenier G (1978). Influence of K nutrition on the response to environmental stress. Potassium research – review and trends. Proceedings of the 11th congress of the international potash institute. International Potassium Institute: 189-222.

Blanco MJS, Álvarez S, Navarro A, Bañón S (2008). Changes in leaf water relations, gas exchange growth and flowering quality in potted geranium plants irrigated with different water regimes. Journal of Plant Physiology, 166: 468-475.

Boyer JS (1968). Relationships of water potential to growth of leaves. Plant Physiology, 43: 1056-1062.

Boyer JS (1976). Photosynthesis at low water potentials. Philosophical transactions of the royal society of London. Series B, Biological Sciences, 273 (927): 501-512.

Bray EA (1997). Plant responses to water deficit. Trends in plant Science, 2 (2): 48-54.

Bradford KJ, Hsiao TC (1982). Physiological responses to moderate water stress. Encyclopedia of Plant Physiology, 12B: 264-324.

Brodribb T (1996). Dynamics of changing intercellular CO_2 concentration (C_i) during drought and determination of minimum functional C_i. Plant Physiology, 111: 179-185.

Cabello MJ, Castellanos MT, Romojaro F, Martinez – Madrid C, Ribas F (2008). Yield and quality of melon grown under different irrigation and nitrogen rates. Agricultural Water Management, 96: 866-874.

Cameron RWF, Harrison Murray RS, Scott MA (1999). The use of controlled water stress to manipulate growth of container grown *Rhodendron* cv. Hoppy Journal Horticulturae Scientia Biotechnology, 74: 161-169.

Cannon WN, Roberts BR (1994). Stomatal resistance and the ratio of intercellular to ambient carbon dioxide in container grown yellow poplar seedlings exposed to chronic ozone fumigation and water stress. Environmental and Experimental Botany, 35 (2): 161-165.

Castellarin SD, Pfeiffer A, Sivilotti P, Degan M, Peterlunger E, Di Gaspero G (2007b). Transcriptional regulation of anthocyanin biosynthesis in ripening and induce changes in gene expression regulating flavonoid biosynthesis in grape berries. Planta, 227: 101-112.

Ceccarelli S (1984). Plant responses to water stress. Genetica Agraria, 38: 43-74.

Cetin Ö, Uygon D (2008). The effect of drip line spacing, irriagation regimes and planting geometries of tomato on yield, irrigation, water use efficiency and net return. Agricultural Water Management, 95: 949-957.

Chalker-Scott L (1999). Environmental significance of anthocyanins in plant stress response. Photochemistry Photobiology, 70: 1-9.

Chaves MM (1991). Effects of water deficits on carbon assimilation. Journal of Experimental Botany, 42: 1-16.

Chung IM, Kim, JJ, Lim, JD, Yu CY, Kim SH, Hahn SS (2005). Comparison of resveratrol, SOD activity, phenolic compounds and free amino acids in *Rehmannia glutinosa* under temperature and water stress. Environmental and Experimental Botany, 56: 44-52.

Chung SM, Staub JE (2003). The development and evaluation of consensus chloroplast primer pairs that possess highly variable sequence regions in a diverse array of plant taxa. Theoretical Applied Genetics,107: 757-767.

Combrink NJJ (2005). Nutrient solutions and greenhouse management. Stellenbosch, South Africa, Combrink Familietrust: 34.

Cornic G (2000). Drought stress inhibits photosynthesis by decreasing stomatal aperture-not by affecting ATP synthesis. Trends in Plant Science, 5: 187-188.

Cornic G, Briantais JM (1991). Partitioning of photosynthetic electron flow between CO_2 and O_2 reduction in a C3 leaf (*Phaseolus vulgaris* L.) at different CO_2 concentrations and during drought stress. Planta, 183: 178-184.

Cornic G, Fresnau C (2002). Photosynthetic carbon reduction and carbon oxidation cycles are the main electron sinks for photosysthem II activity during a mild drought. Annual Botany, 89: 887-894.

Davies WJ, Tardieu F, Trejo CI (1994). How do chemical signals work in plants that grown in drying soil? Plant Physiology, 104: 309-314.

Davies WJ, Zhang J (1987). Increased synthesis of ABA impartially dehydrated root tips and ABA transport from root to leaves. Journal of Experimental Botany, 38: 2015-2023.

Davies WJ, Zhang J (1991). Root signals and the regulation of growth and development of plants in drying soil. Annual Review of Plant Physiology and Plant Molecular Biology, 42: 55-76.

De Herralde F, Biel C, Savé, Morales MA, Torrecillas A, Alarcón JJ, Sánchez – Blanco MJ (1998). Effect of water and salt stresses on the growth, gas exchange and water relations in *Argyranthemum coronopifolium* plants. Plant Science, 139: 9-17.

Donavon LA, Ehleringer JR (1994). Potential for selection on plants for water use efficiency as estimated by carbon isotope discrimination. American Journal of Botany, 81: 927-935.

El Nadi AH, Brouwer R, Locher J (1969). Some responses of the root and shoot of *Vicia faba* plants to water stress. Netherlands Journal Agricultural Science, 17: 133-142.

Erlandsson G (1975). Rapid effects on ion and water uptake induced by changes of water potential in young wheat plants. Physiologica Plant, 35: 256-262.

Farquhar GD, Sharkey TD (1982). Stomatal conductance and photosynthesis. Annual Review Plant Physiology, 33: 317-345.

Flexas J, Bota J, Loreto F, Cornic F, Sharkey TD (2004). Diffusive and metabolic limitations to photosynthesis under drought and salinity in C_3 plants. Plant Biology, 6: 269-279.

Flexas J, Diaz-Espejo A, Galmés J, Kaldenhoff R, Medrano H, Ribas-Carbo M (2007). Rapid variations of mesophyll conductance in response to changes in CO_2 concentration around leaves. Plant Cell Environment, 30: 1284-1298.

Green PB (1968). Growth physics in *Nitella*: a method for continuous in vivo analysis in extensibility based on a micro – manometer technique for turgor pressure. Plant Physiology, 43: 1169-1184.

Greenway H (1967). Effects of exudation on ion relationships of excised roots. Physiologia Plantarum, 20: 903-910.

Greenway H, Klepper B (1969). Relation between anion transport and water flow in tomato plants. Physiologica Plant, 22: 208-219.

Guehl JM, Picon C, Aussenac G, Gross P (1994). Interactive effects of elevated CO_2 and soil drought on growth and transpiration efficiency and its determinants in two European forest tree species. Tree Physiology, 14: 707-724.

Guerfel M, Baccouri O, Boujnah D, Chaibi W, Zarrouk M (2008). Impacts of water stress on gas exchange, water relations, chlorophyll content and leaf structure in the two main Tunisian olive (*Olea europea L.*) cultivars. Scientia Horticulture, 119: 257-262.

Harbone J, Williams C (2000). Advances in flavonoid research since 1992. Phytochemistry, 55: 481-504.

Heuvelink E, Körner O (2001). Parthenocarpic fruit growth reduces yield fluctuation and blossom-end-rot in sweet pepper. Annals of Botany, 88: 69-74.

Hoffman GJ, Rawlins SL, Garber MJ, Cullen EM (1971). Water relations and growth of cotton as influenced by salinity and relative humidity. Agronomy Journal, 63: 822-826.

Hopkins WG, Hüner NPA (2004). Introduction to plant physiology New Jersey United, John Wiley and Sons Incorporated,14: 291.

Hsiao TC (1973). Plant responses to water stress. A Revision Plant Physiology, 24: 519-570.

Hsiao TC, Acevedo E (1974). Plant responses to water deficits, water use efficiency and drought resistance. Agricultural Meteorology, 14: 59-84.

Hu Y, Burucs Z, von Tucher S (2006). Short-term effects of drought and salinity on mineral nutrient distribution along growing leaves of maize seedlings. Environmental and Experimental Botany, 60: 268-275.

Huber SC, Rogers HH, Mowry FL (1984). Effects of water stress on photosynthesis and carbon partitioning in Soybean (*Glycine max* [L.] Merr.) plants grown in the field at different CO_2 levels. Plant Physiology, 76(1): 244-249.

Hubick KT, Shorter R, Farquhar GD (1988). Heritability and genotype X environment interactions of carbon discrimination and transpiration efficiency in peanut. Australian Journal of Plant Physiology, 15: 799-813.

Huluka G, Hileman DR, Biswas PK, Lewin KF, Nagy J, Hendrey GR (1994). Effects of elevated CO_2 and water stress on mineral concentration of cotton. Agricultural and Forest Meteorology, 70 (1-4): 141-152.

Kaiser WM (1987). Effects of water deficit on photosynthetic capacity. Physiologia plantarum, 71: 142-149.

Keck RW, Boyer JS (1974). Chloroplast response to low leaf water potentials. Plant Physiology, 53: 474-479.

Kennedy JA, Matthews MA, Waterhouse AL (2002). Effect of maturity and vine water status on grape skin and wine flavonoids. American Journal of Enology and Viticulture, 53: 268-274.

Kramer PJ, Boyer JS (1995). Water relations of plants and soils. San Diego, Academic press Incorporated.

Krause GH (1988). Photoinhibition of photosynthesis. An evaluation of damaging and protective mechanisms. Physiologia plantarum, 74: 566-574.

Kukić J, Petrović S, Niketić M (2006). Antioxidant activity of four endemic *Stachys*. Taxa Biology Pharmaceutical Bulletin 29 (4): 725-729.

Kumar S, Imtiyaz M, Kumar A, Singh R (2007). Response of onion (*Allium cepa L*.) to different levels of irrigation water. Agricultural Water Management, 89: 161-166.

Lawlor DW (2002). Limitation to photosynthesis in water stressed leaves: stomata vs. metabolism and the role of ATP. Annual Botany, 89: 871-885.

Lawlor DW, Cornic G (2002). Photosynthetic carbon assimilation and associated metabolism in relation to water deficits in higher plants. Plant Cell and Environment, 25: 275-294.

Leopald AC (1964). Plant growth and development. United States of America, McGraw–Hill Incorporated: 31-32.

Li S, Pezeshki SR, Goodwin S (2003). Effects of soil moisture regimes on photosynthesis and growth in cattail (*Typha latifolia*). Acta Oecologica, 25: 17-22.

Long SP, Humphries S, Falkowski PG (1994). Photoinhibition of photosynthesis in nature. Annual rev. plant physiol. Plant Molecular Biology, 45: 633-662.

Makoi JHJR, Belane AK, Chimphango SBM, Dakora FD (2010). Seed flavonoids and anthocyanins as markers of enhanced plant defence in nodulated cowpea (*Vigna unguiculata* L. Walp.). Field Crops Research, 118: 21-27

Makoi JHR, Ndakidemi PA (2007). Biological, ecological and agronomic significance of plant phenolic compounds in rhizosphere of the symbiotic legumes. African Journal of Biotechnology, 6(12): 1358-1368.

Makoi JHJR, Ndakidemi PA (2012). Allelopathy as protectant, defence and growth stimulants in legume cereal mixed culture systems. *New Zealand Journal of Crop and* HorticulturalScience.Published online: http://dx.doi.org/10.1080/01140671.2011.630737.

Mao X, Liu M, Wang X, Liu C, Hou Z, Shi J (2002). Effects of deficit irrigation on yield and water use of greenhouse grown cucumber in the North China Plain. Agricultural Water Management, 61: 219-228.

Marais JPJ, Deavours B, Dixon RA, Ferreira D (2006). Stereochemistry of flavonoids. The Science of Flavonoids, 1:1-46.

Marschner H (1995). Mineral nutrition of higher plants. London, Academic Press.

Mattivi F, Guzzon R, Vrhovsek U, Stefanini M, Velasco R (2006). Metabolite profiling of grape: flavonols and anthocyanins. Journal of Agriculture and Food Chemistry, 54: 7692-7702.

Ndakidemi PA (2006). Manipulating legume/cereal mixtures to optimize the above and below ground interactions in the traditional African cropping systems. African Journal of Biotechnology, 5(25): 2526-2533.

Ndakidemi PA, Dakora FD (2003). Legume seed flavonoids and nitrogenous metabolites as signals and protectants in early seedling development. Functional Plant Biology, 30: 729-745.

Noctor G, Veljovic-Jovanovic S, Driscoll S, Novitskaya L, Foyer CH (2002). Drought and oxidative load in the leaves of C_3 plants: a predominant role for photorespiration? Annual Botany, 89: 841-850.

O`Toole JC, Baldia EP (1982). Water deficits and mineral uptake in rice. Crop Science, 22: 1144-1150.

Pearson RW (1966). Soil environment and root development. American Social Agronomy, 95-126.

Petela R (2007). An approach to the exergy analysis of photosynthesis. Solar Energy, 82: 311-327.

Pezeshki SR (2001). Wetland plant responses to soil flooding. Environmental Experimental Botany, 46:299-312.

Pinkerton A, Simpson JR (1986). Interactions of surface drying and subsurface nutrients affecting plant growth on acidic soil profiles from an old pasture. Australian Journal Experimental Agriculture, 26: 681-689.

Ramos S (2007). Effects of dietary flavooids on approptotic pathways related to cancer chemoprevention. Journal of Nutritional Biochemistry, 18(7): 427-442.

Robinson JC, Alberts AJ (1986). Growth and yield response of banana (Cultivar `Williams`) to drip irrigation under drought and normal rainfall conditions in the subtropics. Scientia Horticulturae, 30: 187-202.

Sánchez-Blanco MJ, Rodriguez P, Morales MA, Ortuno MF, Torrecillas A (2002). Comparative growth and water relation of *Cistus albidus* and *Cistus monspeliensis* plants during water deficit conditions and recovery. Plant Science, 162: 107-113.

Schapendonk AHCM, Spitters CJT, Groot PJ (1989). Effects of water stress on photosynthesis and chlorophyll fluorescence of five potato cultivars. Potato research, 32: 17-32.

Scherer HW (2001). Sulphur in crop production. European Journal Agronomy, 14: 81-111.

Schneider GW, Childers NF (1941). Influence of soil moisture on photosynthesis, respiration and transpiration of apple leaves. Plant Physiology, 16: 565 – 583.

Shaw N, Cantliffe N, Rodriguez J, Taylor S, Spencer D (2000). Beit Alpha cucumber, an exciting new greenhouse crop. Proceedings of the Florida State Horticultural Society, 113: 247-253.

Shetty NV, TC Wehner (1998). Evaluation of oriental trellis cucumbers for production in North Carolina. HortScience, 33(5): 891-896.

Sherwin HW, Farrant JM (1998). Protection mechanisms against excess light in the resurrection plants *Craterostigma wilmsii* and *Xerophyta viscose*. Plant Growth Regulation, 24: 203-210.

Shock CC (2006). Drip irrigation: an introduction. Sustainable Agriculture Techniques, Oregon State University Extension Service.

Silva EN, Ribeiro RV, Ferreira-Silva SL, Viégas RA, Silveira JAG (2010). Comparative effects of salinity and water stress on photosynthesis, water relations and growth of *Jatropha curcas* plants. Journal of Arid Environments, 74: 1130-1137.

Smika D, Haas H, Power W (1965). Effects of moisture and nitrogen fertilizer on growth and water use by native grass. Agronomy Journal, 57: 483-486.

Smith SD, Osmond CB (1987). Stem photosynthesis in a desert ephemeral, *Eriogonum inflatum*. Oceologia, 72: 533-541.

Smittle DA, Dickens WC, Stansell JR (1994). Irrigation regimes affect yield and water use by bell pepper. Journal of American Society Horticultural Science, 119: 936-939.

Souza RP, Machado EC, Silva JAB, Lagôa AMMA, Silveira JAG (2003). Photosynthetic gas exchange, chlorophyll fluorescence and some associated metabolic changes in cowpea (*Vigna unguiculata*) during water stress and recovery. Environmental and Experimental Botany, 51: 45-56.

Tanguilig VC, Yambao EB, O`Toole JC, De Datta SK (1987). Water stress on leaf elongation, leaf water potential, transpiration, and nutrient uptake of rice, maize and soybean. Plant and Soil, 103: 155-168.

Thornber JP (1975). Chlorophyll proteins: light harvesting and reaction center components of plants. Annual Review Plant Physiology, 26: 127-158.

Viets Jr. FG (1972). Water deficits and nutrient availability in Kozlowski, T.T: Water deficits and plant growth. Vol III: Plant Responses and Control of Water Balance: 217-240.

Wardlaw IF (1967). The effect of water stress on translocation in relation to photosynthesis and growth. Effect during grain development in wheat. Australian Journal of Biological Sciences, 20: 25-39.

Westgate ME, Boyer JS (1985). Osmotic adjustment and the inhibition of leaf, root, stem and silk growth at low water potentials in maize. Planta, 164: 540-549.

Wettstein-Westersheim W, Minelli H (1962). Breeding intersectional Populus hybrids. Allgemeine Forstzeitung: 73.

Wingler A, Quick WP, Bungard RA, Bailey KJ, Lea PJ, Leegood RC (1999). The role of photorespiration during drought stress: an analysis utilizing barley mutants with reduced activities of photorespiratory enzymes. Plant Cell Environment, 22: 361-373.

Winkel BSJ (2006). Biosynthesis of flavonoids. The Science of Flavonoids, 3: 71.

Yambao EB, O`Toole JC (1984). Effects of nitrogen nutrition and root medium water potential on growth, nitrogen uptake and osmotic adjustment of rice. Physiologia Plantarum, 60: 507-515.

Younis ME, El – Shahaby OA, Abo – Hamed SA, Ibrahim AH (2000). Effects of water stress on growth, pigments and $^{14}CO_2$ assimilation in three sorghum cultivars. Agronomy Crop Science, 185 (2): 73-82.

Yuan BZ, Nishiyama S, Kang Y (2003). Effects of different irrigation regimes on the growth and yield of drip – irrigated potato. Agricultural Water Management, 63: 153-167.

Zeng CZ, Bie ZL, Yuan BZ (2009). Determination of optimum irrigation water amount for drip – irrigated muskmelon (*Cucumis melo* L.*)* in plastic greenhouse. Agricultural Water Management, 96: 597-601.

Zhang J, Davies WJ (1989). Abscisic acid produced in dehydrating roots may enable the plant to measure the water status of the soil. Plant Cell Environment, 12: 73-81.

CHAPTER TWO

JUSTIFICATION, HYPOTHESIS, AIM AND OBJECTIVES OF THE STUDY

2.1 Justification

Cucumber (*Cucumis sativa* L.) is one of the most widespread vegetables grown hydroponically in South Africa. It is commonly grown by large scale cucumber farmers in open fields where the climatic conditions are suitable. However, it is much more beneficial to grow the crop in a greenhouse under a control environment, as this will provide better quality yield of crop, higher yield and crops can be grown throughout the entire year. The growers could also save on expenses if they knew precisely what quantity of drip irrigated water is required to obtain high-quality fruits and plant growth from the crop. There is currently limited information available on the effect various quantities of fertigated water will have on cucumber crops grown under hydroponic systems in South Africa.

Plants that are subjected to various quantities of drip fertigated water could react differently in growth, photosynthesis, yield and manufacturing of plant metabolites consisting of phenolic compounds such as flavonoids and anthocyanins in plant tissues, which are known to influence produce quality. The proposed research will enable us to study the physiological and biochemical effects various quantities of drip fertigated water will have on nutrient uptake, photosynthesis, transpiration rate, chlorophyll content, flavonoid content, anthocyanin content, growth and yield on *Cucumis sativus* L. in a controlled greenhouse in Elsenburg, Stellenbosch, South Africa.

2.2 Hypothesis

Delivering various quantities of drip irrigated water to *Cucumis sativa* L. will have a different effect on the following parameters: nutrient uptake, photosynthesis, transpiration rate, chlorophyll content, flavonoid content, anthocyanin content, growth and yield.

2.3 Aim

This research was aimed at studying the physiological and biochemical effects of various quantities of drip fertigated water on nutrient uptake, photosynthesis, transpiration rate, chlorophyll content, flavonoid content, anthocyanin content, growth and yield on *Cucumis sativus* L. under controlled greenhouse conditions in South Africa.

2.4 Objectives of the research

2.4.1 Main Objectives

To investigate the effects of various quantities of drip irrigated water on the growth processes and yield of *Cucumis sativa* L.

2.4.2 Specific Objectives

1) To assess the effects of various quantities of drip irrigated water on photosynthesis and chlorophyll formation in *Cucumis sativa* L.
2) To assess the effects various quantities of drip irrigated water on the nutrient uptake of *Cucumis sativa* L.
3) To assess the effects of various quantities of drip irrigated water on the flavonoid and anthocyanin metabolism in *Cucumis sativa* L.
4) To assess the effects of various quantities of drip irrigated water on the growth and yield of *Cucumis sativa* L.

CHAPTER THREE

THE EFFECTS OF VARIOUS DRIP FERTIGATED WATER QUANTITIES ON PHOTOSYNTHESIS AND CHLOROPHYLL CONTENT OF HYDROPONICALLY CULTIVATED *CUCUMIS SATIVA* L.

The effects of various drip fertigated water quantities on photosynthesis and chlorophyll content of hydroponically cultivated *Cucumis sativa* L.

Donavon Sonnenberg[1], Patrick A. Ndakidemi[2], and Charles Laubscher[1]*

[1]Faculty of Applied Science, Cape Peninsula University of Technology, Cape Town Campus, P.O. Box 652, Cape Town 8000, South Africa.

[2]The Nelson Mandela African Institute of Science and Technology, School of Life Sciences and Bio-engineering, Nelson Mandela Rd, P O Box 447. Arusha- Tanzania.

