UNIVERSITI PUTRA MALAYSIA

EFFECTS OF NUTRIENT DEFICITS ON GROWTH, PHYSIO-BIOCHEMICAL CHANGES, AND YIELD OF CHILLI (Capsicum annuum L.) GROWN IN SOILLESS CULTURE

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By

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October 2013

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Chilli (*Capsicum annuum* L.) is one of the most important vegetable crops commonly grown in soilless culture. It is widely consumed in Malaysia. Limited fresh water resources and fluctuating fertilizer prices, as well as excessive fertigation used by local growers, have led to higher costs and also wastage in water and fertilizer use. Deficit fertigation (DF) and fertigation frequency are irrigation strategies that imposed plants to nutrient deficit, which can improve fertigation use efficiency (FUE) without significant reduction in yield. Therefore, in the present study, the effects of different levels of DF and fertigation frequency on yield, growth, physiological and biochemical responses of chilli plants under soilless culture was evaluated and compared with the standard local grower's practice (control). Plants subjected to control employing fertigation practice as recommended by the Department of Agriculture, Malaysia. Deficit fertigation (100, 75, 50 and 30% ET_c) led to reduce in plant growth, dry matter partitioning into plant parts, total dry mass, photosynthetic rate, stomatal conductance, fresh fruit yield and FUE compared to control. In addition, different fertigation frequencies viz daily fertigation, one, two and three day fertigation intervals have shown significantly reduced plant growth, decreased photosynthetic rate, stomatal conductance, relative chlorophyll content and resulted in reduced fresh fruit yield. However, FUE was higher in fertigation frequency treatments than in the control.

Deficit fertigation (100, 75 and 50% ET_c) corresponding to two day fertigation intervals resulted in decreased substrate moisture content (SMC), plant growth, photosynthetic rate, stomatal conductance and relative chlorophyll content. The nutrient contents in the leaves as well as P, Ca and Mg were decreased in DF compared to control at the fruit ripening stage. Antioxidant enzymes such as catalase (CAT), ascorbate peroxidase (APX), guaiacol peroxidase (GPX) and proline significantly increased in DF compared to control, but decreased progressively by growth stages. Fresh fruit yield decreased in DF compared to the control, but FUE

values in 100% ET_c with two day fertigation intervals were higher than in the control but no significant difference with 100% ET_c daily fertigation and 75% ET_c with two day fertigation intervals.

An attempt has been made to improve yield and increase FUE by increasing the levels of fertigation and use of dual-K_c. Result demonstrated that there were slight reduction in plant growth and total dry mass under 200% ET_c and dual-K_c compared to control presumably attributed to the higher photosynthetic rate and stomatal conductance. Plants grown in 200% ET_c and dual-K_c reduced 24% of fresh fruit yield and saved 29% of the amount of nutrient solution applied compared to control.

However, plants supplied with 200% ET_c dual-K_c employing six times fertigation scheduling has shown improved root growth, no significant difference in the total leaf area and dry matter partitioning to the plant parts with the control. The photosynthetic rate, stomatal conductance and leaf water potential on 15:00 h were enhanced in six fertigation scheduling compared to control. Six times fertigation scheduling improved FUE value and saved 35% of nutrient solution compared to control as well as no significant difference in ripe fresh fruit yield with the control. Therefore, this fertigation strategy could be the best water and nutrients saving strategy of chilli grown in soilless culture.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KESAN NUTRIEN DEFISIT TERHADAP TUMBESARAN, PERUBAHAN FISIO-BIOKIMIA, DAN HASIL CILI (*Capsicum annuum* L.) YANG DITANAM DALAM KULTUR TANPA TANAH

