UNIVERSITI PUTRA MALAYSIA

MODELING WATER AND FERTILIZER USE IN WICK IRRIGATION SYSTEM FOR SMALLHOLDER GREENHOUSE CROP PRODUCTION

JAVED SHAHEEN

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By

JAVED SHAHEEN

Thesis Submitted to the School of Graduate Studies, University Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

June 2017

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DEDICATIONS

This dissertation dedicated to every individual of my family. Especially my loving and caring parents “My Beloved Father Dr. Muhammad Javed” and “My Dearest Mother Sabra Javed” who always encouraged me in every step of my life. It is also dedicated to My Love and Life My Son “Ertugrul Roonjho” and also to My Sweetheart my Husband “Abdul Rehman Roonjho.”

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in Fulfilment of the Requirement for the Degree of Master of Science.

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June 2017

Chairmen: **Md. Rowshon Kamal, PhD**
Faculty: **Engineering**

Water shortage has become the crucial issue of the current world, and it is going to be harder day by day to fulfill the food requirements of the increasing world population with the available fresh water resources using traditional irrigation systems. Therefore, there is urgent need to develop and adopt efficient irrigation methods and proper irrigation management strategies. No doubt among micro irrigation systems, drip irrigation saves a substantial amount of water and labor, increases yields, and often also improves the quality of the produce. However, the higher investment and energy cost limit the development of the low-cost irrigation system for subsistence farmers. There has been immense interest in developing new micro-irrigation systems, and wick irrigation system as promising irrigation methods to address this issue. This study, by conducting laboratory experiments, compared and confirmed hydraulic characteristics and performance of cotton-bonded non-woven material against local materials. The performance of hanging and buried wick was compared in the laboratory and glasshouse as well. Factors, such as water level inside PVC pipe, wick length inside PVC pipe, initial volumetric water contents and pot size, related to discharge variation of the wick emitter were evaluated in the laboratory. The relationship was investigated among crop water use (ET), pot size and water level in the glasshouse. In this study, the wick emitter discharge equation was developed for both hanging and buried wick. Moreover, the wick irrigation design was developed using water circulating pump, hose pipes and PVC pipes for glasshouse to avoid algae growth and evaporation. Algae growth was observed visually, and water loss was measured before and after algae growth to evaluate the effects of algae growth on the discharge of buried wick. An experiment was carried out for tomato crop to simulate water distribution and wetting pattern using HYDRUS 2D/3D. Two water levels inside the pipe, three types of pots by size and "peatgrow" as growing media were used to develop the proper water application strategies and irrigation efficacy. Soil moisture contents were also measured. Crop nutrients management was evaluated by measuring EC and pH at a different stage of the crop using EC and pH meters, and the amount of

nutrients (N, P, K, Mg, Na and Ca) was determined in leachate. The results from this study showed and proved that cotton-bonded non-woven wick material has better capillarity action, maximum capillary height and water holding capacity than local materials. The results also showed the effects of water level inside the pipe, wick length inside the pipe, pot size, ET and initial volumetric water contents on the discharge of wick irrigation system. Factors related to the wick emitter discharge used to develop equations for compensating wick emitter discharge by replacing the pressure head of a drip emitter with controlling factors of the wicking emitter. The measured water volume was close to the simulated water using wick emitter discharge equation. The results of collected ET using different methods were in order $ET_{WBE} > ET_{gvi} > ET_{CROPWAT} > ET_{gauge}$. Algae was observed at the end of the 3rd month with 6% decreasing effects on the discharge of buried wick. Results from this study revealed that the tomato plant growth showed insignificant differences when fresh water was used at two discharge levels. In contrast, the tomato plants growth showed differences among the pot size, in small pots roots were exceeded out from the bottom of the pot. The results obtained for EC and pH showed significant difference based on the age of the plant. The leachate was observed and the results of nutrients determination in leachate revealed the highest amount of P followed by Ca, Mg, Na, K and N. The results of simulation of water movement using HYDRUS 2D/3D disclosed the water movement of wick irrigation system in a container planted with tomatoes. The findings from this study suggested opportunities to improve an effective Capillary Wick Irrigation System (CWIS) for smallholder greenhouse production.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains.