*Corresponding author

Tel: +27 21 4603198. Fax: +27 4603193

Email: laubscherc@cput.ac.za

3.1 Abstract

Effects of various quantities of water were investigated on the photosynthesis and chlorophyll content of cucumber plants that was grown hydroponically in a controlled greenhouse. The treatments included 8 various water regimes (2l/h, 4l/h, 6l/h, 8l/h, 10l/h, 12l/h, 14l/h, and 16l/h. The plants received water five times a day, making it 10, 20, 30, 40, 50, 60, 70 and 80 litres per day. Results showed that generally the Photosynthesis (A), intercellular CO_2 concentration (C_i), stomatal conductance (gs) and the transpiration rate (e) of the cucumber plants were significantly increased by increasing water quantities compared with lower water quantities. Additionally, there were significant improvements in leaf colour at weeks 2, 3, 4, 5, 6, 7 and 8. Overall, the foliage colour was improved as water supply was increased. The greener leaves were documented in treatments supplied with higher water doses. Additionally, the chlorophyll content of cucumber plants was increased significantly with varying water quantities. The highest chlorophyll contents were found in plants treated with 16l/h.

Key words: intercellular CO_2 concentration, stomata conductance, transpiration rate.

3.2 INTRODUCTION

Photosynthesis is a process by which in the presence of chlorophyll, the energy of the photosynthetically active radiation (within the wavelength range 400 – 700 nm) is used to separate geaseous carbon dioxide and liquid water and recombining them into gaseous oxygen and a sugar named glucose (Petela, 2007). Photosynthetic rate (A), intercellular CO_2 concentration (C_i), stomatal conductance (gs), transpiration rate (e) and dry matter production of plants are narrowly linked processes. These processes are closely supported by water availability in plants. Photosynthesis is responsible for the accumulation of the majority of dry mass in plants, and dry matter yield is decreased when plants are exposed to limited water conditions (Boyer, 1976).

At limited water conditions, plants can decrease the photosynthetic rate indirectly by closing the stomata or directly by decreasing the photosynthetic capacity of foliage by inhibiting the Calvin cycle or the rate of electron transport above the chloroplast membranes (Kaiser, 1987). Studies by Bradford and Hsiao (1982), Ceccarelli (1984) showed that the greater the resistance of the stomata for CO_2 diffusion, results in a reduction of CO_2 concentration inside the leaves and as a whole reduces the rate of photosynthesis. Bodlaender et al. (1986) showed that limited water conditions reduced leaf water potential in potato crops by decreasing the internal CO_2 concentration and finally decreased the photosynthesis by 58%.

Photosynthesis is proportional to stomatal conductance (gs). Any changes in water relations will manipulate stomatal functioning. For instance, reduced photosynthesis build up through midday is due to limited amount of water which leads to the stomata being partially closed. The stomata plays a pivotal role in guiding the reduction of the net CO_2 uptake through a mechanism involving reduction of leaf internal CO_2 concentrations when crops are exposed to mild limited water conditions (Cornic and Briantais, 1991; Cornic, 2000). Nevertheless, CO_2 accumulation managed by stomata closure promotes irregularity among activity and electrons essential for photosynthesis (Krause, 1988; Long et al., 1994). In cowpea crops exposed to limited water conditions, the CO_2 assimilation rates were reduced due to stomata closure, and as result decreased available internal CO_2 and limited water loss via transpiration. This indicates that decrease in net CO_2 uptake is the end result of stomata closure.

Several studies have shown that the reduction in chlorophyll (Chl) build up in plants is a result of limited water conditions (Mondal and Paul, 1992; Begun and Paul, 1993; Moran et al., 1994; Zayed and Zeid, 1997; Younis et al., 2000). Water stress may decrease the photosynthetic electron-chain activity in plant chloroplasts and eventually the chlorophyll content in plants (Keck and Boyer, 1974). The chlorophyll loss is an outcome of a reduction in the lamellar content of chlorophyll a/b which is targeted particularly by limited water conditions (Alberte and Thornber, 1977). Alberte and Thornber (1977) mentioned that the majority of Chl exposed to limited water conditions is lost from the mesophyll cells. The reason for this loss is a result of the mesophyll cells being farther detached from the vascular supply of water than the bundle sheath cells, and consequently developing better cellular water deficiency which leads to greater loss in Chl.

From the above background, this study was conducted to ascertain the impact of water availability on photosynthetic parameters such as photosynthetic rate (A), intercellular CO_2 concentration (C_i), stomatal conductance (gs), transpiration rate (E) and chlorophyll concentration in *Cucumis sativa* L. subject to different water quantities under controlled greenhouse conditions.

3.3 MATERIALS AND METHODS

3.3.1 Site location and description

The research was conducted at the greenhouse of the Agronomy and Vegetables Department of the Cape Institute for Agricultural Training in Elsenburg, South Africa during the 2009-winter season and 2009-2010 summer season. The greenhouse had a fully automated fertigation system. The cucumber plants were placed in 20l black bags consisting of sawdust as a growth medium. The plants were irrigated via drip irrigation and plants were staked with polyethylene twines.

3.3.2 Experimental design and treatments

The experiment was set out in a randomised complete block design. The treatments included 8 various water regimes. These different water regimes were 2l/h (control), 4l/h, 6l/h, 8l/h, 10l/h,

12l/h, 14l/h, 16l/h. The plants received water five times a day, making it 10, 20, 30, 40, 50, 60, 70, 80l per day.

Seeds of *Cucumis sativa* L. variety Alladin a new high yield cucumber variety in South Africa was purchased from A. Ford & Co. (Pty) Ltd. (1 Hazelden drive Business Park Garden Pavillion, Tel: 021 – 850 0011). These were germinated by Propagating Plants Company (Klein Joostenburg farm, corner of R101 and R304, Tel. /Fax: 021 – 884 4513).

The trial was in a drain-to-waste system and was conducted over 3 months. There were 8 replicates and all the treatments received the same amount of nutrients. The electrical conductivity of the nutrient solution was set at 1.65 $mS.cm^{-1}$(Combrink, 2005).

3.3.3 Photosynthesis and Chlorophyll measurements

Photosynthesis and other related measurements were taken at 1-8 weeks after planting. The photosynthetic rate (A), intercellular CO_2 concentration (C_i), stomatal conductance (gs) and transpiration rate (E) were measured in young leaves (flag leaf) per treatment using a portable infra-red gas analyzer (LCpro+ 1.0 ADC, Bioscientific Ltd., Hoddesdon, Hertfordshire, UK). Measurements were done from 8 a.m to 11 a.m. Leaves were allowed to acclimatize to the light environment in the chamber for 5 min. Under normal conditions, each measurement took approximately 2 min, which was the minimum time allowed for the readings to stabilize before they were recorded. During measurements, the conditions in the leaf chamber were: photosynthetic photon flux density (PPFD) = 1100 µmol (quantum) $m^{-2}.s^{-1}$, relative humidity = 44%, leaf vapor pressure deficit = 1.83 kPa, flow rate = 400 $\mu mol.s^{-1}$, reference CO_2 = 400 ppm, and leaf temperature = 25^oC.

Chlorophyll concentrations were extracted by dimethylsulphoxide (DMSO) (Hiscox and Israelstam, 1979). One third of the plants` foliage, starting at the tip, was collected and placed in a bag. One hundred (100) mg containing the central section of fresh leaf pieces was positioned in a 15mL vial consisting of 7mL DMSO and incubated at 4°C for 72 hours. After the incubation, the extract was diluted to 10 mL with DMSO and 3 mL of extract was used to read the absorbance at 645 nm and 663 nm on a spectrophotometer (UV/Visible Spectrophotometer, Pharmacia LKB. Ultrospec II E) against DMSO blank.

Chlorophyll levels were calculated using the following equations used by Arnon (1949).

$$\text{Chl } a = 12.7D_{663} - 2.69D_{645}$$

$$\text{Chl } b = 22.9D_{645} - 4.68D_{663}$$

$$\text{Total Chl} = 20.2D_{645} + 8.02D_{663}$$

3.3.4 Statistical analysis

Statistical analysis was attained with the use of the 1-way analysis of variance (ANOVA) by using the software program STATISTICA 2012 (Stat soft Inc Tulsa,Ok, USA).

3.4 RESULTS

At week 1 of the study, the A and the E of the cucumber plants were significantly ($P \leq 0.001$) increased by different water quantities compared with some other treatments (Table 1). Both parameters were significantly higher starting at 10-16l/h at week one.

At week 2, the E increased significantly in all other treatments compared with the control treatment (Table 1). The best results were recorded in 14l/h. At week 2, irregular significant trends were reported for C_i and gs.

At week 3 (Table 2), the E, C_i and gs increased significantly ($P \leq 0.001$). The E showed greater increase at 10l/h in comparison with other treatments and the C_i and gs displayed greater increase at 12l/h relative to other water treatments.

In week 4 (Table 2), the E and C_i increased significantly ($P \leq 0.001$). The E increased as more water was supplied in comparison with the control treatment. However, in week 4, the C_i increased between the 8l/h to 14l/h water treatments

The A, E, C_i and gs increased significantly ($P \leq 0.001$) in week 5. The 16l/h treatment had the best rate of A relative to the control and other treatments (Table 3). The C_i and gs in week 5 peaked at treatments which received 10l/h.

At week 6, there were significant ($P \leq 0.001$) increases in the A, E, C_i and gs. However, irregular trends were observed with increasing water quantities although in the A the greatest increase was noted at 16l/h.

At week 7 (Table 4), the A, E, C_i and gs increased significantly (P≤0.001) with different water treatments. At the 16l/h treatment (Table 4) the A, E and gs displayed the greatest quantities in comparison with other treatments. Contrarily, the C_i displayed higher values at lower water quantities.

At week 8 (Table 4), the A, E, C_i and gs increased significantly (P≤0.001) with changing water quantities. However, the A displayed irregular patterns while E, C_i and gs were increased at treatments with water supply ranging between 8l/h to 14l/h.

The results of the foliage colour are shown in Table 5. There were significant improvements in leaf colour at weeks 2, 3, 4, 5, 6, 7 and 8. Overall, the foliage colour was improved as water supply was increased. In week 2, greener leaves were recorded in treatments supplied with 10l/h, whereas in week 3-8 foliage colour was highly improved in treatment supplied with 16l/h in comparison with the control treatment.

The effect of water quantities on the chlorophyll content of cucumber plants is indicated in Table 6. Significant results were observed at weeks 2, 3, 7 and 8 (Table 6). The highest chlorophyll contents were found in plants treated with 16l/h.

3.5 DISCUSSION

In this study, *Cucumis sativa* L. plants exposed to various water regimes showed positive effects on photosynthesis in comparison with the control. Photosynthesis (A) transpiration (E), intercellular CO_2 concentration (C_i) and stomata conductance (gs) all increased with the exposure to higher water quantities compared with the control treatment of 2l/h (Table 1-4). This justifies that the more water the cucumber crop received the greater the increase in photosynthesis, an important phenomenon for plant growth. The same results were reported by Bodlaender et al., (1986); Schapendonk et al., (1989); Pezeshki, (1993); Blanco et al., (2008) who revealed that when crops were exposed to limited water conditions there was a decline in photosynthesis.

The C_i also displayed increases at treatments higher than 2l/h (Table 1-4). This proves the theory that if there is a decrease in water supply to crops the C_i also declines (Bradford and Hsiao, 1982; Ceccarelli, 1984; Bodlaender et al., 1986; Kaiser, 1987). This decline in C_i was

due to stomatal closure leading to reduced CO_2 concentration within the leaves and ultimately resulting in a reduced rate of photosynthesis (Bradford and Hsiao, 1982, Ceccarelli, 1984, Kaiser, 1987).

Results shown in Tables 1-4 indicated that the gs was enhanced at higher water levels supplied to the plants. At limited water conditions, the stomata opening is greatly reduced, which will then influence other photosynthetic parameters. Similar to this study, Leopald (1964); Cornic and Briantais (1991) reported reduced stomata functioning with limited water supply.

Crops that were exposed to high water regimes contained more foliage green colour in comparison with the control treatment. Foliage green colour is one indication of the chlorophyll content in crops. At weeks 3, 6, 7 and 8 (Table 5) foliage green colour content was highest at 16l/h relative to the control treatment (2l/h). The same trend was recorded with regard to chlorophyll content in plants (Table 6). In other similar studies by Alberte and Thornber (1977); Pierce and Raschke (1980); Massacci and Jones (1989); Mondal and Paul (1992); Begun and Paul (1993), it was confirmed that plants that received less water had lower chlorophyll contents in their leaves. The lower water levels in plant tissues negatively impacts the photosynthetic electron-chain activity, thus reducing the chlorophyll content in chloroplasts and ultimately affecting the photosynthesis products (Keck and Boyer, 1974).

3.6 CONCLUSION

In conclusion, increasing the water supply resulted into positive improvements of photosynthesis rate, stomata conductance, intercellular CO_2 concentration, transpiration rate and chlorophyll content in leaves of *Cucumis sativa* L. However, in some cases, at very higher levels of water supply, some of the photosynthetic apparatus were negatively affected. Therefore, it is important to establish the optimum levels of water supply for *Cucumis sativa* L. establishment.

3.7 ACKNOWLEDGEMENTS

This study was supported by the Western Cape Department of Agriculture and Cape Peninsula University of Technology.

3.8 REFERENCES

Alberte RS, Thornber JP (1977). Water stress effects on the content and organization of chlorophyll in mesophyll and bundle sheath chloroplasts of maize. Plant Physiology, 59:351-353.

Arnon DI (1949). Copper enzymes in isolated chloroplasts, polyphenoxidase in beta vulgaris. Plant Physiology, 24:1-15.

Begun FA, Paul NK (1993). Influence of soil moisture on growth, water use and yield of mustard. Journal of Agronomy and Crop Science, 170:136-141.

Blanco MJS, Álvarez S, Navarro A, Bañón S (2008). Changes in leaf water relations, gas exchange growth and flowering quality in potted geranium plants irrigated with different water regimes. Journal of Plant Physiology, 166:468-475.

Bodlaender KBA, van de Waart M, Marinus J (1986). Effects of drought on water use, photosynthesis and transpiration of potatoes. Potato Research of Tomorrow 44-54.

Boyer JS (1976). Photosynthesis at low water potentials. Philosophical transactions of the royal society of London. Series B, Biological Sciences, 273 (927):501-512.

Bradford KJ, Hsiao TC (1982). Physiological responses to moderate water stress. Encyclopedia of Plant Physiology, 12B:264-324.

Ceccarelli S (1984). Plant responses to water stress. Genetica Agraria, 38:43-74.

Combrink, NJJ (2005). Nutrient solutions and greenhouse management. Stellenbosch, South Africa, Combrink Familietrust: 34.

Cornic G (2000). Drought stress inhibits photosynthesis by decreasing stomatal aperture-not by affecting ATP synthesis. Trends in Plant Science, 5:187-188.

Cornic G, Briantais JM (1991). Partitioning of photosynthetic electron flow between CO_2 and O_2 reduction in a C3 leaf (*Phaseolus vulgaris* L.) at different CO_2 concentrations and during drought stress. Planta, 183:178-184

Hiscox JD, Israelstam GF (1979). A method for the extraction of chlorophyll from leaf tissue without maceration. Canadian Journal of Botany, 57: 1332-1334.

Kaiser WM (1987). Effects of water deficit on photosynthetic capacity. Physiologia plantarum, 71:142-149.

Keck RW, Boyer JS (1974). Chloroplast response to low leaf water potentials. Plant Physiology, 53:474-479.

Krause GH (1988). Photoinhibition of photosynthesis. An evaluation of damaging and protective mechanisms. Physiologia Plantarum, 74:566-574.

Leopald AC (1964). Plant growth and development. United States of America McGraw – Hill Incorporated: 31-32.

Long SP, Humphries S, Falkowski PG (1994). Photoinhibition of photosynthesis in nature. Annual revision plant physiology, Plant molecular Biology, 45:633-662.

Massacci A, Jones HG (1989). Use of simultaneous analysis of gas exchange and chlorophyll fluorescence quenching for analyzing the effects of water stress on photosynthesis in apple leaves. Trees, 4:1-8.

Mondal RK, Paul NK (1992). Effect of irrigation on growth and some physiological characters of mustard (*Brassica juncea* L.). Bangladesh Journal of Agricultural Research, 17:29-36.

Moran JF, Becan M, Iturbe-Ormaetyl I, Frechilla S, Klucas RV, Aparicio-Tejo P (1994). Drought induces oxidative stresses in pea plants. Planta, 194:346-352.

Petela R (2007). An approach to the exergy analysis of photosynthesis. Solar energy, 82:311-327.

Pezeshki, SR (1993). Differences in patterns of photosynthetic responses to hypoxia in flood – tolerant and flood sensitive tree species. Photosynthetica, 28:423-430.

Pierce M, Raschke K (1980). Correlation between loss of turgor and accumulation of abscisic acid in detached leaves. Planta (Berlin), 148:174-182.

Schapendonk AHCM, Spitters CJT, Groot PJ (1989). Effects of water stress on photosynthesis and chlorophyll fluorescence of five potato cultivars. Potato research, 32:17-32.

Younis ME, El – Shahaby OA, Abo – Hamed SA, Ibrahim AH (2000). Effects of water stress on growth, pigments and CO_2 assimilation in three sorghum cultivars. Agronomy Crop Science, 185(2):73-82.

Zayed MA, Zeid IM (1997). Effect of water and salt stresses on growth, chlorophyll, mineral ions and organic solutes contents, and enzymes activity in mung bean seedlings. Biologia plantarum, 40(3):351-356.

Table 3.1: Effect of different water quantities on photosynthesis and gas-exchange parameters of leaves of *Cucumus sativa* L. as measured from Week 1 to Week 8 during 2010.

	WEEK 1				WEEK 2			
Treatment	A	E	Ci	Gs	A	E	Ci	Gs
$L.h^{-1}$	$\mu mol\ CO_2.m^{-2}.s^{-1}$	$mmol.m^{-2}.s^{-1}$	$mmol\ CO_2.mol^{-1}$ air	$mmol\ H_2O.m^{-2}.s^{-1}$	$\mu mol\ CO_2.m^{-2}.s^{-1}$	$mmol.m^{-2}.s^{-1}$	$mmol\ CO_2.mol^{-1}$ air	$mmol\ H_2O.m^{-2}.s^{-1}$
2	**10.20±1.06ab**	**1.24±0.12d**	227.70±10.82a	0.15±0.02a	3.65±0.36a	**0.92±0.12c**	**243.20±14.98bc**	**0.06±0.01ab**
4	**9.00±0.76bc**	**1.88±0.14bc**	207.20±8.29a	0.15±0.01a	2.92±0.28a	**1.38±0.11ab**	**281.60±6.48a**	**0.07±0.01a**
6	**6.35±1.17d**	**1.87±0.12bc**	242.10±16.92a	0.11±0.01a	3.60±0.25a	**1.15±0.11bc**	**213.50±14.62c**	**0.05±0.01b**
8	**7.40±1.31cd**	**1.65±0.17c**	222.20±16.38a	0.17±0.04a	2.91±0.17a	**1.26±0.17b**	**242.60±10.47bc**	**0.05±0.01b**
10	**11.76±0.23a**	**2.19±0.02ab**	185.80±4.44a	0.16±0.01a	3.40±0.41a	**1.42±0.11ab**	**251.10±8.66ab**	**0.06±0.00ab**
12	**10.42±0.86ab**	**1.81±0.10c**	221.20±9.11a	0.19±0.02a	2.63±0.40a	**1.38±0.08ab**	**281.70±11.89a**	**0.06±0.01ab**
14	**11.11±0.57ab**	**2.49±0.08a**	213.50±6.77a	0.20±0.01a	3.89±0.34a	**1.65±0.06a**	**270.20±11.55ab**	**0.07±0.00a**
16	**11.19±0.32ab**	**2.20±0.09a**	226.20±12.30a	0.18±0.02a	3.40±0.34a	**1.32±0.07b**	**271.10±9.11ab**	**0.07±0.00a**
One - Way ANOVA (F-Statistic)								
Rep	**5.001*** **	**11.282*** **	2.135ns	2.1195ns	1.7459ns	**3.768*** **	**4.374*** **	**2.4040*** **

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at ***: $P \leq 0.001$, ns: non-significant

Table 3.2: Effect of different water quantities on photosynthesis and gas-exchange parameters of leaves of *Cucumus sativa* L. as measured from Week 1 to Week 8 during 2010.