Oleh

A'FIFAH BINTI ABD RAZAK

Oktober, 2013

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Cili (Capsicum annuum L.) adalah salah satu daripada tanaman sayur-sayuran yang paling penting yang biasanya ditanam dalam kultur tanpa tanah. Ia digunakan secara meluas di Malaysia. Sumber air segar yang terhad, harga baja yang tidak menentu dan fertigasi yang berlebihan oleh penanam tempatan telah membawa kepada kos yang tinggi dan juga pembaziran dalam penggunaan air dan baja. Defisit fertigasi (DF) dan kekerapan fertigasi adalah strategi pengairan yang mana tumbuhan didedahkan dengan defisit nutrien, yang boleh meningkatkan penggunaan kecekapan fertigasi (FUE) tanpa pengurangan hasil yang sangat ketara. Oleh itu, dalam kajian ini, kesan tahap DF yang berbeza dan kekerapan fertigasi pada pertumbuhan, tindak balas fisiologi dan biokimia cili yang ditanam dalam kultur tanpa tanah dibandingkan dengan amalan penanam tempatan piawai (kawalan). Tumbuhan tertakluk kepada kawalan menggunakan amalan fertigasi seperti yang disyorkan oleh Jabatan Pertanian, Malaysia. Defisit fertigasi (100, 75, 50 dan 30% ET_c) menunjukkan pertumbuhan tumbuhan, pembahagian bahan kering ke dalam bahagian-bahagian tumbuhan, jumlah jisim kering, kadar fotosintesis, stomata konduktans, hasil buah-buahan segar dan FUE berkurangan berbanding dengan kawalan. Kekerapan fertigasi yang berbeza iaitu fertigasi harian, satu, dua dan tiga hari selang fertigasi telah menunjukkan pertumbuhan yang berkurangan, penurunan kadar fotosintesis, stomata konduktans, kandungan klorofil relatif dan pengurangan hasil buah-buahan segar. Walau bagaimanapun, FUE adalah lebih tinggi pada kekerapan fertigasi daripada dalam kawalan.

Defisit fertigasi (100, 75 dan 50% ET_c) dengan dua hari selang fertigasi menyebabkan pengurangan dalam kelembapan dalam substrat (SMC), pertumbuhan tumbuhan, kadar fotosintesis, stomata konduktans dan kandungan klorofil relatif Kandungan nutrien dalam daun seperti P, Ca dan Mg telah menurun dengan DF berbanding dengan kawalan pada peringkat buah-buahan masak. Enzim antioksidan seperti katalase (CAT), askorbat peroksidase (APX), guaiacol peroksidase (GPX) dan proline meningkatkan dengan ketara dengan DF berbanding kawalan, tetapi menurun berperingkat mengikut peringkat pertumbuhan. Hasil buah-buahan segar menurun di dalam DF berbanding dengan kawalan, tetapi nilai-nilai FUE dalam 100% ETc selang dua hari fertigasi adalah lebih tinggi daripada kawalan tetapi ia

tiada perbezaan yang signifikan dengan 100% ET_c fertigasi harian dan 75% ET_c selang dua hari fertigasi.

Satu percubaan telah dibuat untuk meningkatkan hasil dan nilai FUE dengan meningkatkan tahap fertigasi dan penggunaan dwi-K_c. Keputusan menunjukkan bahawa terdapat sedikit pengurangan dalam pertumbuhan tumbuhan dan jisim kering dengan 200 % ET_c dan dwi-K_c berbanding dengan kawalan mungkin disebabkan oleh kadar fotosintesis dan stomata konduktans yang tinggi. Sebanyak 24% daripada hasil buah-buahan segar berkurangan dan 29% daripada jumlah nutrien yang dapat dijimatkan dengan 200% ET_c dan dwi-K_c berbanding kawalan.

Tumbuhan yang dibekalkan dengan 200% ET_c dan dwi-K_c menggunakan enam kali penjadualan fertigasi telah menunjukkan peningkatan pertumbuhan akar, tiada sebarang perbezaan yang signifikan dengan kawalan dalam jumlah keluasan daun dan pembahagian bahan kering ke bahagian-bahagian. Kadar fotosintesis, stomata konduktans dan potensi air daun pada jam 15:00 telah meningkat dalam enam kali penjadualan fertigasi berbanding kawalan. Di samping itu, enam kali penjadualan fertigasi telah meningkatkan nilai FUE dan menjimatkan 35% daripada jumlah nutrien berbanding dengan kawalan serta tiada perbezaan yang signifikan dalam hasil buah-buahan segar masak dengan kawalan. Oleh itu, strategi fertigasi ini boleh menjadi strategi terbaik untuk penjimatan air dan baja untuk tanaman cili yang ditanam dalam kultur tanpa tanah .