PEMODELAN PENGGUNAAN AIR DAN BAJA DALAM SISTEM PENGAIRAN SUMBU UNTUK PENGUSAHA KECIL PENGELUARAN TANAMAN RUMAHKACA

Oleh

JAVED SHAHEEN

Jun 2017

Pengerusi: **Md. Rowshon Kamal, PhD**
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Kekurangan air menjadi isu penting dalam dunia sekarang, dan ia akan menjadi lebih teruk lagi hari demi hari bagi memenuhi keperluan makanan penduduk dunia yang semakin meningkat disebabkan oleh sumber air tawar yang boleh didapati dengan menggunakan sistem pengairan tradisional. Oleh itu, terdapat keperluan segera untuk membangun dan mengamalkan kaedah pengairan yang cekap dan strategi pengurusan pengairan yang betul. Tiada keraguan pada sistem pengairan mikro, pengairan titisan menjimatkan sejumlah besar air dan tenaga kerja, meningkatkan hasil, dan sering juga meningkatkan kualiti hasil. Walau bagaimanapun, pelaburan dan kos tenaga yang lebih tinggi menghadkan pembangunan kos rendah sistem pengairan bagi sara diri petani. Terdapat minat yang besar dalam membangunkan sistem pengairan mikro baru dan pengairan sistem pengairan sebagai kaedah pengairan yang dijanjikan untuk menangani isu ini. Kajian ini, dengan menjalankan ujikaji makmal, dibandingkan dan mengesahkan ciri-ciri hidraulik dan prestasi bahan kapas-terikat bukan tenunan terhadap bahan-bahan tempatan. Prestasi sumbu gantung dan ditanam telah dibandingkan di makmal dan rumah kaca juga. Faktor-faktor, seperti tahap air di dalam paip PVC, panjang sumbu dalam paip PVC, kandungan air isipadu awal dan saiz periuk, yang berkaitan dengan perbezaan pelepasan pemancar sumbu telah dinilai di dalam makmal. Hubungan itu disiasat antara penggunaan air tanaman (ET), saiz periuk dan paras air di dalam rumah kaca.

Dalam kajian ini, persamaan pelepasan sumbu pemancar telah dibangunkan untuk kedua-dua sumbu tergantung dan yang ditanam. Selain itu, reka bentuk pengairan sumbu telah dibangunkan menggunakan air pam edar, paip hos dan paip PVC untuk rumah kaca bagi mengelakkan pertumbuhan alga dan penyejatan. Pertumbuhan alga diperhatikan secara visual, dan kehilangan air diukur sebelum dan selepas pertumbuhan alga untuk menilai kesan pertumbuhan alga pada pelepasan sumbu yang terkubur. Satu eksperimen telah dijalankan untuk tanaman tomato untuk mensimulasikan pengagihan air dan corak pembasahan menggunakan Hydrus 2D / 3D. Dua tahap air di dalam paip, tiga jenis pasu mengikut saiz dan "peatgrow" sebagai media penanaman telah digunakan untuk membangunkan strategi penggunaan air yang betul dan keberkesanan pengairan. Kandungan kelembapan tanah juga diukur. Pengurusan nutrien tanaman telah dinilai dengan mengukur EC dan pH di peringkat yang berbeza daripada tanaman menggunakan EC dan pH meter, dan jumlah nutrien (N, P, K, Mg, Na dan Ca) telah ditentukan dalam larut resapan. Hasil daripada kajian ini menunjukkan dan membuktikan bahawa bahan sutera bukan terikat kapas mempunyai tindakan kapilari yang lebih baik, ketinggian kapiler maksimum dan kapasiti pegangan air daripada bahan tempatan. Keputusan juga menunjukkan kesan paras air di dalam paip, panjang sumbu di dalam paip, saiz periuk, ET dan kandungan air isipadu awal pada pelepasan sistem pengairan sumbu. Faktor-faktor yang berkaitan dengan penunaian sumbu pemancar digunakan untuk membangunkan persamaan untuk menampung pelepasan pemancar sumbu dengan menggantikan kepala tekanan dengan mengawal faktor pemancar sumbu. Jumlah air yang diukur adalah dekat dengan air yang disimulasi menggunakan sumbu persamaan pelepasan pemancar. Keputusan ET yang dikumpulkan menggunakan kaedah yang berbeza adalah untuk ETWBE> ETgvi> ETCROPWAT> ETgauge. Alga diperhatikan pada akhir bulan ke-3 dengan 6% peratus kesan berkurangan pada pelepasan sumbu ditanam. Hasil daripada kajian ini menunjukkan bahawa pertumbuhan tumbuhan tomato menunjukkan perbezaan yang tidak ketara apabila air tawar yang digunakan pada dua tahap pelepasan. Sebaliknya, pertumbuhan tanaman tomato menunjukkan perbezaan antara saiz periuk, di dalam pasu kecil akar telah melebihi keluar dari bahagian bawah periuk. Keputusan yang diperolehi untuk EC dan pH menunjukkan perbezaan yang ketara berdasarkan umur tumbuhan. Larut resapan diperhatikan dan keputusan penentuan nutrien dalam larutan resapan mendedahkan jumlah tertinggi P diikuti oleh Ca, Mg, Na, K dan N. Keputusan simulasi pergerakan air menggunakan Hydrus 2D / 3D mendedahkan pergerakan air sistem pengairan sumbu dalam bekas yang ditanam dengan tomato. Penemuan kajian ini mencadangkan peluang untuk memperbaiki Sistem Pengairan Silikon Kapilari (CWIS) yang berkesan untuk pengeluaran rumah hijau pekebun kecil.