Treatment	WEEK 3				WEEK 4			
	A	E	Ci	Gs	A	E	Ci	Gs
$L.h^{-1}$	µmol $CO_2.m^{-2}.s^{-1}$	$mmol.m^{-2}.s^{-1}$	mmol $CO_2.mol^{-1}$ air	mmol $H_2O.m^{-2}.s^{-1}$	µmol $CO_2.m^{-2}.s^{-1}$	$mmol.m^{-2}.s^{-1}$	mmol $CO_2.mol^{-1}$ air	mmol $H_2O.m^{-2}.s^{-1}$
2	3.96±0.34a	**0.90±0.06cd**	**236.10±11.94cd**	**0.07±0.01cd**	3.97±0.28a	**0.76±0.10cd**	**187.00±9.92d**	0.12±0.08a
4	5.00±0.61a	**1.22±0.09b**	**253.00±7.67bc**	**0.09±0.01b**	3.40±0.36a	**1.17±0.14a**	**220.90±19.29bcd**	0.06±0.01a
6	4.20±0.61a	**1.16±0.10b**	**234.20±9.81cd**	**0.06±0.01d**	3.16±0.43a	**0.96±0.13ab**	**204.50±15.38cd**	0.03±0.01a
8	3.57±0.32a	**1.09±0.07bc**	**250.20±6.90bc**	**0.06±0.01cd**	2.91±0.24a	**0.92±0.09abc**	**253.80±11.64ab**	0.05±0.01a
10	4.87±0.32a	**1.43±0.09a**	**220.40±6.32d**	**0.07±0.01cd**	2.68±0.28a	**0.98±0.09ab**	**266.60±5.81a**	0.05±0.01a
12	3.42±0.58a	**1.14±0.04b**	**316.00±8.90a**	**0.13±0.01a**	2.94±0.31a	**0.66±0.06d**	**252.40±5.33ab**	0.05±0.01a
14	4.86±0.71a	**1.16±0.06b**	**274.10±6.67b**	**0.08±0.01bc**	2.91±0.41a	**1.03±0.06ab**	**277.30±12.62a**	0.07±0.01a
16	4.13±0.42a	**0.86±0.06d**	**249.00±10.51c**	**0.06±0.01d**	3.16±0.32a	**0.75±0.07cd**	**222.60±11.74bc**	0.05±0.01a
One - Way ANOVA (F-Statistic)								
Rep	1.41ns	**5.81*** **	**11.31*** **	**7.83*** **	1.41ns	**2.96*** **	**6.68*** **	0.92ns

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at ***: $P \leq 0.001$, ns: non-significant

Table 3.3: Effect of different water quantities on photosynthesis and gas-exchange parameters of leaves of *Cucumus sativa* L. as measured from Week 1 to Week 8 during 2010.

	WEEK 5				WEEK 6			
Treatment	A	E	Ci	Gs	A	E	Ci	Gs
$L.h^{-1}$	µmol $CO_2.m^{-2}.s^{-1}$	$mmol.m^{-2}.s^{-1}$	mmol $CO_2.mol^{-1}$ air	mmol $H_2O.m^{-2}.s^{-1}$	µmol $CO_2.m^{-2}.s^{-1}$	$mmol.m^{-2}.s^{-1}$	mmol $CO_2.mol^{-1}$ air	mmol $H_2O.m^{-2}.s^{-1}$
2	**3.17±0.30e**	**0.73±0.05d**	**256.20±8.42bc**	**0.05±0.00d**	**4.06±0.22ab**	**1.01±0.08ab**	**262.40±10.53b**	**0.10±0.02a**
4	**3.46±0.23de**	**1.31±0.10ab**	**277.70±14.97b**	**0.08±0.02c**	**2.41±0.37c**	**1.17±0.09a**	**301.80±10.76a**	**0.08±0.01ab**
6	**3.47±0.23cde**	**1.23±0.07ab**	**232.60±9.10c**	**0.05±0.00d**	**3.52±0.48ab**	**1.08±0.09ab**	**250.10±12.14b**	**0.06±0.01b**
8	**4.01±0.26bcd**	**1.29±0.12ab**	**265.00±12.43b**	**0.06±0.01d**	**3.41±0.31b**	**1.13±0.08ab**	**262.80±5.54b**	**0.06±0.01b**
10	**4.20±0.18ab**	**1.33±0.03a**	**323.50±7.10a**	**0.17±0.01a**	**3.59±0.41ab**	**0.75±0.11c**	**252.60±8.53b**	**0.06±0.01b**
12	**4.12±0.24abc**	**1.15±0.05ab**	**318.20±4.11a**	**0.13±0.01b**	**4.00±0.41ab**	**0.97±0.09abc**	**255.10±7.34b**	**0.08±0.01ab**
14	**4.18±0.23ab**	**1.12±0.05bc**	**306.00±6.54a**	**0.13±0.01b**	**3.49±0.15ab**	**0.91±0.06bc**	**245.50±9.59b**	**0.06±0.00b**
16	**4.67±0.19a**	**0.92±0.04cd**	**279.70±6.62b**	**0.12±0.01b**	**4.41±0.26a**	**1.04±0.05ab**	**256.20±7.02b**	**0.07±0.01b**
One - Way ANOVA (F-Statistic)								
Rep	**4.58*** **	**9.25*** **	**11.70*** **	**28.10*** **	**3.07*** **	**2.56*** **	**3.66*** **	**2.19*** **

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at ***: $P \leq 0.001$

Table 3.4: Effect of different water quantities on photosynthesis and gas-exchange parameters of leaves of *Cucumus sativa* L. as measured from Week 1 to Week 8 during 2010.

	WEEK 7				WEEK 8			
Treatment	A	E	Ci	Gs	A	E	Ci	Gs
$L.h^{-1}$	µmol $CO_2.m^{-2}.s^{-1}$	$mmol.m^{-2}.s^{-1}$	mmol $CO_2.mol^{-1}$ air	mmol $H_2O.m^{-2}.s^{-1}$	µmol $CO_2.m^{-2}.s^{-1}$	$mmol.m^{-2}.s^{-1}$	mmol $CO_2.mol^{-1}$ air	mmol $H_2O.m^{-2}.s^{-1}$
2	**4.18±0.42b**	**1.14±0.03de**	**284.80±7.60ab**	**0.10±0.01c**	**4.51±0.40ab**	**1.00±0.07cd**	**270.60±7.28c**	**0.10±0.01bc**
4	**2.72±0.39c**	**1.03±0.10e**	**290.10±24.19a**	**0.06±0.01d**	**3.93±0.38bc**	**1.29±0.07ab**	**273.20±9.95bc**	**0.09±0.01cd**
6	**3.77±0.35b**	**1.15±0.08de**	**237.90±8.54c**	**0.06±0.01d**	**4.20±0.38abc**	**1.15±0.08bc**	**243.90±4.72d**	**0.07±0.01d**
8	**3.23±0.39bc**	**1.27±0.12bcd**	**252.00±12.68bc**	**0.06±0.01d**	**2.95±0.16d**	**1.39±0.07a**	**292.20±7.92ab**	**0.08±0.01cd**
10	**4.12±0.48b**	**1.19±0.07cde**	**288.50±5.00a**	**0.12±0.01abc**	**4.79±0.35ab**	**1.23±0.03ab**	**298.10±4.98a**	**0.15±0.01a**
12	**1.13±0.01d**	**1.42±0.08abc**	**247.50±10.94c**	**0.13±0.01ab**	**3.43±0.34cd**	**0.94±0.04d**	**306.80±5.90a**	**0.12±0.01b**
14	**5.78±0.29a**	**1.43±0.06ab**	**247.50±4.64c**	**0.11±0.01bc**	**4.59±0.33ab**	**1.13±0.05bc**	**301.20±4.39a**	**0.15±0.01a**
16	**6.73±0.18a**	**1.61±0.08a**	**250.50±8.13c**	**0.14±0.01a**	**5.03±0.34a**	**1.17±0.04b**	**298.80±8.31a**	**0.18±0.01a**
One - Way ANOVA (F-Statistic)								
Rep	**25.68*** **	**5.70*** **	**3.34*** **	**13.53*** **	**4.32*** **	**6.26*** **	**9.46*** **	**19.04*** **

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at ***: $P \leq 0.001$

Table 3.5: Effect of different water quantities on foliage colour of *Cucumus sativa* L. as measured from Week 1 to Week 8 during 2010.

Treatment	WEEKS 1	2	3	4	5	6	7	8
	Foilage Colour (scale from 1-5)							
$L.h^{-1}$								
2	3.75±0.10a	**3.75±0.10bc**	**3.15±0.15d**	**3.45±0.14bc**	**3.40±0.17bc**	**3.05±0.15d**	**3.00±0.10d**	**3.50±0.11c**
4	3.85±0.08a	**3.25±0.12d**	**3.30±0.18cd**	**3.30±0.16c**	**3.30±0.15c**	**3.05±0.17d**	**3.60±0.18c**	**3.90±0.07b**
6	4.00±0.00a	**3.75±0.10bc**	**3.80±0.14ab**	**4.00±0.10a**	**3.75±0.20abc**	**3.65±0.17bc**	**3.95±0.18bc**	**3.90±0.07b**
8	3.90±0.07a	**3.55±0.15cd**	**3.65±0.20bc**	**3.75±0.18ab**	**3.85±0.18ab**	**3.25±0.18cd**	**4.25±0.16b**	**3.85±0.08b**
10	3.80±0.09a	**4.10±0.10a**	**3.60±0.13bc**	**3.65±0.15abc**	**3.75±0.18abc**	**4.05±0.15ab**	**4.70±0.13a**	**4.20±0.12a**
12	3.85±0.08a	**3.70±0.11bc**	**3.85±0.13ab**	**3.70±0.13ab**	**3.85±0.18ab**	**4.15±0.17a**	**4.85±0.08a**	**3.75±0.12bc**
14	3.85±0.08a	**3.95±0.09ab**	**4.10±0.12a**	**3.85±0.13a**	**4.15±0.17a**	**3.95±0.14ab**	**4.80±0.09a**	**4.35±0.11a**
16	3.95±0.09a	**3.85±0.08abc**	**4.10±0.14a**	**3.90±0.14a**	**4.00±0.19a**	**4.20±0.14a**	**4.85±0.11a**	**4.45±0.14a**
One - Way ANOVA (F-Statistic)								
Rep	1.00ns	**5.64*** **	**5.17*** **	**2.66***	**2.56***	**9.62*** **	**25.59** **	**9.29*** **

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at *: $P \leq 0.1$; **: $P \leq 0.01$; ***: $P \leq 0{,}001$; ns: non-significant.

Table 3.6: Effect of different water quantities on chlorophyll of *Cucumus sativa* L. as measured from Week 1 to Week 8 during 2010.

Treatment	WEEKS 1	2	3	4	5	6	7	8
	Chlorophyll							
$L.h^{-1}$								
2	46.12±1.54a	**47.37±2.22d**	**50.41±0.81b**	49.59±0.85a	50.81±1.42a	52.21±1.59a	**54.02±1.87bcd**	**52.63±1.40c**
4	50.48±1.56a	**51.37±2.48cd**	**50.98±0.78b**	48.56±0.88a	50.80±1.79a	53.77±1.89a	**51.71±1.71d**	**63.88±3.38a**
6	51.81±2.84a	**51.54±1.79bcd**	**51.30±0.96b**	49.83±1.04a	51.88±0.90a	54.63±0.94a	**52.73±1.46cd**	**60.50±1.87ab**
8	51.46±1.73a	**51.99±0.73bc**	**50.06±0.64b**	49.35±0.74a	52.66±1.14a	55.75±1.71a	**56.73±1.77abc**	**61.19±2.32ab**
10	52.26±0.75a	**56.65±1.39a**	**55.33±0.82a**	51.78±1.30a	53.35±1.27a	52.94±1.62a	**56.97±1.05ab**	**63.32±2.60a**
12	53.05±1.14a	**55.12±1.09abc**	**51.81±1.05b**	48.70±1.48a	51.93±1.32a	57.54±2.02a	**56.45±1.28abc**	**60.78±1.69ab**
14	52.77±1.05a	**57.10±1.41a**	**56.56±1.05a**	53.40±1.57a	54.44±1.13a	57.87±1.59a	**58.20±1.30a**	**55.54±1.72bc**
16	50.56±1.22a	**55.99±0.92ab**	**54.82±1.40a**	50.98±1.71a	53.15±0.78a	56.35±1.58a	**60.14±0.92a**	**63.90±1.48a**
One - Way ANOVA (F-Statistic)								
Rep	1.92ns	**4.39*** **	**6.82*** **	1.79ns	1.02ns	1.62ns	**3.81****	**3.62****

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at **: $P \leq 0.01$; ***: $P \leq 0$, ns: non-significant .

CHAPTER FOUR

THE EFFECTS OF VARIOUS DRIP FERTIGATED WATER QUANTITIES ON NUTRIENT UPTAKE OF HYDROPONICALLY CULTIVATED *CUCUMIS SATIVA* L.

The effects of various drip fertigated water quantities on nutrient uptake of hydroponically cultivated *Cucumis sativa* L.

DONAVON SONNENBERG[1], PATRICK A. NDAKIDEMI[2,] , AND CHARLES LAUBSCHER[1*]

[1]Faculty of Applied Science, Cape Peninsula University of Technology, Cape Town Campus, P.O. Box 652, Cape Town 8000, South Africa.

[2]The Nelson Mandela African Institute of Science and Technology, School of Life Sciences and Bio-engineering, Nelson Mandela Rd, P O Box 447. Arusha- Tanzania.

[*]Corresponding author

Tel: +27 21 4603198. Fax: +27 4603193

Email: laubscherc@cput.ac.za

4.1 Abstract

The effects of various quantities of water were assessed on their potential to influence the nutrient uptake of cucumber plants grown hydroponically in the greenhouse. The treatments included supplying 8 different water quantities 2l/h, 4l/h, 6l/h, 8l/h, 10l/h, 12l/h, 14l/h, 16l/h. The plants received water five times a day, making it 10, 20, 30, 40, 50, 60, 70, and 80 litres per day. Results from this study showed that fresh and dry weights of roots, leaves and stems were significantly (P≤0.001) influenced by different water quantities supplied to *Cucumis sativa* L. The largest quantity of fresh roots was recorded in the control treatment (2l/h) in comparison with all other treatments. However, the best growth with regard to fresh and dry weights of leaves and stems were recorded by supplying the water quantities ranging from 10-16l/h. Altering the water supply, significantly (P≤0.001) affected the uptake of nitrogen, phosphorous, potassium, calcium, sodium, copper, zinc, aluminium and iron in roots of *Cucumis sativa* L. Irregular results were recorded in the uptake of these nutrients in the roots. However, leaf uptake of N, P, K, Ca, Mg, S, Cu, Zn, manganese, boron, and aluminium varied significantly (P≤0.001) in the different water treatments. The best result for each was observed in treatments involving 16l/h. In stems of cucumber, water quantities significantly (P≤0.001) affected the uptake of N, P, K, Ca, Mg, Cu, S, Cu, Zn, Mn, B. The highest uptake of N, P, Ca, Mg and S were found at the maximum supply of water (16l/h) compared with the control (2l/h). Na uptake showed irregular patterns, whereas K uptake and Zn peaked at 14l/h.

Key words: nitrogen, phosphorous, potassium, nutrient uptake.

4.2 INTRODUCTION

Nutrient uptake originating from the growth medium involves numerous processes such as: ionic equilibrium between growth medium and solution, transport of nutrients to roots, and the absorption of nutrients by roots. All these processes are influenced by the amount of water supplied to plants which may ultimately limit nutrient uptake by plants. Nutrients` accessibility for plant development and growth in hydroponics systems is imperative particularly for all year round vegetable production. In controlled hydroponic systems, nutrient availability is one of the fundamental growth factors that may be influenced by the amount of water supplied to the plants.

Water stress influences the uptake of mineral elements in plant tissues by affecting root development and nutrient movement in the growth medium and ultimately the nutrient uptake in plant tissues (Fageria et al., 2002, Samarah et al., 2004). The most significant end-product of water deficits is observed on the mobility of nutrients to the root and on root enlargement and expansion. The decrease in nutrient element absorption is a result of an interference with nutrient uptake and unloading mechanisms and reduction in transpiration flow (Marschner, 1995; Baligar et al., 2001). Tanguilig et al. (1987) reported that the greater the transpiration rate, the higher the nutrient uptake. This is clearly identified when little quantities of water is provided to the crop. At less supply of water, nutrient uptake by the roots is then decreased and so does their movement to the shoots (Richards and Wadleigh, 1952; Menzel et al., 1986; Fageria et al., 2002; Samarah et al., 2004). This decreased nutrient uptake is a result of limitation in the transpiration rates which lead to impaired active transport and membrane permeability (Greenway et al., 1969; Viets, 1972; Hsiao, 1973; O`Toole and Baldia, 1982; Yamboa and O`Toole, 1984; Tanguilig et al., 1987; Pinkerton and Simpson, 1986; Kramer and Boyer, 1995; Alam, 1999).

Water stress can cause harm to the crop due to impaired ion uptake. The damage will however depend on how severe the water stress is. A decrease in water potential reduces the total amount of ions that are transported to the shoots due to a decrease in water flow (Greenway, 1967; Erlandsson, 1975). Therefore plants exposed to limited water conditions will reduce the uptake of plant mineral elements as a result of low moisture and reduced transpiration flow (Marschner, 1995).

The quantity of water that plants receive has a significant influence on the amount of nutrients it will contain. Identifying the optimum amount of water, to obtain the optimum nutrient concentration in crops is useful, as this will have a significant effect on the final yield. This study was aimed at quantifying the effects of supplying different quantities of water, on macronutrients (Phosphorous, Potassium, Calcium, Magnesium, and Sodium) and micronutrients (Copper, Zinc, Manganese, Iron, Aluminium, Boron) uptake in *Cucumis sativa* L.

4.3 MATERIALS AND METHODS

4.3.1 Site location and description

The research was conducted at the greenhouse of the Agronomy and Vegetables Department of the Cape Institute for Agricultural Training in Elsenburg, South Africa during the 2009-winter season and 2009-2010 summer season. The greenhouse had a fully automated fertigation system. The cucumber plants were placed in 20L black bags consisting of sawdust as a growth medium. The plants were irrigated via drip irrigation and plants were staked with polyethylene twines.

4.3.2 Experimental design and treatments

The experiment was set out in a randomised complete block design. The treatments included 8 various water regimes. These different water regimes were 2l/h (control), 4l/h, 6l/h, 8l/h, 10l/h, 12l/h, 14l/h, 16l/h. The plants received water five times a day, making it 10, 20, 30, 40, 50, 60, 70, 80l per day.

The crop *Cucumis sativa* L. variety Alladin was purchased from A. Ford & Co. (Pty) Ltd. (1 Hazelden drive Business Park Garden Pavillion, Tel: 021 – 850 0011) and the seeds were germinated by Propagating Plants Company (Klein Joostenburg farm, corner of R101 and R304, Tel. /Fax: 021 – 884 4513). This was a new high yield cucumber variety in South Africa.

The trial was in a drain-to- waste system and was conducted over 3 months. There were 8 replicates and all the treatments received the same amount of nutrients. The electrical conductivity of the nutrient solution was set at 1.65 mS cm^{-1}(Combrink, 2005).

4.3.3 Plant harvest and sample preparation

After 91 days each plant for each treatment was harvested. The stems, leaves, roots and fruits were cut up for each treatment and placed in separate brown bags. The fresh weights were then determined for each bag by using a small scale. Samples were then dried in an oven at 65°C for 72 hrs, weighed, ground into a fine powder (0.85 mm) and stored prior to the bioassay for nutrient uptake and accumulation in plant tissues.

4.3.4 Measurement of nutrients in plant tissue

Measurements of P, K, Ca, Mg, Na, Fe, Cu, Zn, Mn, B and Al were determined by ashing 1 g of ground sample in a porcelain crucible at 500°C overnight. This was followed by dissolving the ash in 5 mL of 6 moles of HCl and placing it in an oven at 50°C for 30 min and 35 mL of deionised water was added. The mixture was filtered through Whatman no. 1 filter paper. Nutrient concentration in plant extracts was determined using the ICP (Giron, 1973). Sulphur (S) was determined by wet digestion procedure using 65% nitric acid. In each case, 1 g of milled plant material was digested overnight with 20 mL of 65% nitric acid in a 250 mL glass beaker. The beaker containing the extract was then placed on a sand bath and gently boiled until approximately 1 mL of the extract was left. After that, 10 mL of 4 mol. of nitric acid was added and boiled for 10 min. The beaker was removed from the sand bath, cooled and the extract washed completely in a 100 mL volumetric flask and filtered through Whatman no. 2 filter paper. Sulphur in the sample was then determined (FSSA 1974) by direct aspiration on the calibrated simultaneous ICP. Total N was determined by the micro-Kjeldahl method (Bremner, 1965).

Nutrient uptake (mg.plant^{-1}) was then calculated as the product of nutrient concentration (mg.g^{-1}, data not shown) and the weight of the plant part dry matter (g.plant^{-1}).

$$N_{uptake}\left(mg.plant^{-1}\right) = ON_{conc.}\left(mg.g^{-1}\ DM\right) \times O_{dry\ mass}\left(g.plant^{-1}\right)$$

Where: N_{uptake} = Microelement uptake, ON_{conc} = Organ nutrient concentration, $O_{dry\ mass}$ = Organ dry mass.

4.3.5 Statistical analysis

Statistical analysis was attained with the use of the 1 - way analysis of variance (ANOVA) by using the software program STATISTICA. 2012 (Stat soft Inc Tulsa,Ok, USA).

4.4 RESULTS

In Table 7, both fresh and dry weights of roots, leaves and stems were significantly (P≤0.001) influenced by different water quantities supplied to *Cucumis sativa* L. The largest quantity of fresh roots was recorded in the control treatment with the lowest amount of water (2l/h control) in comparison with all the other treatments. With dry roots, the best results were obtained by supplying plants with 6l/h and 8l/h of water compared with the other treatments (Table 7). However, the best growth with regard to fresh and dry weights of leaves and stems, were recorded by supplying the water quantities ranging from 10-16l/h (Table 7).

Altering the water supply significantly (P≤0.001) affected the uptake of N, P, K, Ca, and Na in roots of *Cucumis sativa* L. (Table 8). Irregular results were recorded in the uptake of N, P and K, Ca and Na (Table 8). The effect of varying different quantities of water on the root uptake of micronutrients is shown in Table 9. Root uptake of Cu, Zn, Al and Fe were significantly (P≤0.001) influenced by the different water quantities. Uneven results were recorded in the uptake of Cu, Zn, Al and Fe in the roots (Table 9).