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APPROVAL

I certify that an Examination Committee has met on 11 October 2013 to conduct the final examination of A'fifah Bt Abd. Razak on his thesis entitled "Effects of nutrient deficits on growth, physio-biochemical changes and yield of chilli (*Capsicum annuum* L.) grown in soilless culture" in accordance with the universities and University College Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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This is to confirm that:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

%	Percentage
<	Less Than
=	Equal to
>	Greater than
≤	Less than and equal to
*	Significantly different at $P \leq 0.05$
AA	Ascorbic Acid
AAS	Atomic Absorption spectroscopy
ABA	Abscisic Acid
ANOVA	Analysis of Variance
APX	Ascorbate Peroxidase
AQUASTAT	FAO's global information system of water and agriculture
BER	Blossom End Rot
Ca	Calcium
CAT	Catalase
CEC	Cation Exchange Capacity
Cl	Chloride
cm	Centimetre
cm^2	Centimetre Square
CO_2	Carbon Dioxide
CV	Coefficient Variation
cv.	Cultivar
DAT	Day after transplanting
DF	Deficit Fertigation
DF	Degree of Freedom
DI	Deficit Irrigation
dSm^{-1}	Desimeter Per Second
DMRT	Duncan’s Multiple Range Test
DOA	Department of Agriculture
Dual-K_c	Dual Crop Coefficient
E	Evaporation
€	Extinction Coefficient
EDTA	Ethylenediaminetetraacetic Acid
EFB	Empty Fruit Bunches
EC	Electrical Conductivity
EC	Enzyme Commission
E_s	Soil Evaporation
ET	Evapotranspiration
ET_o	Reference Evapotranspiration
ET_c	Crop Evapotranspiration
E_{pan}	Class A Pan Evaporation
et al.,	And Friends
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistical Database
FUE	Fertigation Use Efficiency
F_m	Maximal Fluorescence

F_o	Minimal Fluorescence
F_v/F_m	Quantum Yield of PSII
FW	Fresh Weight
FWC	Fresh Weight Content
g	Gram
GPX	Guaiacol Peroxidase
GR	Glutathione Reductase
g/mol	Gram Per Mole
H	mean maximum plant height during the period of calculation (initial,development, mid season or late season)[m]
H_2O_2	Hydrogen Peroxide
ha	Hectare
h	Hour
IUE	Irrigation use efficiency
K	Potassium
K_c	Crop Coefficient
K_{cb}	Basal coefficient
$K_{c\ max}$	Maximum value of Kc following irrigation
K_e	Soil evaporation coefficient
K_p	Pan Coefficient
KPa	Kilo Pascal
K_r	Dimensionless evaporation reduction coefficient dependent on the cumulative depth of water depleted(evaporated) from the top soil
kg	Kilogram
km^3	Kilometre Per Qubic
L	Litre
LAI	Leaf Area Index
L day^{-1}	Litre per day
LSD	Least Significant Difference
LWP	Leaf Water Potential
M	Mole
MDA	Malondialdehyde
Mg	Magnesium
min	Minute
mM	Milimole
m	Metre
µg	Microgram
ml	Mililitre
µl	Microlitre
mm	Milimetre
μM^{-1}	Micro per Molar
µmol	Micromole
mmol	Milimole
MPa	Mega Pascal
m/s	Meter Per Second
N	Nitrogen
n	number of observation
Na	Natrium