The leaf uptake of N, P, K, Ca, Mg and S in *Cucumis sativa* L. was significantly (P≤0.001) different in response to the various water treatments (Table 10). The uptake of these macronutrients displayed higher values with increasing water supply. The best results for each were observed in treatments involving 16l/h (Table 10).

Cu, Zn, Mn, B, Al were all noted to have significantly (P≤0.001) increased (Table 11) within the leaves of *Cucumis sativa* with different water quantities. Al uptake was irregular, whereas greater quantities of Cu, Zn, Mn and B were found in the treatment supplied with 16l/h of water.

In stems of the cucumber crop, varying water quantities significantly (P≤0.001) affected the uptake of N, P, K, Ca, Mg, Na and S (Table 12). The highest uptake of N, P, Ca, Mg and S were found at the maximum (16l/h) supply of water compared with the control (2l/h) and other treatments (Table 12). Na uptake showed irregular patterns, whereas K uptake peaked at 14l/h. The uptake of micronutrients (Cu, Zn, Mn, B) were significantly (P≤0.001) affected by the different water treatments. Increasing the water supply to 16l/h significantly elevated the shoot uptake of Cu, Mn and B. The uptake of Zn peaked at 14l/h of water supply.

4.5 DISCUSSION

In this study, *Cucumis sativa* L. plants exposed to different water regimes (2, 4, 6, 8, 10, 12, 14 and 16l/h) displayed significantly different effects on nutrient uptake (Table 8-13) in the fresh and dry weights (Table 7) of the different tissues when compared with the control treatment (2l/h).

It is well established that water supply is important in promoting growth and development of plants (Yuan et al., 2003; Sezen et al., 2005). In the roots, the plants that were exposed to the least amount of water 2l/h had the highest root mass and hence the uptake of nutrients. This was due to the fact that plants exposed to little amount of water manipulated a mechanism which promoted extensive root growth to seek out for more nutrients and water. Similar to our study, Pearson (1966); El Nadi et al. (1969); Hoffman et al. (1971) also reported improved root growth in water limited situations. Roots from crops which received more water had to invest little to promote root growth as water and nutrients were readily available for crop uptake (Green, 1968).

In this study, increasing water quantities had a positive influence on the nutrient uptake in the cucumber leaves and stems. The amount of water supplied to plants has been reported to be one of the major factors which influence nutrient uptake and their accumulation in plant tissues (Fageria et al., 2002; Samarah et al., 2004). The leaf and stem uptake of most macro and micronutrients (Table 10-13) were significantly enhanced by exposing plants to higher doses of water 16l/h in comparison with the control (2l/h). At low water supply, plants invested heavily in developing root structures and as a result decreased nutrient movement to the shoots. In related studies, research evidence suggests that the decreased nutrient uptake in treatments receiving reduced amounts of water and, is associated with limited transpiration rates which lead to impaired active transport of different ions in plant tissues (Richards and Wadleigh, 1952; Menzel et al., 1986; Fageria et al., 2002, Samarah et al., 2004). At a higher supply of water, the transpiration rate is enhanced, nutrient removal from the solution by the roots is increased and their movement to the shoots facilitated (Richards and Wadleigh, 1952; Menzel et al., 1986; Fageria et al., 2002; Samarah et al., 2004). In this study, an increased nutrient uptake of macro and micronutrients in leaves and stem tissue of cucumber plants, exposed to higher water

quantities, was a result of higher moisture availability and improved transpiration (data not shown here).

4.6 CONCLUSION

In conclusion, increasing the supply of water resulted in altered growth of roots, leaves and stems of *Cucumis sativa* L. Furthermore, increasing water quantities significantly increased the uptake of macro and micro-nutrients in leaves and stem tissues of *Cucumis sativa* L. Therefore, it is important to establish the optimum levels of water supply to *Cucumis sativa* L. in attaining maximum growth and nutrient accumulation in the hydroponic systems.

4.7 ACKNOWLEDGMENTS

This study was supported by the Western Cape Department of Agriculture and Cape Peninsula University of Technology.

4.8 REFERENCES

Alam SM (1999). Nutrient uptake by plants under stress conditions. New York, Pessarakli M. Handbook of Plant and Crop Stress: 285-314.

Baligar VC, Fageria NK, He ZL (2001). Nutrient use efficiency in plants. Soil Science, 32: 921-950.

Bremner JM (1965). Total Nitrogen in, method of soil analysis. Madison Wisconcin, American Society of Agronomy: 1149-1178.

Combrink NJJ (2005). Nutrient solutions and greenhouse management. Stellenbosch, South Africa, Combrink Familietrust: 34.

El Nadi AH, Brouwer R, Locher J (1969). Some responses of the root and shoot of *Vicia faba* plants to water stress. Netherlands Journal Agricultural Science, 17: 133-142.

Erlandsson G (1975). Rapid effects on ion and water uptake induced by changes of water potential in young wheat plants. Physiologica Plant, 35: 256-262.

Fageria NK, Baligar VC, Clark RB (2002). Micronutrients in crop production. Advances in Agronomy, 77: 185-267.

Fertilizer Society of South Africa (FSSA) (1974). South Africa Pretoria, Manual of Soil Analysis Methods: 37.

Giron HC (1973). Atomic absorption newsletter, 12: 28.

Green PB (1968). Growth physics in *Nitella*: a method for continuous in vivo analysis in extensibility based on a micro – manometer technique for turgor pressure. Plant Physiology, 43: 1169-1184.

Greenway H (1967). Effects of exudation on ion relationships of excised roots. Physiologia Plantarum, 20: 903-910.

Greenway H, Klepper B, Hughes PG (1969). Effects of low water potential on ion uptake and loss for excised roots. Planta (Berlin), 80: 129-141.

Hoffman GJ, Rawlins SL, Garber MJ, Cullen EM (1971). Water relations and growth of cotton as influenced by salinity and relative humidity. Agronomy Journal, 63: 822-826.

Hsiao TC (1973). Plant responses to water stress. A Revision Plant Physiology, 24: 519-570.

Kramer PJ, Boyer JS (1995). Water relations of plants and soils. San Diego, Academic press Incorporated.

Marschner H (1995). Mineral nutrition of higher plants. London, Academic Press.

Menzel CM, Simpson DR, Dowling AJ (1986). Water relations in passionfruit: Effect of moisture stress on growth, flowering and nutrient uptake. Scientia Horticulturae, 29: 239-249.

O`Toole JC, Baldia EP (1982). Water deficits and mineral uptake in rice. Crop Science, 22: 1144-1150.

Pearson RW (1966). Soil environment and root development. American Social Agronomy: 95-126.

Pinkerton A, Simpson JR (1986). Interactions of surface drying and subsurface nutrients affecting plant growth on acidic soil profiles from an old pasture. Australian Journal of Experimental Agriculture, 26: 681-689.

Richards LA, Wadleigh CH (1952). Soil water and plant growth. Agronomy: 73-251.

Samarah N, Mullen R, Cianzio S (2004). Size distribution and mineral nutrients of soybean seeds in response to drought stress. Journal of Plant Nutrition, 27: 815-835.

Sezen SM, Yazar A, Canbolani M, Eker S, Caikel G (2005). Effect of drip management on yield and quality of field grown green beans. Agricultural Water Managment, 71(3): 243-255.

Tanguilig VC, Yambao EB, O`Toole JC, De Datta SK (1987). Water stress on leaf elongation, leaf water potential, transpiration, and nutrient uptake of rice, maize and soybean. Plant and Soil, 103: 155-168.

Viets Jr. FG (1972). Water deficits and nutrient availability.New York, Academic press, Plant Responses and Control of Water Balance, 217-240.

Wardlaw IF (1967). The effect of water stress on translocation in relation to photosynthesis and growth. Effect during grain development in wheat. Australian Journal Biological Sciences, 20: 25-39.

Yambao EB, O`Toole JC (1984). Effects of nitrogen nutrition and root medium water potential on growth, nitrogen uptake and osmotic adjustment of rice. Physiologia Plantarum, 60: 507-515.

Yuan BZ, Nishiyama S, Kang Y (2003). Effects of different irrigation regimes on the growth and yield of drip – irrigated potato. Agricultural Water Management, 63: 153-167.

Table 4.1: Effect of different water quantities on fresh and dry weights of *Cucumus sativa* L. as measured in grams during 2010

Treatment	Fresh Roots	Fresh Leaves	Fresh Stem	Fresh Fruit	Dry Roots	Dry Leaves	Dry Stem	Dry Fruit
$L.h^{-1}$								
2	**131.25±8.76a**	**158.49±22.96d**	**360.60±20.86d**	22.85±3.24a	**20.17±0.35b**	**32.53±2.97cd**	**45.90±1.70c**	12.11±0.96a
4	**118.83±4.38ab**	**153.91±10.57d**	**423.90±20.74bc**	16.27±2.39a	**21.11±0.88b**	**29.52±1.52d**	**49.30±2.29c**	10.07±1.32a
6	**119.45±5.08ab**	**193.56±20.27cd**	**405.04±16.73c**	24.69±2.07a	**23.63±0.79a**	**35.49±1.95cd**	**47.53±1.27c**	14.43±0.36a
8	**113.36±7.70bc**	**152.64±15.19d**	**397.75±12.88cd**	18.43±9.87a	**23.23±0.81a**	**35.77±1.57cd**	**50.24±2.30bc**	7.44±1.49a
10	**98.85±4.24cd**	**201.71±20.92cd**	**454.74±15.08ab**	24.52±6.32a	**19.51±0.44b**	**39.04±2.55c**	**54.80±3.21ab**	10.95±1.67a
12	**100.44±3.68cd**	**242.44±27.05bc**	**450.50±7.30ab**	12.62±3.02a	**21.01±0.24b**	**48.33±3.83b**	**55.14±0.76ab**	8.95±1.77a
14	**85.99±4.93d**	**268.12±31.16ab**	**484.27±10.38a**	9.65±3.51a	**19.82±0.45b**	**53.27±4.25ab**	**57.24±1.20a**	14.96±9.78a
16	**65.39±6.83e**	**313.18±22.99a**	**485.19±7.91a**	10.95±2.79a	**20.93±0.26b**	**58.97±3.16a**	**59.33±1.41a**	8.05±1.56a
One - Way ANOVA (F-Statistic)								
Rep	**12.67*** **	**7.09*** **	**8.74*** **	1.59ns	**6.73*** **	**13.55*** **	**6.40*** **	0.58ns

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at ***: $P \leq 0.001$, ns: non-significant

Table 4.2: Effect of different water quantities on Macro-nutrient uptake(mg.plant^{-1}) of *Cucumus sativa* L. roots as measured during 2010.

Treatment	Nitrogen (N)	Phosphorous (P)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Sulphur (S)
L.h^{-1}							
2	**9.09±0.23a**	**4.77±0.45a**	**18.91±1.72a**	**4.59±0.24a**	**1.44±0.08a**	**159.95±10.39a**	0.95±0.08a
4	**6.39±0.65b**	**2.99±0.25c**	**15.53±2.77abc**	**3.34±0.23bc**	**0.84±0.08c**	**69.88±12.81cd**	0.94±0.17a
6	**6.47±0.51b**	**2.92±0.37c**	**11.09±1.30d**	**3.60±0.24bc**	**1.08±0.08b**	**74.31±9.49cd**	0.65±0.05a
8	**6.37±0.64b**	**3.22±0.34c**	**11.26±1.73d**	**3.89±0.38b**	**1.13±0.09b**	**91.28±15.36bc**	0.72±0.08a
10	**7.10±0.42b**	**3.63±0.32bc**	**12.23±0.72cd**	**3.00±0.16c**	**1.13±0.06b**	**78.99±10.86bcd**	0.70±0.04a
12	**10.44±0.28a**	**4.50±0.17ab**	**14.50±0.52bcd**	**3.65±0.13b**	**1.24±0.04b**	**66.12±7.02cd**	0.83±0.04a
14	**9.49±0.46a**	**4.26±0.25ab**	**13.91±0.94bcd**	**3.46±0.17bc**	**1.06±0.06b**	**52.68±2.76d**	0.80±0.04a
16	**9.73±0.49a**	**4.70±0.34a**	**16.99±1.07ab**	**3.82±0.17b**	**1.24±0.06b**	**106.49±10.41b**	0.87±0.05a
One - Way ANOVA (F-Statistic)							
Rep	**12.73*** **	**5.79*** **	**3.41*** **	**4.19*** **	**6.21*** **	**10.17*** **	1.923ns

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at ***: $P \leq 0.001$, ns: non-significant

Table 4.3: Effect of different water quantities on Micro-nutrient uptake(mg.plant-^{1}) of *Cucumus sativa* L. roots as measured during 2010.

Treatment	Copper (Cu)	Zinc (Zn)	Manganese (Mn)	Boron (B)	Aluminium (Al)	Iron (Fe)
L.h^{-1}						
2	**0.30±0.02a**	**1.36±0.10abc**	0.93±0.05a	0.82±0.07a	**7.12±1.03b**	**7.15±1.29bc**
4	**0.21±0.022d**	**1.53±0.16ab**	0.84±0.06a	0.74±0.20a	**6.98±0.92b**	**7.25±0.98b**
6	**0.21±0.02cd**	**1.24±0.09c**	0.78±0.070a	0.49±0.02a	**8.61±0.88ab**	**9.59±1.22ab**
8	**0.26±0.01ab**	**1.33±0.10bc**	0.82±0.09a	0.53±0.04a	**9.44±1.15a**	**9.98±1.14a**
10	**0.23±0.01bc**	**1.16±0.04c**	0.70±0.04a	0.61±0.02a	**4.02±0.58c**	**4.69±0.65cd**
12	**0.20±0.01cd**	**1.53±0.07ab**	0.91±0.07a	0.70±0.03a	**4.02±0.34c**	**4.24±0.24d**
14	**0.19±0.01cd**	**1.60±0.06a**	0.95±0.05a	0.65±0.02a	**3.69±0.42c**	**3.47±0.24d**
16	**0.17±0.01d**	**1.39±0.08abc**	0.79±0.05a	0.69±0.02a	**3.83±0.55c**	**3.57±0.40d**
One – Way ANOVA (F-Statistic)						
Rep	**6.36*** **	**2.72*** **	1.93ns	1.86ns	**8.98*** **	**9.00*** **

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at ***: $P \leq 0.001$, ns: non-significant

Table 4.4: Effect of different water quantities on Macro-nutrient uptake(mg.plant^{-1}) of *Cucumus sativa* L. leaves as measured during 2010.

Treatment	Nitrogen (N)	Phosphorous (P)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Sulphur (S)
L.h^{-1}							
2	**27.38±3.44c**	**5.27±0.64e**	**36.14±5.68d**	**60.38±11.52e**	**12.57±2.06c**	28.30±3.13a	**6.17±0.90cd**
4	**29.62±3.34c**	**5.51±0.51e**	**41.01±6.59cd**	**71.21±11.58de**	**11.64±2.01c**	28.24±7.74a	**5.54±0.70d**
6	**38.76±2.67c**	**7.52±0.53de**	**47.85±3.85cd**	**76.43±8.24cde**	**16.60±1.53bc**	29.13±3.26a	**8.30±1.23bcd**
8	**41.38±2.47c**	**8.56±0.53cde**	**59.02±6.48cd**	**116.72±11.28bc**	**21.23±0.96b**	35.36±2.88a	**9.80±1.00bcd**
10	**73.64±4.81b**	**11.13±0.75bcd**	**65.87±4.60c**	**109.47±12.07bcd**	**22.10±2.14b**	27.36±1.82a	**10.31±0.94bc**
12	**72.29±10.11b**	**11.78±2.02bc**	**68.08±7.27c**	**131.24±13.06b**	**16.04±1.45bc**	28.69±2.76a	**10.04±1.09bcd**
14	**77.70±11.35b**	**12.30±1.86b**	**99.02±17.00b**	**152.58±17.49b**	**22.80±2.99b**	20.89±1.70a	**12.69±1.99b**
16	**138.25±13.56a**	**21.01±2.04a**	**146.24±18.75a**	**343.35±31.46a**	**52.33±5.76a**	33.62±5.02a	**28.77±3.30a**
One – Way ANOVA (F-Statistic)							
Rep	**22.93*** **	**15.29*** **	**12.50*** **	**31.81*** **	**22.37*** **	1.17ns	**20.95*** **

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at ***: $P \leq 0.001$, ns: non-significant

Table 4.5: Effect of different water quantities on Micro-nutrient uptake(mg.plant^{-1}) of *Cucumus sativa* L. leaves as measured during 2010.

Treatment	Copper (Cu)	Zinc (Zn)	Manganese (Mn)	Boron (B)	Aluminium (Al)	Iron (Fe)
L.h^{-1}						
2	**0.09±0.01d**	**1.86±0.23d**	**4.58±0.42e**	**3.80±0.48cd**	**2.77±0.30cd**	8.13±1.50a
4	**0.12±0.01cd**	**1.72±0.13d**	**4.75±0.78de**	**3.08±0.41d**	**2.53±0.26d**	11.06±2.97a
6	**0.14±0.02bc**	**2.14±0.25cd**	**6.69±0.71c**	**4.80±0.40bc**	**2.65±0.20cd**	12.01±3.05a
8	**0.14±0.01bc**	**2.53±0.21bc**	**6.59±0.52cd**	**4.93±0.30bc**	**3.28±0.30abcd**	7.93±0.93a
10	**0.17±0.01ab**	**2.54±0.25bc**	**9.72±0.90ab**	**5.43±0.34b**	**3.86±0.54a**	16.27±4.00a
12	**0.17±0.02ab**	**2.56±0.27bc**	**7.83±0.53bc**	**4.85±0.35bc**	**3.76±0.44ab**	10.63±1.58a
14	**0.14±0.01bc**	**2.82±0.24b**	**8.71±0.66b**	**4.61±0.55bc**	**2.86±0.22bcd**	8.77±1.80a
16	**0.20±0.02a**	**3.65±0.23a**	**11.39±0.73a**	**8.26±0.57a**	**3.51±0.27abc**	19.20±5.73a
One - Way ANOVA (F-Statistic)						
Rep	**5.55*** **	**6.92*** **	**12.34*** **	**12.11*** **	**2.42*** **	1.72ns

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at ***: $P \leq 0.001$, ns: non-significant

Table 4.6: Effect of different water quantities on Macro-nutrient uptake(mg.plant^{-1}) of *Cucumus sativa* L. stems as measured during 2010.

Treatment	Nitrogen (N)	Phosphorous (P)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Sulphur (S)
L.h^{-1}							
2	**50.34±4.54e**	**15.48±1.34e**	**121.71±11.65e**	**20.94±2.26c**	**6.49±0.55cd**	**62.82±5.49c**	**4.47±0.38d**
4	**47.68±4.96e**	**18.58±1.46de**	**207.70±17.91c**	**31.35±3.01b**	**6.30±0.69d**	**203.53±34.31a**	**5.04±0.49cd**
6	**53.30±3.71de**	**16.89±1.02e**	**169.39±8.57d**	**32.56±3.18b**	**7.62±0.81bcd**	**251.58±33.43a**	**4.72±0.34cd**
8	**61.91±2.85cd**	**21.33±0.57cd**	**220.71±6.39c**	**32.61±1.59b**	**8.75±0.66ab**	**270.66±28.41a**	**5.58±0.22c**
10	**68.61±3.55bc**	**24.04±1.15bc**	**216.65±12.53c**	**29.22±1.00b**	**8.40±0.45ab**	**131.84±8.33bc**	**5.74±0.20c**
12	**74.15±2.33b**	**27.04±0.92b**	**258.04±8.12b**	**32.50±1.01b**	**8.02±0.43bc**	**132.60±13.51b**	**6.78±0.24b**
14	**89.56±2.91a**	**33.61±1.40a**	**298.01±11.99a**	**41.38±1.28a**	**8.89±0.35ab**	**104.62±9.45bc**	**8.34±0.29a**
16	**88.45±5.38a**	**31.63±1.72a**	**290.42±18.81ab**	**43.51±2.50a**	**9.93±0.59a**	**221.96±36.39a**	**8.63±0.59a**
One – Way ANOVA (F-Statistic)							
Rep	**17.59*** **	**29.38*** **	**21.95*** **	**10.72*** **	**4.41*** **	**9.33*** **	**19.01*** **

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at ***: $P \leq 0.001$

Table 4.7: Effect of different water quantities on Micro-nutrient uptake(mg.plant^{-1}) of *Cucumus sativa* L. stems as measured during 2010.

Treatment	Copper (Cu)	Zinc (Zn)	Manganese (Mn)	Boron (B)	Aluminium (Al)	Iron (Fe)
L.h^{-1}						
2	**0.22±0.01e**	**1.89±0.18e**	**2.26±0.22c**	**1.05±0.06e**	0.70±0.10a	3.54±0.35a
4	**0.26±0.01cd**	**2.52±0.26cde**	**2.34±0.14bc**	**1.31±0.06d**	0.84±0.08a	3.19±0.22a
6	**0.26±0.01d**	**2.11±0.28de**	**2.59±0.17bc**	**1.38±0.05d**	0.92±0.13a	3.26±0.28a
8	**0.30±0.01bc**	**2.88±0.23bcd**	**2.79±0.12b**	**1.56±0.03c**	1.23±0.14a	3.48±0.28a
10	**0.33±0.02ab**	**3.72±0.62b**	**3.58±0.25a**	**1.58±0.04bc**	1.09±0.14a	3.82±0.15a
12	**0.31±0.01b**	**3.79±0.22b**	**3.52±0.12a**	**1.68±0.03abc**	1.21±0.23a	8.42±3.46a
14	**0.32±0.02ab**	**4.87±0.29a**	**3.72±0.17a**	**1.69±0.04ab**	0.96±0.13a	3.70±0.25a
16	**0.36±0.02a**	**3.20±0.32bc**	**3.42±0.18a**	**1.74±0.05a**	0.87±0.10a	3.27±0.19a
One - Way ANOVA (F-Statistic)						
Rep	**10.44*** **	**9.26*** **	**11.67*** **	**26.63*** **	1.80ns	2.00ns

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at ***: $P \leq 0.001$, ns: non-significant

CHAPTER FIVE

THE EFFECTS OF VARIOUS DRIP FERTIGATED WATER QUANTITIES ON FLAVONOID AND ANTHOCYANIN CONTENT OF HYDROPONICALLY CULTIVATED *CUCUMIS SATIVA* L.

The effects of various drip fertigated water quantities on flavonoid and anthocyanin content of hydroponically cultivated *Cucumis sativa* L.

DONAVON SONNENBERG[1], PATRICK A. NDAKIDEMI[2], AND CHARLES LAUBSCHER[1*]

[1]Faculty of Applied Science, Cape Peninsula University of Technology, Cape Town Campus, P.O. Box 652, Cape Town 8000, South Africa.

[2]The Nelson Mandela African Institute of Science and Technology, School of Life Sciences and Bio-engineering, Nelson Mandela Rd, P O Box 447. Arusha- Tanzania.

[*]Corresponding author

Tel: +27 21 4603198. Fax: +27 4603193

Email: laubscherc@cput.ac.za

5.1 Abstract

The effects of various quantities of water were assessed on their potential to influence the metabolism of flavonoid and anthocyanin contents in different tissues of cucumber plants grown hydroponically in a controlled greenhouse. The treatments included supplying 8 different water quantities 2l/h, 4l/h, 6l/h, 8l/h, 10l/h, 12l/h, 14l/h, 16l/h. The plants received water five times a day, making it 10, 20, 30, 40, 50, 60, 70, and 80 litres per day. The data from our study showed that flavonoid metabolism was not significantly affected by different water quantities supplied to cucumber plants. However, the anthocyanin content in roots, leaves, and stems were significantly influenced by the different water applications. Lowest water quantity 2-6 l/h significantly increased the levels of anthocyanins in all tissues tested. Increasing water quantities to higher quantities significantly decreased the anthocynanin metabolism in all tissues.

Key words: phenolic compounds, secondary metabolites

5.2 INTRODUCTION

Flavonoid and anthocyanins are known around the world as a wide group of natural products of which the chemical structure consist of a carbon framework (Marais et al., 2006). They are polyphenolic plant secondary metabolites. Flavonoids have a great influence on colour pigmentation originating in plants and are also linked to be beneficial to human health (Winkel, 2006). For example, the colour blue found in petals of flowers are as a result of the presence of anthocyanins (delphinidin-based) in plant tissues. In some plant species, anthocyanins play a vital role in the autumn colours and photo-protection of leaf cells against stress (Ndakidemi and Dakora, 2003). It is capable of being a natural UV filter because of its ability to absorb light in the 280-315 nm regions. A wide range of plant flavonoids act as a defence mechanism against microbes, insects and mammalian herbivory. Furthermore, isoflavones, flavons and flavanones are recognized as constitutive antifungal plant agents (Ndakidemi and Dakora, 2003; Makoi and Ndakidemi, 2009; Makoi et al., 2010; Makoi and Ndakidemi, 2012). Flavonoids are also able to transform enzymatic and chemical reactions, which can impact human health negatively or positively (Beecher, 2003). They are also recognized for their antioxidant activity in a sense that antioxidants are compounds that protect cells from the harm reactive oxygen species can cause (Kukić et al., 2006). Research on flavonoids revealed that it reduces chronic diseases, including cancer (Chung et al., 2005; Ramos, 2007).

The synthesis and release of phenolic compounds such as flavonoids and anthocyanins are induced by various biotic and abiotic factors. Phosphorous deficiency can, for example, induce the accumulation of phenolics in plants (Ndakidemi, 2006). Studies conducted by Mattivi et al. (2006); Castellarin et al. (2007) showed that under limited water conditions anthocyanin build up increased through the stimulation of anthocyanin hydroxylation by up-regulating the gene encoding the enzyme. In another case Castellarin et al. (2007) stated that when berries of grapes were exposed to limited water conditions, early sugars build up increased which accelerated anthocyanin synthesis.

Phenolic compounds such as anthocyanin and flavonoids have demonstrated a wide variety of biological activities, mainly from their antioxidant activity and the potential of health benefits to humans (Hodek et al., 2002). Research evidence suggests that plants that are tolerant to limited water conditions build up three to four times more anthocyanins during dehydration in comparison to when they are in their fully hydrated state (Sherwin and Farrant, 1998). At altered water supply, phenolic compounds in cucumbers may vary in quantity and can affect the quality,

taste and possibly its digestibility. Additionally excessive phenolic compounds can cause browning and structural alterations that may adversely change the functional properties of the proteins and their activities in crops such as cucumber (Synge, 1975). The aim of this study was to assess the effects of various quantities of drip irrigated water on the flavonoid and anthocyanin metabolism in *Cucumis sativa* L. grown in the hydroponic culture.

5.3 MATERIALS AND METHODS

5.3.1 Site location and description

The research was conducted at the greenhouse of the Agronomy and Vegetables Department of the Cape Institute for Agricultural Training in Elsenburg, South Africa during the 2009-winter season and 2009-2010 summer seasons. The greenhouse had a fully automated fertigation system. The cucumber plants were placed in 20L black bags consisting of sawdust as a growth medium. The plants were irrigated via drip irrigation and plants were staked with polyethylene twines.

5.3.2 Experimental design and treatments

The experiment was set out in a randomised complete block design. The treatments included 8 various water regimes. These different water regimes were 2l/h (control), 4l/h, 6l/h, 8l/h, 10l/h, 12l/h, 14l/h, 16l/h. The plants received water five times a day, making it 10, 20, 30, 40, 50, 60, 70, and 80l per day.

The crop *Cucumis sativa* L. variety Alladin was purchased from A. Ford & Co. (Pty) Ltd. (1 Hazelden drive Business Park Garden Pavillion, Tel: 021 – 850 0011) and the seeds were germinated by Propagating Plants Company (Klein Joostenburg farm corner of R101 and R304, Tel. /Fax: 021 – 884 4513). This was a new high yield cucumber variety in South Africa.

The trial was in a drain-to-waste system and was conducted over 3 months. There were 8 replicates and all the treatments received the same amount of nutrients. The electrical conductivity of the nutrient solution was set at 1.65 $mS.cm^{-1}$(Combrink, 2005).

5.3.3 Plant harvest, sample preparation and metabolite extraction

After 91 days, each plant in each treatment was harvested. The stems, leaves, roots were cut up for each treatment and placed in separate paper bags. The plant organs were oven-dried at 60°C for 48h, weighed, ground into fine powder (0.85mm) and stored prior to bioassay for flavonoids and anthocyanins. About 0.1g of ground powder (root, leaves and stem) was weighed and mixed with 50mL of acidified methanol prepared from a ratio of 79:20:1 (MeOH: H_2O: HCl). The mixture was incubated for 72h in darkness for auto-extraction, filtered through Whatman paper Number 2 and absorbance of the clear supernatant measured spectrometrically at 300, 530, and 657nm using acidified methanol as a standard. Concentrations of flavonoids were measured at 300nm and expressed as Abs $g.DM^{-1}$ (Mirecki and Teramura, 1984), while the anthocyanin concentration was measured as $Abs_{530} - 1/3Abs_{657}$ (Lindoo and Caldwell, 1978) and expressed as Abs $g.DM^{-1}$.

5.3.4 Statistical analysis

The analysis was performed using STATISTICA software (StatSoft Inc., 2007 Tulsa, OK, USA). One-way ANOVA analysis was used to compare treatment means of the metabolites in plant organs.

5.4 RESULTS

In this study, the flavonoids and anthocyanins (Abs $g.DM^{-1}$) in tissues (roots, leaves, and stem) of cucumber were extracted in aqueous methanol (10g of seed in 50mL of acidified MeOH), and their concentrations measured spectrophotometrically.

The data from our study showed that flavonoid metabolism was not significantly affected by different water quantities supplied to cucumber plants. However, the anthocyanin content in roots, leaves, and stem were significantly influenced by the different water quantities (Figure 1-3). For example, the lowest water quantity 2-6 l/h significantly ($P \leq 0.001$) increased the levels of anthocyanins in roots. As water quantities increased, the anthocynanin metabolism in roots also decreased (Fig 1). The lowest anthocyanin content in roots was recorded in the treatment supplied with 16l/h of water.

Figure 2 shows the effect of different water quantities on the anthocyanin content in leaves. The data showed that the levels of anthocyanin content in leaves were significantly (P≤0.001) affected by the different water quantities. Relative to higher water levels (12-16l/h), the lower water levels 2-6 l/h exhibited greater concentrations of anthocyanins in leaves (Fig. 2).

The concentration of anthocyanins in stems of cucumber plants differed significantly (P≤0.001) with the various water quantities supplied. Lowest water quantities (2-4l/h) produced stems which had a significantly higher anthocyanin content than those supplies with 10-16l/h. The lowest concentration of anthocyanin in stems was recorded in a treatment supplied with water at a rate of 16l/h.

5.5 DISCUSSION

In this study, roots, leaves and stems of cucumber were assayed for flavonoids and anthocyanins with the objective of quantifying the levels of these phenolic compounds at exposure to different water quantities. Our findings reported that the *Cucumis sativa* L. plants which were exposed to different water regimes, responded significantly different in their metabolism of anthocyanins. Plants that received the least amount of water (2l/h control treatment) had the highest anthocyanin content compared with those supplied with greater water quantities (16l/h). The higher anthocyanin content present in the different cucumber organs supplied with low water quantities, could serve as defence molecules against abiotic stresses, such water stress. This report is consistent with the finding that the presence of anthocyanins in plant tissues provided protection of plant tissues against abiotic stress such as water (Chalker-Scott, 1999). In a similar study, Mattivi et al. (2006); Castellarin et al. (2007) reported anthocyanin content increases in plant tissues exposed to limited water conditions. This increase in anthocyanin content is due to the stimulation of anthocyanin hydroxylation by up-regulating the gene encoding its enzyme (Mattivi et al., 2006; Castellarin et al., 2007). It can also be as a result of early sugar accumulation increases, which as a result, accelerates anthocyanin production (Castellarin et al., 2007).

5.6 CONCLUSION

In conclusion, this study has shown that the concentration of anthocyanins in tissues of cucumber differed markedly between different water treatments tested, with plants supplied with

lowest quantities (2l/h) showing higher levels of anthocyanins relative to the highest water quantities (16l/h). The higher concentration of these compounds at lower water levels is result of mechanisms adopted by plants to protect themselves from abiotic constraints such as water stress (Chalker-Scott, 1999).

5.7 ACKNOWLEDGEMENTS

This study was supported by the Western Cape Department of Agriculture and Cape Peninsula University of Technology.

5.8 REFERENCES

Beecher G (2003). Overview of dietary flavonoids: Nomenclature, occurance and intake. Journal of Nutrition, 133: 3248-3254.

Castellarin SD, Pfeiffer A, Sivilotti P, Degan M, Peterlunger E, Di Gaspero G (2007). Transcriptional regulation of anthocyanin biosynthesis in ripening and induce changes in gene expression regulating flavonoid biosynthesis in grape berries. Planta, 227: 101-112.

Chalker-Scott L (1999). Environmental significance of anthocyanins in plant stress response. Photochemistry Photobiology, 70: 1-9.

Chung IM, Kim, JJ, Lim, JD, Yu CY, Kim SH, Hahn SS (2005). Comparison of resveratrol, SOD activity, phenolic compounds and free amino acids in *Rehmannia glutinosa* under temperature and water stress. Environmental and Experimental Botany, 56: 44 – 52.

Combrink NJJ (2005). Nutrient solutions and greenhouse management. Stellenbosch, South Africa, Combrink Familietrust: 34.

Hodek P, Pavel T, Marie S (2002). Flavonoids potent and versatile biologically active compounds interacting with cytochromes P450. Chemico-Biological Interactions 139: 1-21.

Kukić J, Petrović S, Niketić M (2006). Antioxidant activity of four endemic *Stachys*. Taxa Biology Pharmaceutical Bulletin, 29 (4): 725-729.

Lindoo SJ, Caldwell MM (1978). Ultraviolet – B radiation induced inhibition of leaf expansion and promotion of anthocyanin production. Lack of the involvement of the low irradiation phytochrome system. Plant Physiology, 61: 278-282.

Makoi JHJR, Belane AK, Chimphango SBM, Dakora FD (2010). Seed flavonoids and anthocyanins as markers of enhanced plant defence in nodulated cowpea (*Vigna unguiculata* L. Walp.). Field Crops Research, 118: 21-27

Makoi JHJR, Ndakidemi PA (2009). Biological, ecological and agronomic significance of plant phenolic compounds in rhizosphere of the symbiotic legumes. African Journal of Biotechnology, 6(12): 1358-1368.

Makoi JHJR, Ndakidemi PA (2012). Allelopathy as protectant, defence and growth stimulants in legume cereal mixed culture systems. *New Zealand Journal of Crop and* HorticulturalScience.Published online: http://dx.doi.org/10.1080/01140671.2011.630737.

Marais JPJ, Deavours B, Dixon RA, Ferreira D (2006). Stereochemistry of flavonoids. The Science of Flavonoids, 1: 1-46.

Mattivi F, Guzzon R, Vrhovsek U, Stefanini M, Velasco R (2006). Metabolite profiling of grape: flavonols and anthocyanins. Journal of Agriculture and Food Chemistry, 54: 7692-7702.

Mirecki RM, Teramura AH (1984). Effects of ultraviolet-B irradiance on soybean. Plant Physiology*,* 74: 450-480.

Ndakidemi PA (2006). Manipulating legume/cereal mixtures to optimize the above and below ground interactions in the traditional African cropping systems. African Journal of Biotechnology, 5(25): 2526-2533.

Ndakidemi PA, Dakora FD (2003). Legume seed flavonoids and nitrogenous metabolites as signals and protectants in early seedling development. Functional Plant Biology, 30: 729-745.

Ramos S (2007). Effects of dietary flavooids on approptotic pathways related to cancer chemoprevention. Journal Nutritional Biochemistry, 18(7): 427-442.

Sherwin HW, Farrant JM (1998). Protection mechanisms against excess light in the resurrection plants *Craterostigma wilmsii* and *Xerophyta viscose*. Plant Growth Regulation, 24: 203-210.

Synge RLM (1975). Interactions of polyphenols with proteins in plants and plant products. Qualitas Plantarum-Plant Foods for Human Nutrition, 24: 337-350.

Winkel BSJ (2006). Biosynthesis of flavonoids. The Science of Flavonoids, 3: 71.

Table 5.1: Effect of different water quantities on flavanoids and anthocyanins of *Cucumus sativa* L. stems as measured in Abs $g.DM^{-1}$ units during 2010.

Treatment	Flavonoid roots	Anthocyanin roots	Flavonoid leaves	Anthocyanin leaves	Flavonoid stems	Anthocyanin stems
$L.h^{-1}$						
2	0.16±0.01a	**0.44±0.04a**	0.25±0.01a	**0.47±0.04a**	0.19±0.01a	**0.44±0.03a**
4	0.16±0.01a	**0.44±0.07a**	0.23±0.01a	**0.43±0.02ab**	0.21±0.01a	**0.39±0.04ab**
6	0.18±0.01a	**0.43±0.04a**	0.22±0.01a	**0.42±0.04ab**	0.20±0.02a	**0.32±0.02bc**
8	0.16±0.01a	**0.40±0.06ab**	0.25±0.01a	**0.33±0.03bc**	0.17±0.02a	**0.33±0.02bc**
10	0.19±0.01a	**0.34±0.05abc**	0.20±0.01a	**0.37±0.03abc**	0.20±0.01a	**0.27±0.02cd**
12	0.20±0.01a	**0.29±0.03bc**	0.21±0.01a	**0.31±0.05c**	0.18±0.02a	**0.26±0.03cd**
14	0.17±0.01a	**0.40±0.04ab**	0.22±0.01a	**0.20±0.04d**	0.20±0.00a	**0.18±0.03de**
16	0.17±0.02a	**0.21±0.03c**	0.22±0.01a	**0.17±0.02d**	0.19±0.02a	**0.13±0.06e**
One - Way ANOVA (F-Statistic)						
Rep	1.88ns	**2.96*** **	1.61ns	**9.14*** **	1.18ns	**9.02*** **

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at ***: $P \leq 0.001$, ns: non-significant

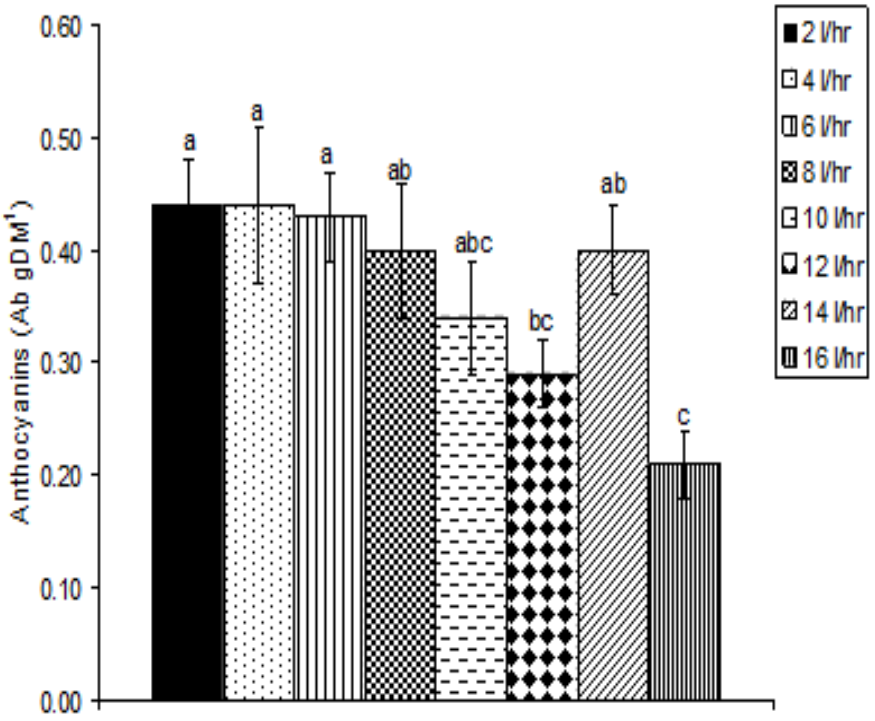

Fig 1: Effect of different amounts of water quantities on anthocyanins in the roots of *Cucumus sativa* as measured during 2010. Mean values within each bar followed by different letter differ significantly at *P*= 0.05 according to Fishers least significance difference.

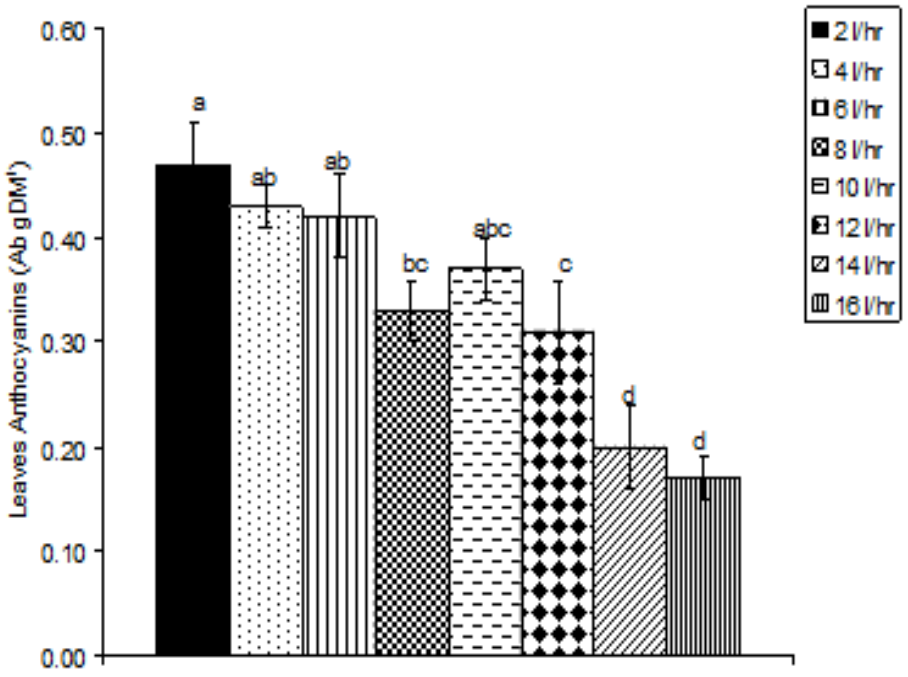

Fig 2: Effect of different amounts of water quantities on anthocyanins In the leaves of *Cucumus sativa* as measured during 2010. Mean values within each bar followed by different letter differ significantly at *P*≤ 0.05 according to Fishers least significance difference.