No.	Number
ns	Not Significant
°C	Degree Celcius
O_2	Oxygen
O_2^-	Superoxide
$O^1{}_2$	Singlet Oxygen
OH	Hydroxyl
OM	Organic Matter
P	Probability
pH	Measurement of Acidity/Alkalinity
pm	Evening
POX	Peroxidase
PPFD	Photosynthethic photon flux density
ProT2	Specific Proline Transporter
PSII	Photosystem II
P5C	Pyrroline-5-carboxylatem
P5CS	P5C synthetase
P5CR	P5C reductase
Q_A	Quinine acceptor
RCBD	Randomized Complete Block Design
RH	Relative Humidity
RHmin	Minimal Relative Humidity
RO	Alkoxyl Radical
ROS	Reactive Oxygen Species
rpm	Rotation Per Minute
RuBP	Ribulose-1,5-biphosphate
Rubisco	Ribulose-1,5-biphosphate carboxylase oxygenase
RWC	Relative Water Content
SAS	Statistical Analysis System
SLA	Specific Leaf Areaa
Single-K_c	Single Crop Coefficient
SMC	Substrate Moisture Content
SOD	Superoxide Dismutase
T	Transpiration
T_p	Transpiration
U	Windspeed
Var	Variety
v:v	Volume per Volume
Wm^{-2}	Watts per Meter Square
w/v	Weight per Volume

CHAPTER 1

INTRODUCTION

Vegetables are the fourth largest of crops that contribute significantly to the agriculture industry in Malaysia, covering an area of about 40,980 ha with a total annual production of 534,370 tonnes in 2010. Chilli (*Capsicum annuum* L.) is one of the most important vegetables in Malaysia. The demand for this hot and pungent fruit vegetable is growing at the rate of 13.8% per year. In 2009 Malaysia had 2,594 ha of land under chilli cultivation, which increased to 2,993 ha in 2011. In 2011, production of chilli was 32,780 tonnes which was 2,559 tonnes higher than in 2010 (Anonymous, 2011).

Recently, chilli is commercially grown in soilless culture under protected structures or rain shelters. The widespread adoption of the cultivation system is to create a favourable environment for crop growth, sustain yields under certainty due to weather, pests and diseases, and assure continuous supply of fresh vegetables throughout the year (Ismail, 2000). Soilless culture is a growing system that has been used widely in vegetable production in Malaysia. Winsor and Baudoin (1992) reported that soilless culture offers a valuable alternative compared to crop cultivation in soil and has been widely adopted to produce vegetables in the greenhouse all over the world. Development of suitable substrates for soilless cultivation could avoid crop production problems such as soilborne pests and diseases, soil salinity, and limitations of water and other factors. This growing system was reported to produce higher yields and quality of vegetables compared to soil cultivation (Varis and Altay, 1992; Abak et al., 1994; Alan et al., 1994).

Freshwater is an absolute essential input for all agricultural activities. Water requirement varies significantly between different agricultural activities and climatic regions. In 2000, water withdrawal in the agriculture sector in Malaysia was about 5.6 km^3 (FAOSTAT, 2006). Water and fertilizers are crucial inputs in a soilless culture system. This system is operated with irrigation that supply water and nutrients at various concentrations and is called fertigation (Leith and Oki, 2008). Growers need to supply both inputs to the plants through the fertigation system to make sure plants are provided with essential elements (Ismail, 2000). In order to sustain better crop performance and yield, plants need an appropriate supply of macro and micro-nutrients. Fertilizer is well known as the highest variable cost item in crop production budget (Anonymous, 2009). However, as fresh water supply becomes limited and global fertilizer prices increase, it creates problems to the growers and affects chilli production. Molden (2007) claimed that to produce food on a global scale over the next 50 years, there was sufficient water resources but only if water for agriculture is better managed. The Malaysia government aids growers by giving incentives in the form of fertilizer subsidy, but this does not increase the fertilizer use efficiency. Therefore, it is necessary to take necessary initiatives to improve on fertilizer use efficiency.

Besides the fluctuation in fertilizer prices and limited water supply, there is another problem that needs to be overcome which is the poor management of fertilizer and water by growers There is a tendency by growers to over-supply nutrient solutions to the plants. The over-supply of nutrient solution includes fertilizers and water. This results in increased cost of production and non profitable.