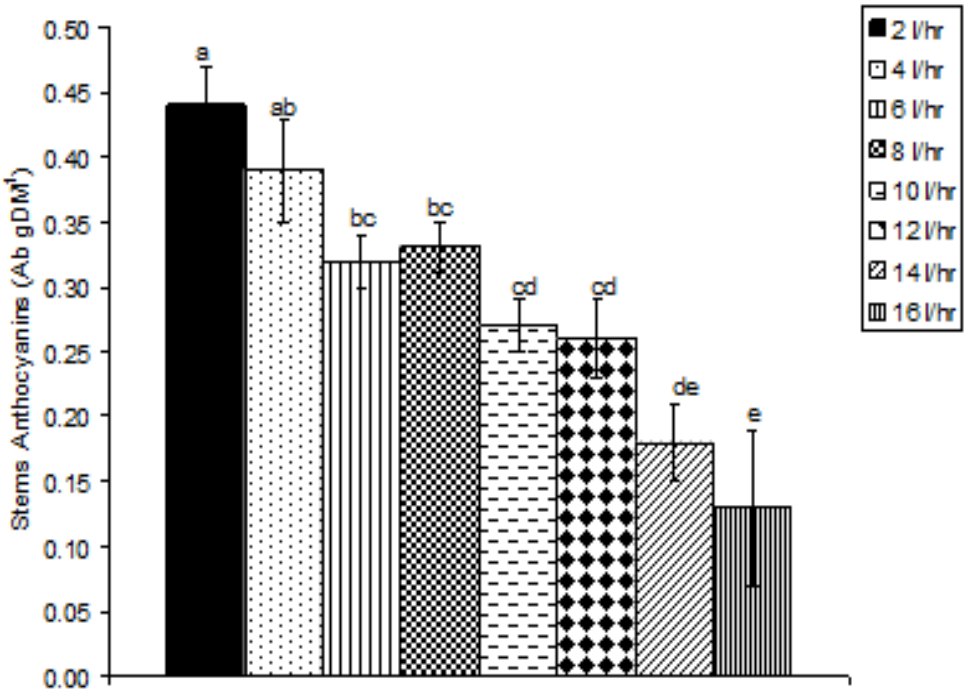

Fig 3: Effect of different amounts of water quantities on anthocyanins in the stems of *Cucumus sativa* as measured during 2010. Mean values within each bar followed by different letter differ significantly at *P*≤ 0.05 according to Fishers least significance difference.

CHAPTER SIX

THE EFFECTS OF VARIOUS DRIP FERTIGATED WATER QUANTITIES ON THE GROWTH OF HYDROPONICALLY CULTIVATED *CUCUMIS SATIVA* L.

The effects of various drip fertigated water quantities on the growth of hydroponically cultivated *Cucumis sativa* L.

DONAVON SONNENBERG[1], PATRICK A. NDAKIDEMI[2], AND CHARLES LAUBSCHER[1*]

[1]Faculty of Applied Science, Cape Peninsula University of Technology, Cape Town Campus, P.O. Box 652, Cape Town 8000, South Africa.

[2]The Nelson Mandela African Institute of Science and Technology, School of Life Sciences and Bio-engineering, Nelson Mandela Rd, P O Box 447. Arusha- Tanzania.

[*]Corresponding author

Tel: +27 21 4603198. Fax: +27 4603193

Email: laubscherc@cput.ac.za

6.1 Abstract

The effects of various quantities of water were assessed on their potential to influence the growth of cucumber plants grown hydroponically in the greenhouse. The treatments included supplying 8 different water quantities 2l/h, 4l/h, 6l/h, 8l/h, 10l/h, 12l/h, 14l/h, 16l/h. The plants received water five times a day, making it 10, 20, 30, 40, 50, 60, 70, and 80 litres per day. Plant height displayed significant differences with water quantities from weeks 1-8. At week 1, the plant height was superior at supplying 4l/h in comparison with other treatments. In week 2 and 5 irregular trends were detected. At weeks 3 and 4, supplying 8-12 displayed superior performance. At week 7-8, significant and best results were shown at water quantities ranging from 4-16l/h compared with the control treatment. Water quantities significantly ($P \leq 0.001$) affected the number of leaves per plant from weeks 2-8. Irregular results were displayed at week 2 and 3. At week 4 and 5, the highest numbers of leaves were reported by supplying 12l/h and 10l/h, respectively. Generally, leaf numbers increased with increasing water levels from weeks 6-8. Plant vigour was significantly affected by the alteration of water quantities at weeks 1, 2, 4, 5, 6, 7 and 8. At weeks 1 and 4 the more vigorous plants were found in treatments that received between 10-16l/h. At weeks 2 and 5 good results were found at treatments involving between 6-14l/h. In weeks 6, 7 and 8 the most vigorous plants were found at the highest water supply of 16l/h. With fruit length, fruit width, rind colour, fruit quality (marketable fruit) and weight, results from the harvest done in the first, second and third week, displayed that water quantities significantly influenced these parameters. Best results were reported when the plants were supplied with water ranging between 14-16l/h. At week 4, the fruit length, width, rind colour, displayed good results at 16l/h. Generally, plants that received highest amount of water (16l/h) had highest cucumber yields compared with all other treatments.

Key words: fruit length, fruit quality, fruit width, plant height, plant vigour, number of leaves per plant, rind colour.

6.2 INTRODUCTION

The quantity of water a crop receives will have a great impact on the plants` growth as well as the quality and quantity of the crops yield (Sezen et al., 2005; Yuan et al., 2003). One of the major constraints to most vegetable growers in South Africa is an issue related to water management and water use efficiency. This problem has added to the already enormous problem of drought in the country (Sedibe, 2003). Consequently, it is extremely important for growers to determine the exact amount of water required for their crops to get exceptional yields of high quality. Achieving this will support vegetable growers in saving extra costs on water and hence, increase their profits (Sedibe, 2003; Chartzoulakis and Drosos, 1995).

Cell multiplication is responsible for tissue, organ and plant growth (Hsiao and Acevedo, 1974). Cell division and hence growth, is very sensitive to limited water conditions (Smittle et al., 1994). It is widely accepted that cell enlargement cannot be maintained in the absence of water. Water stress may limit meristematic cells from expanding to the maximum size. From this fact, water is very essential for all plants` growth processes, ranging from cell to enlargement to fruit formation and growth (Westgate and Boyer, 1985; Smittle et al., 1994; Hopkins and Hüner, 2004). When a plant is subjected to water shortage, the cellular water deficit can result in a concentration of solutes, changes in cell volume and membrane shape, disruption of membrane integrity and denaturation of protein, and thus disrupting growth processes (Bray, 1997).

Water is responsible for the formation of dry or fresh matter of the plant. During the photosynthesis process, glucose is the end-product as illustrated in the following formula: $6\ CO_2 + 12\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$. In the presence of water, the starch build up in leaves is the primary element of dry weight accumulation which is accessible for export to other organs (Huber et al., 1984). When plants are exposed to limited quantities of water, leaf biomass may decrease (De Herralde et al., 1998). Conversely, application of large amounts of water may increase total accumulation of dry matter in plants such as tomato (Rendon-Poblete, 1980). Jamma and Ottman (1993) reported that water stress at the early growth stage, reduces plant dry weight as a result of reduced plant height, leaf area expansion, lower crop growth rate and decreased grain yield.

Other consequences of exposing plant to limited quantities of water in terms of plant growth is the production of smaller leaves, shorter internode sections and reductions in flower numbers, size and quality (Cameron et al., 1999; Sánchez-Blanco et al., 2002). Van Loon (1981, 1986) stated that a reduction in water supply decreased yield by reducing growth of crop canopy and biomass. In other studies, potato height increased faster with increasing the amount of irrigation water (Yuan et al., 2003). Wiedenfeld (1995) observed that there was reduction in cane yield and sugar content when plants were exposed to water stress. Other researchers showed increased fruit size and yield in crops supplied with an adequate amount of water compared with crops exposed to low quantities (Begg and Turner, 1976; Mao et al., 2002; Kumar et al., 2007; Zeng et al., 2009).

Therefore, understanding the optimum quantities of water required by plants to achieve maximum growth in hydoponic systems, is essential. This study was conducted with the objective of assessing the effects of different water quantities on the growth of *Cucumis sativa* L. grown in hydoponic systems.

6.3 MATERIALS AND METHODS

6.3.1 Site location and description

The research was conducted at the greenhouse of the Agronomy and Vegetables Department of the Cape Institute for Agricultural Training in Elsenburg, South Africa during the 2009-winter season and 2009-2010 summer season. The greenhouse had a fully automated fertigation system. The cucumber plants were placed in 20L black bags consisting of sawdust as a growth medium. The plants were irrigated via drip irrigation and plants were staked with polyethylene twines.

6.3.2 Experimental design and treatments

The experiment was set out in a randomised complete block design. The treatments included 8 various water regimes. These different water regimes were 2l/h (control), 4l/h, 6l/h, 8l/h, 10l/h, 12l/h, 14l/h, 16l/h. The plants received water five times a day, making it 10, 20, 30, 40, 50, 60, 70, 80L/H per day.

The crop *Cucumis sativa* L. variety Alladin was purchased from A. Ford & Co. (Pty) Ltd. (1 Hazelden drive Business Park Garden Pavillion, Tel: 021 – 850 0011) and the seeds were germinated by Propagating Plants Company (Klein Joostenburg farm, corner of R101 and R304, Tel. /Fax: 021 – 884 4513). This was a new high yield cucumber variety in South Africa.

The trial was in a drain-to-waste system and was conducted over 3 months. There were 8 replicates. All the treatments received the same amount of nutrients. The electrical conductivity of the nutrient solution was set at 1.65 $mS.cm^{-1}$(Combrink, 2005).

6.3.3 Plant growth measurements

All data was collected from the point the plants were planted into bags containing sawdust inside the greenhouse. All data regarding growth was collected once a week after planting. The plants height was measured with the use of a measuring tape. The leaves were counted to obtain the number of leaves for each plant. The plants vigour was rated on a scale of 1-5 where 1= least vigorous and 5 = most vigorous. 42 days after planting, the first fruit were harvested and the harvesting continued weekly for a period of four weeks. The length of the longest and shortest fruit was measured for each plant using a tape measure. Measurements were also taken for the thinnest and widest fruit. The number of fruit was also counted and divided into fruit that were marketable and non-marketable. Fruit weight was recorded using a standard scale. The rind colour of the cucumbers was also rated on a scale of 1 – 5 where 1 = least green and 5= most green.

6.3.4 Statistical analysis

Statistical analysis was attained with the use of the one-way analysis of variance (ANOVA) and the calculations were computed by using the software program STATISTICA 2012 (Stat soft Inc Tulsa,Ok, USA).

6.4 RESULTS

Plant height displayed significant differences with water quantities from weeks 1-8 (Table 15). At week 1, the plant height was superior at supplying 4l/h in comparison with other treatments. At weeks 2 and 5 irregular trends were detected in the plant height (Table 15). At weeks 3 and 4, supplying 8-12 l/h displayed superior performance in the plant height. At weeks 7-8, significant

and best results were shown in plant height at water quantities ranging from 4-16l/h compared with the control treatment.

Water quantities significantly (P≤0.001) affected the number of leaves per plant from weeks 2-8 (Table 16). Irregular results were displayed in week 2 and 3. At week 4 and 5, the highest number of leaves was reported at treatments of 12l/h and 10l/h, respectively. Generally, leaf numbers increased with increasing water levels from weeks 6-8.

The alteration of water quantities in the hydroponic system significantly affected the plant vigour at weeks 1, 2, 4, 5, 6, 7 and 8 (Table 17). At weeks 1 and 4, the more vigorous plants were found in treatments that received between 10-16l/h (Table 17). At weeks 2 and 5 good results were found at treatments involving between 6-14l/h (Table 17). At weeks 6, 7 and 8 the most vigorous plants were found at the highest water supply of 16l/h.

Results from the harvest done in the first, second and third week indicated that water quantities had a significant influence on the fruit length, fruit width, rind colour, fruit quality (marketable fruit) and weight (Tables 18 and 19). The fruit length, width, rind colour, quality and weight all displayed best results when the plants were supplied with the highest amount of water between 14-16l/h (Tables 18 and 19).

At week 3, the changes in water quantity had significant (P≤0.01; P≤0.001) influences on the fruit length, fruit thickness, rind colour, marketable fruit and weight (Table 20). The fruit length, fruit thickness, rind colour, marketable fruit and weight all displayed superior results at the treatment with the highest water supply 16l/h in comparison to the other treatments which received less water (Table 20).

Water quantities significantly affected the fruit length, fruit width, rind colour, fruit quality (marketable fruit) and weight for fruits harvested at weeks 3, 4 and 5 (Tables 20, 21 and 22). The fruit length, width, rind colour, displayed good results at 16l/h where the plants were supplied with the largest amount of water as compared with other treatments. At week 4, best results for fruit quality (marketable fruit) and weight was recorded at 10l/h (Table 21). At week 5, fruit width displayed irregular trends with different water quantities (Table 22).

6.5 DISCUSSION

Water plays a major role in plant growth, especially in cucumber fruits as about 96% of its content is water (Gebhardt et al., 1982; Haytowitz and Matthews, 1984; Rubatzky and Yamaguchi, 2000). In this study, *Cucumis sativa* L. plants exposed to various drip fertigated water quantities, displayed significant effects on plant growth (i.e. plant height, shoots, fruits, foliage and entire plant). In tables 15 to 17, and 18 to 23 it is clearly indicated that the increase in water quantities increased plant growth and yield. The cucumber size, colour and weight were all improved by increasing water supply. The increased plant growth is due to the favourable influence of water quantity on cell division, multiplication and tissue enlargement and development. At the optimum supply of water, the meristematic cell expands to the maximum size and hence, causing enlargements in different tissues such as leaves and fruits. In the treatments which were supplied with small quantities of water, the growth processes were reasonably retarded. Similar to this study, Zeng et al. (2009) showed improved growth of closely related plant species (*Cucumis melo* L.) by increasing water supply.

6.6 CONCLUSION

In conclusion, different water quantities had a greater influence on cucumber plant growth and yield. Increasing water quantity was associated with improved growth and yield. Results from this study clearly suggest the range of quantities which may provide best results for cucumber grown in the hydroponic cultures.

6.7 ACKNOWLEDGEMENTS

This study was supported by the Western Cape Department of Agriculture and Cape Peninsula University of Technology.

6.8 REFERENCES

Begg JE, Turner NC (1976). Crop water deficits. Advances in Agronomy, 28: 161-217

Bray EA (1997). Plant responses to water deficit. Trends in Plant Science Volume, 2(2): 48-54.

Cameron RWF, Harrison Murray RS, Scott MA (1999). The use of controlled water stress to manipulate growth of container grown *Rhodendron* cv. Hoppy. Journal Horticulturae Scientia Biotechnology, 74: 161-169.

Chartzoulakis K, Drosos N (1995). Water use and yield of greenhouse grown eggplant under drip irrigation. Agricultural Water Management, 28: 113-120.

Combrink NJJ (2005). Nutrient solutions and greenhouse management, Stellenbosch, South Africa, Combrink Familietrust: 34.

De Herralde F, Biel C, Savé, Morales MA, Torrecillas A, Alarcón JJ, Sánchez – Blanco MJ (1998). Effect of water and salt stresses on the growth, gas exchange and water relations in *Argyranthemum coronopifolium* plants. Plant Science, 139: 9-17.

Gebhardt SER, Cutrufelli RH, Matthews REH (1982). United States Department of Agriculture handbook, Composition of Foods: 8-9.

Haytowitz DB, Matthews REH (1984). United States Department of Agriculture handbook, Compositon of Foods, Vegetables and Vegetable Products, Raw, Processed and Prepared: 8-11.

Hopkins WG, Hüner NPA (2004). Introduction to plant physiology. New Jersey United States of America, John Wiley and Sons Incorporated: 14: 291.

Hsiao TC, Acevedo E (1974). Plant responses to water deficits, water use efficiency and drought resistance. Agricultural Meteorology, 14: 59-84.

Huber SC, Rogers HH, Mowry FL (1984). Effects of water stress on photosynthesis and carbon partitioning in Soybean (*Glycine max* [L.] Merr.) Plants grown in the field at different CO_2 levels. Plant Physiology, 76(1): 244-249.

Jamma AO, Ottman MJ (1993). Timing of the first irrigation in corn and water stress conditioning. Agronomy Journal, 85: 1159-1164.

Kumar S, Imtiyaz M, Kumar A, Singh R (2007). Response of onion (*Allium cepa* L.) to different levels of irrigation water. Agricultural Water Management, 89: 161-166.

Mao X, Liu M, Wang X, Liu C, Hou Z, Shi J (2002). Effects of deficit irrigation on yield and water use of greenhouse grown cucumber in the North China Plain. Agricultural Water Management, 61: 219-228.

Rendon – Poblete E (1980). Effect of soil water status on yield, quality and root development of several tomato genotypes. University of California, Davis, Ph.D. Dissertation: 76.

Rubatzky VE, Yamaguchi M (2000). World vegetables: Principles, production and nutritive values. Plant Growth Regulation, 30 (3): 276.

Sánchez-Blanco MJ, Rodriguez P, Morales MA, Ortuno MF, Torrecillas A (2002). Comparative growth and water relation of *Cistus albidus* and *Cistus monspeliensis* plants during water deficit conditions and recovery. Plant Science, 162: 107-113.

Sedibe MM (2003). Optimising water using efficiency for crop production. University of Stellenbosch.

Sezen SM, Yazar A, Canbolani M, Eker S, Caikel G (2005). Effect of drip management on yield and quality of field grown green beans. Agricultural Water Managment ,71(3): 243-255.

Smittle DA, Dickens WC, Stansell JR (1994). Irrigation regimes affect yield and water use by bell pepper. Journal of American Society Horticultural Science, 119: 936-939.

Van Loon CD (1981). The effect of water stress on potato growth, development and yield. American Potato Journal, 58: 51-69.

Van Loon CD (1986). Drought, a major constraint in potato production and possibilities for screening for drought resistance. Potato Research for Tomorrow: 5-16.

Westgate ME, Boyer JS (1985). Osmotic adjustment and the inhibition of leaf, root, stem and silk growth at low water potentials in maize. Planta, 164: 540-549.

Wiedenfeld RP (1995). Effects of irrigation and N fertilizer application on sugarcane yield and quality. Field Crops Research, 43: 101-108.

Yuan BZ, Nishiyama S, Kang Y (2003). Effects of different irrigation regimes on the growth and yield of drip – irrigated potato. Agricultural Water Management, 63: 153-167.

Zeng CZ, Bie ZL, Yuan BZ (2009). Determination of optimum irrigation water amount for drip – irrigated muskmelon (*Cucumis melo* L.*)* in plastic greenhouse. Agricultural Water Management, 96: 597-601.

Table 6.1: Effect of different water quantities on plant height of *Cucumus sativa* L. as measured from Week 1 to Week 8 during 2010.

	WEEKS							
Treatment	1	2	3	4	5	6	7	8
	Plant height (m)							
$L.h^{-1}$								
2	**0.08±0.00c**	**0.11±0.00bc**	**0.27±0.01ef**	**0.64±0.01bc**	**1.01±0.03bc**	**1.30±0.05d**	**1.51±0.07c**	**1.55±0.05c**
4	**0.09±0.00a**	**0.12±0.00a**	**0.28±0.01cde**	**0.63±0.01c**	**1.03±0.02abc**	**1.36±0.03bcd**	**1.71±0.04ab**	**1.86±0.05ab**
6	**0.08±0.00b**	**0.12±0.00ab**	**0.29±0.01bcd**	**0.66±0.02ab**	**1.08±0.02a**	**1.39±0.02abc**	**1.73±0.03ab**	**1.85±0.04ab**
8	**0.08±0.00bc**	**0.12±0.00ab**	**0.29±0.01ab**	**0.67±0.01ab**	**1.06±0.01a**	**1.37±0.02abcd**	**1.65±0.04b**	**1.74±0.05b**
10	**0.08±0.00bc**	**0.12±0.00a**	**0.30±0.01a**	**0.66±0.01ab**	**1.05±0.02ab**	**1.40±0.02ab**	**1.69±0.03ab**	**1.79±0.05ab**
12	**0.07±0.00d**	**0.11±0.00c**	**0.30±0.00a**	**0.67±0.01a**	**1.07±0.01a**	**1.44±0.02a**	**1.78±0.03a**	**1.88±0.06a**
14	**0.07±0.00d**	**0.11±0.00c**	**0.27±0.00fg**	**0.61±0.01cd**	**0.99±0.02c**	**1.33±0.02cd**	**1.75±0.02ab**	**1.92±0.04a**
16	**0.07±0.00d**	**0.10±0.00d**	**0.25±0.01g**	**0.59±0.01d**	**0.99±0.01c**	**1.31±0.01d**	**1.72±0.01ab**	**1.90±0.03a**
One - Way ANOVA (F-Statistic)								
Rep	19.79**	8.23***	9.14***	7.00***	3.99***	3.64***	4.61***	6.55***

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at **: $P \leq 0.01$; ***: $P \leq 0.001$

Table 6.2: Effect of different water quantities on number of leaves of *Cucumus sativa* L. as measured from Week 1 to Week 8 during 2010.

	WEEKS							
Treatment	1	2	3	4	5	6	7	8
	Number of Leaves (scale from 1-5)							
$L.h^{-1}$								
2	4.05±0.05a	**5.55±0.11a**	**8.35±0.11a**	**11.60±0.20cd**	**15.80±0.37e**	**18.00±0.37b**	**19.90±0.40c**	**15.55±0.60d**
4	4.00±0.00a	**5.05±0.05c**	**7.95±0.05c**	**11.50±0.22d**	**16.10±0.20de**	**18.45±0.34b**	**22.05±0.57b**	**18.80±0.62abc**
6	4.05±0.05a	**5.15±0.08bc**	**8.00±0.10bc**	**12.20±0.24b**	**16.95±0.25abc**	**19.80±0.34a**	**22.30±0.48b**	**18.35±0.54bc**
8	4.00±0.00a	**5.35±0.11ab**	**8.00±0.18bc**	**12.35±0.23ab**	**16.85±0.28bcd**	**19.70±0.48a**	**22.50±0.43b**	**17.75±0.48c**
10	4.00±0.00a	**5.30±0.11abc**	**7.85±0.11cd**	**12.25±0.18b**	**17.70±0.22a**	**20.15±0.39a**	**23.65±0.31a**	**18.75±0.45abc**
12	4.00±0.00a	**5.45±0.11a**	**8.30±0.11ab**	**12.90±0.19a**	**17.40±0.32ab**	**20.20±0.25a**	**24.05±0.20a**	**18.75±0.61abc**
14	4.05±0.05a	**5.15±0.08bc**	**7.90±0.12cd**	**12.10±0.24bc**	**16.65±0.27bcd**	**18.60±0.29b**	**23.80±0.26a**	**19.90±0.20a**
16	3.95±0.05a	**5.05±0.05c**	**7.60±0.15d**	**12.00±0.18bcd**	**16.60±0.31cd**	**19.65±0.36a**	**24.00±0.21a**	**19.30±0.40ab**
One - Way ANOVA (F-Statistic)								
Rep	1.0ns	**4.10*** **	**3.94*** **	**4.36*** **	**4.89*** **	**5.56*** **	**13.96*** **	**6.76*** **

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at ***: $P \leq 0.001$; ns: non-significant

Table 6.3: Effect of different water quantities on vigour of *Cucumus sativa* L. as measured from Week 1 to Week 8 during 2010.

Treatment	WEEKS 1	2	3	4	5	6	7	8
	Vigour (scale from 1-5)							
L.h^{-1}								
2	**3.35±0.17bc**	**3.60±0.17abc**	3.10±0.19a	**2.95±0.11e**	**3.10±0.19c**	**3.30±0.13b**	**2.90±0.16e**	**2.75±0.10e**
4	**3.30±0.15bc**	**3.45±0.14bc**	3.15±0.22a	**3.30±0.16de**	**3.40±0.18bc**	**3.30±0.21b**	**3.60±0.18d**	**3.60±0.20cd**
6	**3.40±0.15bc**	**3.90±0.19a**	3.55±0.25a	**3.65±0.21bcd**	**3.90±0.20a**	**3.65±0.22ab**	**3.55±0.20d**	**3.90±0.12bc**
8	**3.20±0.12c**	**3.60±0.13abc**	3.55±0.26a	**3.50±0.18cd**	**3.60±0.13ab**	**3.25±0.18b**	**3.95±0.15cd**	**3.45±0.14d**
10	**3.70±0.11ab**	**3.80±0.12ab**	3.45±0.17a	**3.95±0.20abc**	**3.70±0.15ab**	**3.90±0.18a**	**4.15±0.17bc**	**3.75±0.14cd**
12	**3.90±0.14a**	**3.85±0.13ab**	3.60±0.20a	**4.40±0.13a**	**3.75±0.18ab**	**3.85±0.18ab**	**4.55±0.15ab**	**3.65±0.18cd**
14	**3.55±0.18abc**	**3.70±0.19ab**	3.40±0.17a	**4.40±0.13a**	**4.00±0.19a**	**3.65±0.15a**	**4.30±0.15bc**	**4.30±0.13ab**
16	**3.65±0.15ab**	**3.20±0.16c**	3.40±0.15a	**4.10±0.18ab**	**3.30±0.13bc**	**4.05±0.17a**	**4.95±0.05a**	**4.45±0.11a**
One - Way ANOVA (F-Statistic)								
Rep	**2.54***	**2.21***	0.83ns	**9.78*****	**3.22****	**2.97****	**16.71*****	**13.39*****

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at *: $P \leq 0.1$; **: $P \leq 0.01$; ***: $P \leq 0{,}001$
ns: non-significant.

Table 6.4: Effect of different water quantities on fruits of *Cucumus sativa* L. as measured from Week 1 to Week 5 during 2010.

	Week 1				
Treatment	Fruit Length (In CM)	Fruit Width (In CM)	Rind colour (scale from 1-5)	Marketable fruit	Weight (In Kg)
$L.h^{-1}$					
2	**31.49±2.80c**	**16.26±1.26b**	**2.25±0.18e**	**1.45±0.15e**	**1.10±0.09cd**
4	**38.75±0.60b**	**18.43±0.28a**	**3.40±0.11d**	**1.95±0.18cde**	**1.40±0.13bc**
6	**38.17±0.61b**	**17.60±0.30ab**	**3.45±0.22d**	**1.70±0.18de**	**1.04±0.08d**
8	**39.48±0.46ab**	**17.87±0.27a**	**3.50±0.14cd**	**2.25±0.16bcd**	**1.31±0.08bcd**
10	**39.88±0.76ab**	**18.63±0.29a**	**3.75±0.10bcd**	**2.70±0.26ab**	**1.58±0.13ab**
12	**40.08±0.37ab**	**18.23±0.28a**	**3.85±0.08abc**	**2.30±0.16bc**	**1.42±0.13bc**
14	**40.08±0.61ab**	**18.34±0.19a**	**4.00±0.15ab**	**2.40±0.22abc**	**1.47±0.16ab**
16	**42.15±0.67a**	**18.60±0.19a**	**4.20±0.09a**	**2.90±0.23a**	**1.76±0.12a**
One - Way ANOVA (F-Statistic)					
Rep	**7.74*** **	**2.37***	**17.95****	**6.09*** **	**4.06*** **

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at *: $P \leq 0.1$; **: $P \leq 0.01$; ***: $P \leq 0{,}001$.

Table 6.5: Effect of different water quantities on fruits of *Cucumus sativa* L. as measured from Week 1 to Week 5 during 2010.

			Week 2		
Treatment	Fruit length (In CM)	Fruit width (In CM)	Rind colour (scale from 1-5)	Marketable fruit	Weight (In Kg)
$L.h^{-1}$					
2	33.55±0.43a	**17.49±0.94ab**	**3.20±0.21d**	**1.75±0.20c**	**1.15±0.07c**
4	34.12±0.44a	**18.05±0.17ab**	**3.35±0.13d**	**2.25±0.19bc**	**1.23±0.10bc**
6	31.07±1.68a	**15.19±1.18c**	**3.25±0.29d**	**2.20±0.24c**	**1.01±0.12c**
8	31.68±1.78a	**16.77±0.97bc**	**3.40±0.31cd**	**2.30±0.24bc**	**1.20±0.10c**
10	33.63±0.43a	**17.82±0.25ab**	**3.95±0.14abc**	**2.80±0.25ab**	**1.47±0.10ab**
12	34.38±0.57a	**17.50±0.23ab**	**3.75±0.16bcd**	**3.15±0.20a**	**1.65±0.09a**
14	34.72±0.35a	**18.18±0.22ab**	**4.15±0.13ab**	**3.10±0.18a**	**1.70±0.08a**
16	34.89±1.91a	**18.80±0.21a**	**4.35±0.25a**	**2.80±0.16ab**	**1.58±0.07a**
One - Way ANOVA (F-Statistic)					
Rep	1.48ns	**2.78****	**4.18*****	**5.62*****	**7.86*****

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at **: $P \leq 0.01$; ***: $P \leq 0{,}001$; ns: non-significant.

Table 6.6: Effect of different water quantities on fruits of *Cucumus sativa* L. as measured from Week 1 to Week 5 during 2010.

	Week 3				
Treatment	Fruit length (In CM)	Fruit thickness (In CM)	Rind colour (scale from 1-5)	Marketable fruit	Weight (In Kg)
$L.h^{-1}$					
2	**24.78±3.74c**	**12.79±1.96b**	**2.60±0.31d**	**1.00±0.23d**	**0.90±0.15d**
4	**36.47±0.54b**	**18.39±0.27a**	**3.45±0.23c**	**2.35±0.25ab**	**1.75±0.15a**
6	**38.17±0.61ab**	**17.60±0.30a**	**3.45±0.22c**	**1.70±0.18c**	**1.04±0.08cd**
8	**39.48±0.46ab**	**17.87±0.27a**	**3.50±0.14bc**	**2.25±0.16bc**	**1.31±0.08bc**
10	**39.88±0.76ab**	**18.63±0.29a**	**3.75±0.10abc**	**2.70±0.26ab**	**1.58±0.13ab**
12	**40.08±0.37ab**	**18.23±0.28a**	**3.85±0.08abc**	**2.30±0.16b**	**1.42±0.13ab**
14	**40.08±0.61ab**	**18.34±0.19a**	**4.00±0.15ab**	**2.25±0.18bc**	**1.34±0.10bc**
16	**42.15±0.67a**	**18.60±0.19a**	**4.20±0.09a**	**2.90±0.23a**	**1.76±0.12a**
One - Way ANOVA (F-Statistic)					
Rep	**14.45*** **	**7.13*** **	**7.12*** **	**7.96*** **	**6.50*** **

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at ***: $P \leq 0{,}001$.

Table 6.7: Effect of different water quantities on fruits of *Cucumus sativa* L. as measured from Week 1 to Week 5 during 2010.

	Week 4				
Treatment	Fruit Length (In CM)	Fruit thickness (In CM)	Rind colour (scale from 1-5)	Marketable fruit	Weight (In Kg)
$L.h^{-1}$					
2	**17.43±4.44c**	**8.25±2.10c**	**1.50±0.39c**	**0.40±0.15d**	**0.41±0.12d**
4	**26.98±4.57bc**	**9.84±2.05bc**	**2.15±0.46bc**	**0.65±0.18cd**	**0.59±0.13cd**
6	**19.93±4.61c**	**8.43±2.14c**	**1.65±0.42c**	**0.85±0.23bcd**	**0.63±0.14bcd**
8	**34.74±3.43ab**	**15.29±1.54a**	**3.35±0.34a**	**1.45±0.21a**	**0.97±0.14abc**
10	**37.85±3.00a**	**15.63±1.53a**	**3.45±0.36a**	**1.55±0.27a**	**1.08±0.14a**
12	**30.91±4.16ab**	**15.12±2.03a**	**3.40±0.41a**	**1.25±0.20ab**	**0.81±0.14abc**
14	**34.53±3.99ab**	**13.64±1.85ab**	**3.20±0.38ab**	**1.15±0.17abc**	**0.99±0.15ab**
16	**39.70±2.26a**	**16.21±1.30a**	**3.70±0.31a**	**1.35±0.22ab**	**0.99±0.15ab**
One - Way ANOVA (F-Statistic)					
Rep	**4.41*** **	**3.39** **	**5.23*** **	**3.87*** **	**3.00** **

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at **: $P \leq 0.01$; ***: $P \leq 0{,}001$.

Table 6.8: Effect of different water quantities on fruits of *Cucumus sativa* L. as measured from Week 1 to Week 5 during 2010.

Treatment	Fruit length (In CM)	Fruit thickness (In CM)	Week 5 Rind colour (scale from 1-5)	Marketable fruit	Weight (In Kg)
$L.h^{-1}$					
2	**41.53±0.90ab**	**19.45±0.37a**	3.60±0.15a	2.05±0.23a	1.75±0.09a
4	**33.28±4.47bc**	**15.94±1.87abc**	3.55±0.29a	1.80±0.34a	1.56±0.24a
6	**33.55±3.90bc**	**14.67±1.76bc**	3.60±0.37a	1.90±0.29a	1.35±0.23a
8	**26.65±5.06c**	**12.55±2.15c**	2.55±0.48a	1.55±0.27a	1.20±0.19a
10	**41.82±3.30ab**	**18.28±1.44ab**	3.60±0.29a	1.85±0.20a	1.72±0.20a
12	**36.53±4.23bc**	**15.41±1.80abc**	3.30±0.45a	1.85±0.33a	1.70±0.23a
14	**42.96±3.39ab**	**17.96±1.42ab**	3.75±0.31a	1.90±0.20a	1.93±0.19a
16	**48.10±0.79a**	**19.16±1.13a**	3.55±0.42a	1.95±0.29a	1.95±0.17a
One - Way ANOVA (F-Statistic)					
Rep	**3.65****	**2.37***	1.11ns	0.28ns	1.75ns

Values (Mean ± SE, n = 10) followed by dissimilar letters in a column are significantly different at *: $P \leq 0.1$; **: $P \leq 0.01$, ns: non-significant.

CHAPTER SEVEN

GENERAL DISCUSSION AND CONCLUSION

7.1 General Discussion and Conclusion

Cucumber (*Cucumis sativa* L.) is one of the most important commercial vegetable crops grown in South Africa. It is commonly grown by large scale cucumber farmers in open fields where the climatic conditions are suitable. With current scarcity of water facing South Africa and the rest of the global community, the adoption of intensified systems such as greenhouse cultivation is a viable option. Economic yields could be achieved by optimizing the quantity of fertigated water to be supplied in the greenhouse setting.

Results from this study conducted in an environmentally controlled greenhouse have shown that higher water quantities increased plant growth, improved chlorophyll content in the leaves, the rate of photosynthesis and nutrient uptake. However, lower water quantities resulted in higher accumulation of anthocyanins in roots, leaves and stems of *Cucumis sativa* L. As shown in this study, increasing water quantities resulted into significant increases in photosynthesis and chlorophyll contents in the plants. Both these parameters play a pivotal role in growth and development in plants.

Increasing water quantities also resulted in significant uptake of mineral nutrients (N, P, K, Ca, Mg, Na, S, Fe, Cu, Zn, Mn, Al and B) in plant tissues. This suggests that water had a positive effect on the amount of nutrients taken by the plants. In roots, the uptake of some nutrients was increased when exposed to low water quantities. This increase in roots was due to the fact that when the cucumber plant was exposed to low water quantities, more energy and nutrients were sent to roots to promote root growth as a compensatory mechanism to search for more water and nutrients.

Furthermore, low water levels as compared with higher water supply improved the anthocyanin content of *Cucumis sativa* L. in different organs. For example in root, leaves and stem values of anthocyanin content were all elevated in the lowest water treatment of 2l/h and decrease at the highest water supply of 16l/h. These increases in anthocyanin content of *Cucumis sativa* L. organs in this study could have an impact on the quality and tolerance to abiotic and biotic stresses.

Results from the studies have shown that supplying adequate quantities of water increased growth, and the final fruit yield of *Cucumis sativa* L. plants. Furthermore, decreased water quantities significantly lowered yield and fruit quality. The increase in growth and productivity of *Cucumis sativa* L. was due to the enhancement of other processes such as photosynthesis, chlorophyll synthesis and nutrient uptake, due to adequate supply of water.

More studies are recommended to come up with optimum quantity of water supply for hydroponic cultures.

In conclusion, it is clear that cucumber is a water-loving crop. Higher water quantities in this study resulted into improved physiological processes such as photosynthesis and nutrient uptake and hence, higher fruit yields. In water limited environments, results from this study could assist growers with achieving reasonable cucumber yields while saving water for other farm uses.

CHAPTER EIGHT

REFERENCES

8.1 REFERENCES

Acevedo, E., Hsiao, T.C., Henderson, D.W. 1971. Immediate and subsequent growth responses of maize leaves to changes in water status. Plant Physiology, 48: 631-636.

Ahmad, N., Ani, M. 2005. In Vitro mass propagation of *Cucumis sativus* L. from nodal segments. Turkey Botany Journal, 29: 237.

Alam, S.M. 1999. Nutrient uptake by plants under stress conditions. New York, Handbook of Plant and Crop Stress Marcel Dekker: 285-314.

Albert, R.S., Fiscus, E.L., Naylor, A.W. 1975. The effects of water stress on the development of the photosynthetic apparatus in greening leaves. Plant Physiology, 55: 317-321.

Alberte, R.S., Thornber, J.P. 1977. Water stress effects on the content and organization of chlorophyll in mesophyll and bundle sheath chloroplasts of maize. Plant Physiology, 59: 351-353.

Álvarez, S., Navarro, A., Banón, S., Sánchez-Blanco, M.J. 2009. Regulated deficit irrigation in potted *Dianthus* plants: Effects of severe and moderate water stress on growth and physiological responses. Scientia Horticulturae, 122: 579-585.

Arnon, D.I. 1949. Copper enzymes in isolated chloroplasts, polyphenoxidase in *Beta vulgaris*. Plant Physiology, 24: 1-15.

Ashton, F.M. 1956. Effects of a series of cycles of low and high soil water on the rate of apparent photosynthesis in sugar cane. Plant Physiology, 31: 266-274

Bajracharya, R.M., Shorma, S. 2005. Influence of drip irrigation method on performance and yields of cucumber and tomato. Kathmandu University Journal of Science, Engineering and Technology, 1(1): 1-7.

Baligar, V.C., Fageria, N.K., He, Z.L. 2001. Nutrient use efficiency in plants. Soil Science, 32: 921-950.

Barraclough, P.B. 1989. Root growth, macro-nutrient uptake dynamics and soil fertility requirements of a high-yielding winter oilseed rape crop. Plant and Soil, 119: 59-70.

Beecher, G. 2003. Overview of dietary flavonoids: Nomenclature, occurance and intake. Journal of Nutrition, 133: 3248-3254.

Begg, J.E., Turner, N.C. 1976. Crop water deficits. Advances in Agronomy, 28: 161-217.

Begun, F.A., Paul, N.K. 1993. Influence of soil moisture on growth, water use and yield of mustard. Journal of Agronomy and Crop Science, 170: 136-141.

Ben G.Y., Osmond, C.B., Sharkey T.D. 1987. Comparisons of photosynthetic responses of *Xanthium strumarium* and *Helianthus annus* to chronic and acute water stress in sun shade. Plant Physiology, 84: 476-482.

Beringer, H., Trolldenier, G. 1978. Influence of K nutrition on the response to environmental stress. Potassium research – review and trends. Proceedings of the 11th congress of the international potash institute. International Potassium Institute: 189-222.

Blanco, M.J.S., Álvarez, S., Navarro, A., Bañón S. 2008. Changes in leaf water relations, gas exchange growth and flowering quality in potted geranium plants irrigated with different water regimes. Journal of Plant Physiology, 166: 468-475.

Bodlaender, K.B.A., van de Waart, M., Marinus, J. 1986. Effects of drought on water use, photosynthesis and transpiration of potatoes. Potato Research of Tomorrow: 44-54.

Boyer, J.S. 1968. Relationships of water potential to growth of leaves. Plant Physiology, 43: 1056-1062.

Boyer, J.S. 1976. Photosynthesis at low water potentials. Philosophical transactions of the royal society of London, Biological Sciences, 273(927): 501-512.

Bradford, K.J., Hsiao, T.C. 1982. Physiological responses to moderate water stress. Encyclopedia of Plant Physiology, 12B: 264-324.

Bray, E.A. 1997. Plant responses to water deficit. Trends in Plant Science, 2(2): 48-54.

Bremner, J.M. 1965. Total Nitrogen in, method of soil analysis. Madison Wisconcin, American Society of Agronomy: 1149-1178.

Brodribb, T. 1996. Dynamics of changing intercellular CO_2 concentration (C_i) during drought and determination of minimum functional C_i. Plant Physiology, 111: 179-185.

Cabello, M.J. Castellanos, M.T., Romojaro, F., Martinez – Madrid, C., Ribas, F. 2009. Yield and quality of melon grown under different irrigation and nitrogen rates. Agricultural Water Management, 96: 866-874.

Cameron, R.W.F., Harrison Murray, R.S., Scott, M.A. 1999. The use of controlled water stress to manipulate growth of container grown *Rhodendron* cv. Hoppy. Journal Horticulturae Scientia Biotechnology, 74: 161-169.

Cannon, W.N., Roberts, B.R. 1994. Stomatal resistance and the ratio of intercellular to ambient carbon dioxide in container grown yellow poplar seedlings exposed to chronic ozone fumigation and water stress. Environmental and Experimental Botany, 35(2): 161-165.

Castellarin, S.D., Pfeiffer, A., Sivilotti, P., Degan, M., Peterlunger, E., Di Gaspero, G. 2007b. Transcriptional regulation of anthocyanin biosynthesis in ripening and induce changes in gene expression regulating flavonoid biosynthesis in grape berries. Planta, 227: 101-112.

Ceccarelli, S. 1984. Plant responses to water stress. Genetica Agraria, 38: 43-74.

Cetin, Ö., Uygon, D. 2008. The effect of drip line spacing, irriagation regimes and planting geometries of tomato on yield, irrigation, water use efficiency and net return. Agricultural Water Management, 95: 949-957.

Chalker-Scott, L. 1999. Environmental significance of anthocyanins in plant stress response. Photochemistry Photobiology, 70: 1-9.

Chartzoulakis, K., Drosos, N. 1995. Water use and yield of greenhouse grown eggplant under drip irrigation. Agricultural Water Management, 28: 113-120.

Chaves, M.M. 1991. Effects of water deficits on carbon assimilation. Journal of Experimental Botany, 42: 1-16.

Chung. I.M., Kim, J.J., Lim, J.D., Yu, C.Y., Kim, S.H., Hahn, S.S. 2005. Comparison of resveratrol, SOD activity, phenolic compounds and free amino acids in *Rehmannia glutinosa* under temperature and water stress. Environmental and Experimental Botany, 56: 44-52.