In order to address these problems, there is a need to find management approaches that promote efficient use of both water and nutrients. Postel (1998) suggested that an effective water management strategy should be identified and adopted under limited water supply. Deficit irrigation (DI) is one of the water saving strategies that involves irrigating the entire root zone with less than evapotranspiration (Kang and Zhang, 2004; Dorji et al., 2005). Moreover, DI increases irrigation efficiency, reduces cost of irrigation and consumption of water (English, 1990). Although a slight decrease in yield may be obtained, but the quality of the yield tends to be equal or much better than maximum irrigation (Marouelli and Silva, 2007; Spreer et al., 2007; Cui et al., 2008; Hueso and Cuevas, 2008). Studies on potato plants have shown that DI reduces 37% of water use without hampering the yield (Liu et al., 2006).

Water and fertilizer can be reduced by irrigation/fertigation scheduling. Fertigation scheduling is an irrigation program that usually depends on the frequency of irrigation and delivering only the amount of water and nutrients required by plants. It is managed by many intricate factors, but the major role is the climatic factor. Hence, it is crucial to develop fertigation scheduling for specific environments. Several studies were carried out in the past on the development and assessment of irrigation scheduling techniques under a wide range of irrigation systems and management, soil, climate and crop conditions (Hagan and Laborde, 1964; Jensen et al., 1970; Imtiyaz and Shiromani, 1990; Wanjura et al., 1990; Imtiyaz et al., 1992; Steele et al., 1997). Irrigation frequency could be applied through cyclic irrigation by applying the daily water allotment in a series of cycles comprised of an irrigation and a resting interval which is aimed to decrease the irrigation frequency (Karam, 1993). However, frequent irrigation applied to the crops is to reduce water stress and achieve optimum production and high quality (Sezen et al., 2010). Results of previous studies have demonstrated that increased interval of irrigation improved irrigation use efficiency (IUE) by 25 to 38% (Fare et al., 1993; Lamack and Niemiera, 1993; Tyler et al., 1996). It was also reported that superior fruits and higher IUE were obtained in cucumber plants subjected to frequent irrigation (Ertek et al., 2006). The higher irrigation frequency of water in a day resulted in better growth, higher photosynthetic rate, higher stomatal conductance, increased IUE and lower substrate temperatures in pine bark grown in containers (Warren and Bilderback, 2004).

Improved water and nutrient management can also be achieved by applying water based on the crops water requirement. It is a step in the right direction that can reduce water use while maintaining profitable production. This can be achieved using the principle of crop evapotranspiration (ET_c). To determine water use of a crop there is a need to know the crop coefficient which helps determine the water requirements of the crop at every stage of growth and environmental factors. In the crop coefficient approach, the crop evapotranspiration (ET_c) is calculated by multiplying the reference crop evapotranspiration, (ET_o) by the crop coefficient, (K_c). ET_o represents an index of climatic demand and ET_c is determined by crop type, growth stage and cultural practices. Crop evapotranspiration can be calculated from ET_o if the K_c is known for a given crop. Crop coefficient for the same crop may vary from place to place based on climate and soil evaporation (Kang et al., 2003).

Many studies have been conducted on the effect of DI using ET on growth, physiological and yield with varieties of plant under field and soil grown condition in other countries as well as studies conducted by Costa and Gianquinto (2002) on bell pepper grown in soil under lysimeter, Chartzoulaski and Doros (1997) on pepper grown in unheated glasshouse, Gonzalez-Dugo et al. (2007) on pepper grown in field and Zegbe-Dominguez et al. (2003) on tomato grown in glasshouse. However, application of deficit fertigation and fertigation frequency based on ET_c to chilli plants grown under soilless culture systems in Malaysia are relatively unknown. Therefore, an understanding of the physiological, biochemical responses of plants under water and nutrient deficit, based on ET_c may allow growers not only to manage water and nutrients wisely but also enable them to save water and fertilizer costs. The key issue is that this approach can bring profit to growers even with slight reductions in the yield. Therefore, the present study was undertaken with the following objectives:

1. To characterize the effects of deficit fertigation on plant growth performance and physiological responses of chilli.

2. To examine the effects of fertigation frequency on growth, physiological response and plant nutrient content of chilli.

3. To understand the mechanism of water and nutrient deficit on chilli growth performance and yield.

4. To determine the optimum water and nutrient requirement and crop coefficient of chilli.

5. To determine the best water and nutrient saving strategy that is applicable to growers.

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