Chung, S.M., Staub, J.E. 2003. The development and evaluation of consensus chloroplast primer pairs that possess highly variable sequence regions in a diverse array of plant taxa. Theoretical Applied Genetics, 107: 757-767.

Combrink, N.J.J. 2005. Nutrient solutions and greenhouse management. Stellenbosch, South Africa, Combrink Familietrust: 34.

Cornic ,G. 2000. Drought stress inhibits photosynthesis by decreasing stomatal aperture-not by affecting ATP synthesis. Trends in Plant Science, 5: 187-188.

Cornic, G. and Briantais, J.M. 1991. Partitioning of photosynthetic electron flow between CO_2 and O_2 reduction in a C3 leaf (Phaseolus vulgaris L.) at different CO_2 concentrations and during drought stress. Planta, 183: 178-184.

Cornic, G., Fresnau, C. 2002. Photosynthetic carbon reduction and carbon oxidation cycles are the main electron sinks for photosysthem II activity during a mild drought. Annual Botany, 89: 887-894.

Davies, W.J., Zhang, J. 1987. Increased synthesis of ABA impartially dehydrated root tips and ABA transport from root to leaves. Journal of Experimental Botany, 38: 2015-2023.

Davies, W.J., Zhang, J. 1991. Root signals and the regulation of growth and development of plants in drying soil. Annual Review of Plant Physiology and Plant Molecular Biology, 42: 55-76.

Davies, W.J., Tardieu, F., Trejo, C.I. 1994. How do chemical signals work in plants that grown in drying soil? Plant Physiology, 104: 309-314.

De Herralde, F., Biel, C., Savé Morales, M.A., Torrecillas, A., Alarcón, J.J., Sánchez – Blanco, M.J. 1998. Effect of water and salt stresses on the growth, gas exchange and water relations in *Argyranthemum coronopifolium* plants. Plant Science, 139: 9-17.

Donavon, L.A., Ehleringer, J.R. 1994. Potential for selection on plants for water use efficiency as estimated by carbon isotope discrimination. American Journal of Botany, 81: 927-935.

El Nadi, A.H., Brouwer, R., Locher, J. 1969. Some responses of the root and shoot of *Vicia faba* plants to water stress. Netherlands Journal Agricultural Science, 17: 133-142.

Erlandsson, G. 1975. Rapid effects on ion and water uptake induced by changes of water potential in young wheat plants. Physiologica Plant, 35: 256-262.

Fageria, N.K., Baligar, V.C., Clark, R.B. 2002. Micronutrients in crop production. Advances in Agronomy, 77: 185-267.

Farquhar, G.D., Sharkey, T.D. 1982. Stomatal conductance and photosynthesis. Annual Review Plant Physiology, 33: 317-345.

Fertilizer society of South Africa (FSSA), 1974. Manual of soil analysis methods, South Africa Pretoria: 37.

Flexas, J., Bota, J., Loreto, F., Cornic, F., Sharkey, T.D. 2004. Diffusive and metabolic limitations to photosynthesis under drought and salinity in C_3 plants. Plant Biology, 6: 269-279.

Flexas, J., Diaz-Espejo, A., Galmés, J., Kaldenhoff, R., Medrano, H., Ribas-Carbo, M. 2007. Rapid variations of mesophyll conductance in response to changes in CO_2 concentration around leaves. Plant Cell Environment, 30: 1284-1298.

Gebhardt, S.E.R., Cutrufelli, R.H., Matthews, 1982. : United States Department of Agriculture, Handbook Composition of Foods: 8-9.

Giron, H.C. 1973. Atomic Absorption Newsletter, 12: 28.

Green, P.B. 1968. Growth physics in *Nitella*: a method for continuous in vivo analysis in extensibility based on a micro – manometer technique for turgor pressure. Plant Physiology, 43: 1169-1184.

Greenway, H. 1967. Effects of exudation on ion relationships of excised roots. Physiologia Plantarum, 20: 903-910.

Greenway, H., Klepper, B. 1969. Relation between anion transport and water flow in tomato plants. Physiologica Plant, 22: 208-219.

Greenway, H., Klepper, B., Hughes, P.G. 1969. Effects of low water potential on ion uptake and loss for excised roots. Planta (Berlin), 80: 129-141.

Guehl, J.M., Picon, C., Aussenac, G., and Gross, P. 1994. Interactive effects of elevated CO_2 and soil drought on growth and transpiration efficiency and its determinants in two European forest tree species. Tree Physiology, 14: 707-724.

Guerfel, M., Baccouri, O., Boujnah, D., Chaibi, W., Zarrouk, M. 2008. Impacts of water stress on gas exchange, water relations, chlorophyll content and leaf structure in the two main Tunisian olive (*Olea europea L.*) cultivars. Scientia Horticulture, 119: 257-262.

Harbone, J., Williams, C. 2000. Advances in flavonoid research since 1992. Phytochemistry, 55: 481-504.

Haytowitz, D.B., Matthews R.E.H. 1984. United States Department of Agriculture handbook Compositon of Foods, Vegetables and Vegetable Products, Raw, Processed, Prepared: 8-11.

Heuvelink, E., Körner, O. 2001. Parthenocarpic fruit growth reduces yield fluctuation and blossom-end-rot in sweet pepper. Annals of Botany, 88: 69-74.

Hiscox, J.D., Israelstam, G.F. 1979. A method for the extraction of chlorophyll from leaf tissue without maceration. Canadian Journal of Botany, 57: 1332-1334.

Hodek, P., Pavel, T., Marie, S. 2002. Flavonoids potent and versatile biologically active compounds interacting with cytochromes P450. Chemico-Biological Interactions, 139: 1-21.

Hoffman, G.J., Rawlins, S.L., Garber, M.J., Cullen, E.M. 1971. Water relations and growth of cotton as influenced by salinity and relative humidity. Agronomy Journal, 63: 822-826.

Hopkins, W.G., Hüner, N.P.A. 2004. Introduction to plant physiology. New Jersey United, John Wiley and Sons Incorporated, 14: 291.

Hsiao, T.C. 1973. Plant responses to water stress. A Revision Plant Physiology, 24: 519-570.

Hsiao, T.C., Acevedo, E. 1974. Plant responses to water deficits, water use efficiency and drought resistance. Agricultural Meteorology, 14: 59-84.

Hu, Y., Burucs, Z., von Tucher, S. 2006. Short-term effects of drought and salinity on mineral nutrient distribution along growing leaves of maize seedlings. Environmental and Experimental Botany, 60: 268-275.

Huber, S.C., Rogers, H.H., Mowry, F.L. 1984. Effects of water stress on photosynthesis and carbon partitioning in Soybean (*Glycine max* [L.] Merr.) plants grown in the field at different CO_2 levels. Plant Physiology, 76(1): 244-249.

Hubick, K.T., Shorter, R., Farquhar, G.D. 1988. Heritability and genotype X environment interactions of carbon discrimination and transpiration efficiency in peanut. Australian Journal of Plant Physiology, 15: 799-813.

Huluka, G., Hileman, D.R., Biswas, P.K., Lewin, K.F., Nagy, J., Hendrey, G.R. 1994. Effects of elevated CO_2 and water stress on mineral concentration of cotton. Agricultural and Forest Meteorology, 70(1-4): 141-152.

Jamma, A.O., Ottman, M.J. 1993. Timing of the first irrigation in corn and water stress conditioning. Agronomy Journal, 85: 1159-1164.

Kaiser, W.M. 1987. Effects of water deficit on photosynthetic capacity. Physiologia Plantarum, 71: 142-149.

Keck, R.W., Boyer, J.S. 1974. Chloroplast response to low leaf water potentials. Plant Physiology, 53: 474-479.

Kennedy, J.A., Matthews, M.A., Waterhouse, A.L. 2002. Effect of maturity and vine water status on grape skin and wine flavonoids. American Journal of Enology and Viticulture, 53: 268-274.

Kramer, P.J., Boyer, J.S. 1995. Water relations of plants and soils. San Diego, Academic press Incorporated.

Krause, G.H. 1988. Photoinhibition of photosynthesis. An evaluation of damaging and protective mechanisms. Physiologia Plantarum, 74: 566-574.

Kukić, J., Petrović, S., Niketić, M. 2006. Antioxidant activity of four endemic *Stachys*. Taxa Biology Pharmaceutical Bulletin, 29 (4): 725-729.

Kumar, S., Imtiyaz, M., Kumar, A., Singh, R. 2007. Response of onion (*Allium cepa L.*) to different levels of irrigation water. Agricultural Water Management, 89: 161-166.

Lawlor, D.W. 2002. Limitation to photosynthesis in water stressed leaves: stomata vs. metabolism and the role of ATP. Annual Botany, 89: 871-885.

Lawlor, D.W., Cornic, G. 2002. Photosynthetic carbon assimilation and associated metabolism in relation to water deficits in higher plants. Plant Cell and Environment, 25: 275-294.

Leopald, A.C. 1964. Plant growth and development. United States of America,McGraw–Hill Incorporated: 31-32.

Li, S., Pezeshki, S.R., Goodwin, S. 2003. Effects of soil moisture regimes on photosynthesis and growth in cattail (*Typha latifolia*). Acta Oecologica, 25: 17-22.

Lindoo, S.J., Caldwell, M.M. 1978. Ultraviolet – B radiation induced inhibition of leaf expansion and promotion of anthocyanin production. Lack of the involvement of the low irradiation phytochrome system. Plant Physiology, 61: 278-282.

Long, S.P., Humphries, S., Falkowski, P.G. 1994. Photoinhibition of photosynthesis in nature. Annual Review of Plant Physiology and Plant Molecular Biology, 45: 633-662.

Makoi, J.H.J.R., Ndakidemi, P.A. 2012. Allelopathy as protectant, defence and growth stimulants in legume cereal mixed culture systems. New Zealand Journal of Crop and HorticulturalScience.Published online: http://dx.doi.org/10.1080/01140671.2011.630737.

Makoi, J.H.J.R., Ndakidemi, P.A. 2009. Biological, ecological and agronomic significance of plant phenolic compounds in rhizosphere of the symbiotic legumes. African Journal of Biotechnology, 6(12): 1358-1368.

Makoi, J.H.J.R., Belane, A.K., Chimphango, S.B.M., Dakora, F.D. 2010. Seed flavonoids and anthocyanins as markers of enhanced plant defence in nodulated cowpea (*Vigna unguiculata* L. Walp.). Field Crops Research, 118: 21-27.

Makoi, J.H.R., Ndakidemi, P.A. 2007. Biological, ecological and agronomic significance of plant phenolic compounds in rhizosphere of the symbiotic legumes. African Journal of Biotechnology, 6(12): 1358-1368.

Mao, X., Liu, M., Wang, X., Liu, C., Hou, Z., Shi, J. 2002. Effects of deficit irrigation on yield and water use of greenhouse grown cucumber in the North China Plain. Agricultural Water Management, 61: 219-228.

Marais, J.P.J., Deavours, B., Dixon, R.A., Ferreira, D. 2006. Stereochemistry of flavonoids. The Science of Flavonoids, 1: 1-46.

Marschner, H. 1995. Mineral nutrition of higher plants. London, Academic Press.

Massacci, A., Jones, H.G. 1989. Use of simultaneous analysis of gas exchange and chlorophyll fluorescence quenching for analyzing the effects of water stress on photosynthesis in apple leaves. Trees, 4: 1-8.

Mattivi, F., Guzzon, R., Vrhovsek, U., Stefanini, M., Velasco, R. 2006. Metabolite profiling of grape: flavonols and anthocyanins. Journal of Agriculture and Food Chemistry, 54: 7692-7702.

McLaughlin, S.B., Wimmer, R. 1999. Calcium physiology terrestrial ecosystem processes. New Phytologist, 142: 373-417.

Menzel, C.M., Simpson, D.R., Dowling, A.J. 1986. Water relations in passionfruit: Effect of moisture stress on growth, flowering and nutrient uptake. Scientia Horticulturae, 29: 239-249.

Mirecki, R.M., Teramura, A.H. 1984. Effects of ultraviolet-B irradiance on soybean. Plant Physiology, 74: 450-480.

Mondal, R.K., Paul, N.K. 1992. Effect of irrigation on growth and some physiological characters of mustard (*Brassica juncea* L.). Bangladesh Journal Agricultural Research, 17: 29-36.

Moran, J.F., Becan, M., Iturbe-Ormaetyl, I., Frechilla, S., Klucas, R.V., Aparicio-Tejo, P. 1994. Drought induces oxidative stresses in pea plants. Planta, 194: 346-352.

Ndakidemi, P.A. 2006. Manipulating legume/cereal mixtures to optimize the above and below ground interactions in the traditional African cropping systems. African Journal of Biotechnology, 5(25): 2526-2533.

Ndakidemi, P.A., Dakora, F.D. 2003. Legume seed flavonoids and nitrogenous metabolites as signals and protectants in early seedling development. Functional Plant Biology, 30: 729-745.

Noctor, G., Veljovic-Jovanovic, S., Driscoll, S., Novitskaya, L., Foyer, C.H. 2002. Drought and oxidative load in the leaves of C_3 plants: a predominant role for photorespiration? Annual Botany, 89: 841-850.

O`Toole, J.C., Baldia, E.P. 1982. Water deficits and mineral uptake in rice. Crop Science, 22: 1144-1150.

Pearson, R.W. 1966. Soil environment and root development. American Social Agronomy: 95-126.

Petela, R. 2007. An approach to the exergy analysis of photosynthesis. Solar Energy, 82: 311-327.

Pezeshki, S.R.1993. Differences in patterns of photosynthetic responses to hypoxia in flood – tolerant and flood sensitive tree species. Photosynthetica, 28: 423-430.

Pezeshki, S.R. 2001. Wetland plant responses to soil flooding. Environmental Experimental Botany, 46: 299-312.

Pierce, M., Raschke, K. 1980. Correlation between loss of turgor and accumulation of abscisic acid in detached leaves. Planta (Berlin), 148: 174-182.

Pinkerton, A., Simpson, J.R. 1986. Interactions of surface drying and subsurface nutrients affecting plant growth on acidic soil profiles from an old pasture. Australian Journal Experimental Agriculture, 26: 681-689.

Ramos, S. 2007. Effects of dietary flavooids on approptotic pathways related to cancer chemoprevention. Journal of Nutritional Biochemistry, 18(7): 427-442.

Rendon – Poblete, E. 1980. Effect of soil water status on yield, quality and root development of several tomato genotypes. University of California, Davis, Ph.D. Dissertation: 76.

Richards, L.A., Wadleigh, C.H. 1952. Soil water and plant growth. Soil water and plant growth. Agronomy: 73-251.

Robinson, J.C., Alberts, A.J. 1986. Growth and yield response of banana (Cultivar `Williams`) to drip irrigation under drought and normal rainfall conditions in the subtropics. Scientia Horticulturae, 30: 187-202.

Rubatzky, V.E., Yamaguchi, M. 2000. World vegetables: Principles, production and nutritive values. Plant Growth Regulation, 30(3): 276

Samarah, N., Mullen, R., Cianzio, S. 2004. Size distribution and mineral nutrients of soybean seeds in response to drought stress. Journal of Plant Nutrition, 27: 815-835.

Sánchez-Blanco, M.J., Rodriguez, P., Morales, M.A., Ortuno, M.F., Torrecillas, A. 2002. Comparative growth and water relation of Cistus albidus and Cistus monspeliensis plants during water deficit conditions and recovery. Plant Science, 162: 107-113.

Schapendonk, A.H.C.M., Spitters, C.J.T., Groot, P.J. 1989. Effects of water stress on photosynthesis and chlorophyll fluorescence of five potato cultivars. Potato Research, 32: 17-32.

Scherer, H.W. 2001. Sulphur in crop production. European Journal Agronomy, 14: 81-111.

Schneider, G.W., Childers, N.F. 1941. Influence of soil moisture on photosynthesis, respiration and transpiration of apple leaves. Plant Physiology, 16: 565-583.

Sedibe, M.M. 2003. Optimising water using efficiency for crop production. University of Stellenbosch. Ph.D. Dissertation

Sezen, S.M., Yazar, A., Canbolani, M., Eker, S., Caikel, G. 2005. Effect of drip management on yield and quality of field grown green beans. Agricultural Water Management, 71(3): 243-255.

Shaw, N., Cantliffe, N., Rodriguez, J., Taylor, S., Spencer, D. 2000. Beit Alpha cucumber, An exciting new greenhouse crop. Proceedings of the Florida State Horticultural Society, 113: 247-253.

Sherwin, H.W., Farrant, J.M. 1998. Protection mechanisms against excess light in the resurrection plants Craterostigma wilmsii and Xerophyta viscose. Plant Growth Regulation, 24: 203-210.

Shetty, N.V., T.C. Wehner, 1998. Evaluation of oriental trellis cucumbers for production in North Carolina. HortScience, 33(5): 891-896.

Shock, C.C. 2006. Drip irrigation: an introduction. Oregon State University Extension Service Sustainable Agriculture Techniques.

Silva, E.N., Ribeiro, R.V., Ferreira-Silva, S.L., Viégas, R.A., Silveira, J.A.G. 2010. Comparative effects of salinity and water stress on photosynthesis, water relations and growth of *Jatropha curcas* plants. Journal of Arid Environments, 74: 1130-1137.

Smika, D., Haas, H., Power, W. 1965. Effects of moisture and nitrogen fertilizer on growth and water use by native grass. Agronomy Journal, 57: 483-486.

Smith, S.D., Osmond, C.B. 1987. Stem photosynthesis in a desert ephemeral, *Eriogonum inflatum*. Oceologia, 72: 533-541.

Smittle, D.A., Dickens, W.C. Stansell, J.R. 1994. Irrigation regimes affect yield and water use by bell pepper. Journal of American Society Horticultural Science, 119: 936-939.

Souza, R.P., Machado, E.C., Silva, J.A.B., Lagôa, A.M.M.A., Silveira, J.A.G. 2003. Photosynthetic gas exchange, chlorophyll fluorescence and some associated metabolic changes in cowpea (*Vigna unguiculata*) during water stress and recovery. Environmental and Experimental Botany, 51: 45-56.

Steudle, E. 1995. Trees under tension. Nature, 378: 663-664.

Steudle, E., Peterson, C.A. 1998. How does water get through roots? Journal Experimental Botany, 49: 775-788.

Synge, R.L.M. 1975. Interactions of polyphenols with proteins in plants and plant products. Qualitas Plantarum-Plant Foods for Human Nutrition, 24: 337-350.

Tanguilig, V.C., Yambao, E.B., O`Toole, J.C., De Datta, S.K. 1987. Water stress on leaf elongation, leaf water potential, transpiration, and nutrient uptake of rice, maize and soybean. Plant and Soil, 103: 155-168.

Thornber, J.P. 1975. Chlorophyll proteins: light harvesting and reaction center components of plants. Annual Review Plant Physiology, 26: 127-158.

Tyree, M.T. 1997. The cohesion-tension theory of sap ascent: current controversies. Journal of Experimental Botany, 48(315): 1753-1765.

Van Loon, C.D. 1981. The effect of water stress on potato growth, development and yield. American Potato Journal, 58: 51-69.

Viets Jr., F.G. 1972. Water deficits and nutrient availability.New York, Academic press, Plant Responses and Control of Water Balance: 217-240.

Wardlaw, I.F. 1967. The effect of water stress on translocation in relation to photosynthesis and growth. Effect during grain development in wheat. Australian Journal biological Sciences, 20: 25-39.

Westgate, M.E., Boyer, J.S. 1985. Osmotic adjustment and the inhibition of leaf, root, stem and silk growth at low water potentials in maize. Planta, 164: 540-549.

Wettstein-Westersheim, W., Minelli, H. 1962. Breeding intersectional Populus hybrids. Allgemeine Forstzeitung: 73-2.

Wiedenfeld, R.P. 1995. Effects of irrigation and N fertilizer application on sugarcane yield and quality. Field Crops Research, 43: 101-108.

Wingler, A., Quick, W.P., Bungard, R.A., Bailey, K.J., Lea, P.J., Leegood, R.C. 1999. The role of photorespiration during drought stress: an analysis utilizing barley mutants with reduced activities of photorespiratory enzymes. Plant Cell Environment, 22: 361-373.

Winkel, B.S.J. 2006. Biosynthesis of flavonoids. The Science of Flavonoids, 3: 71.

Yambao, E.B., O`Toole, J.C. 1984. Effects of nitrogen nutrition and root medium water potential on growth, nitrogen uptake and osmotic adjustment of rice. Physiologia Plantarum, 60: 507-515.

Younis, M.E., El – Shahaby, O.A., Abo – Hamed, S.A., Ibrahim, A.H. 2000. Effects of water stress on growth, pigments and $^{14}CO_2$ assimilation in three sorghum cultivars. Agronomy Crop Science, 185(2): 73-82.

Yuan, B.Z., Nishiyama, S., Kang, Y. 2003. Effects of different irrigation regimes on the growth and yield of drip – irrigated potato. Agricultural Water Management, 63: 153-167

Zayed, M.A., Zeid, I.M. 1997. Effect of water and salt stresses on growth, chlorophyll, mineral ions and organic solutes contents, and enzymes activity in mung bean seedlings. Biologia Plantarum, 40(3): 351-356.

Zeng, C.Z., Bie, Z.L., Yuan, B.Z. 2009. Determination of optimum irrigation water amount for drip – irrigated muskmelon (*Cucumis melo* L.*)* in plastic greenhouse. Agricultural Water Management, 96: 597-601.

Zhang, J., Davies, W.J. 1989. Abscisic acid produced in dehydrating roots may enable the plant to measure the water status of the soil. Plant Cell Environment, 12: 73-81.