ACKNOWLEDGEMENTS

Before all, let me thank Almighty Allah, who is kind gracious, magnificent, benevolent and most merciful and creator of all creations. I extend my countless salutations in the honor of his messenger Holy Prophet Muhammad (peace be upon him) who encouraged pursuing learning from birth until death.

I would take the opportunity to express my humble appreciations to my research supervisor Dr. Md. Rowshon Kamal for diligent supervision and regulation during the entire research process. Here also I would like to appreciate the services rendered by my co-supervisor Dr. Aimrun who helped me during my research whenever I needed. I am highly thankful to Mr Hadi for his valuable support throughout the studies. Thanks to the Soil and Physics laboratory assistant Mr. Abdul Aziz for timely assistance.

Additionally, I would like to express my gratitude to my husband Abdul Rehman Roonjho for his technical and moral support during my entire studies and I am also grateful to my parents, siblings, and all family members for their love, amiable attitude and moral support.

I gratefully acknowledge the funding received for my masters from the Lasbela University of Agriculture, Water and Marine Sciences, Uthal and off course this study would not have been possible without this financial support.

I certify that a Thesis Examination Committee has met on 16 June 2017 to conduct the final examination of Javed Shaheen on her thesis entitled "Modeling Water and Fertilizer Use in Wick Irrigation System for Smallholder Greenhouse Crop Production" in accordance with the Universities and University Colleges 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 Master of Science.

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This thesis was submitted to the senate of university Putra Malaysia and has been accepted as fulfillment of the requirements of the Degree of Master of Science. The members of the Supervisory Committee were as follows:

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I hereby confirm that:

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This is to confirm that:

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LIST OF ABBREVIATIONS

℃	Temperature
2D/3D	Two-dimension/ Three-dimension
ai	experimental coefficient
AI	Airspace
AMIT	Affordable Micro-irrigation Techniques
CC	Container capacity
CDE	Convection-dispersion equation
CNW	Cotton bonded non woven wick
CM	centimeter
CM	Cotton Material
CWIS	Capillary wick irrigation system
D	Drainage
DB	Bulk density
CU	Distribution uniformity
Cm^3	Centimeters cube
EAW	Easily available water
Ebb	Ebb and flow irrigation system
EC	Electrical conductivity
Eq	Equation
ET	Evapotranspiration
ET_O	Potential evapotranspiration
ET_A	Actual evapotranspiration
ET_C	Evapotranspiration of the crop
FW	Final Weight
FC	Controlling factor
g	Gramme
GBM	Gunny bag material
h	Pressure head
h_e	Pressure head of emitter
h	Hour
I	Irrigation
IAE	Irrigation application efficiency
IE	Irrigation efficiency
IW	Initial Weight
IDE	International Development Enterprises
K(θ) or K (h)	Unsaturated hydraulic conductivity
K_c	Crop coefficient
k_e	Emitter discharge coefficient
kpa	Kilopascal
K_s	Saturated hydraulic conductivity
L	Litters
L_w	Wick length
⌊	Pore-connectivity parameter
LF	Leaching fraction
$M\ M^{-1}$	Mass per mass
$M^3\ M^{-3}$	Volume per volume
MCH	Maximum capillary height

M_d	Mass of dry wick
Mm	Millimeter
M_s	Mass of wet wick
Mg	milligram
Ml	milliliters
NFW	Nutrient-flow wick culture
NGO	Non-Government Organization
P	Experimental constant
PAW	Plant available water
pD	Particle density
PT	Pour-Through
PVC	polyvinyl chloride
q	Water flux
q_e	Discharge of emitter
RAW	Readily available water
RH	Relative humidity
S	Sink term
S_e	Effective saturation
SM	Soil moisture
S_d	Standard Deviation
SD	Sufficient distilled
SDC	Swiss Development co-operation
SME	Saturated media extract
TP	Total porosity
UC	Uniformity coefficient
UC	University of California
V_{avg}	Volume Average
VG	Van Genuchten
V_{lq}	Volume of lowest value
VWC	Volumetric water content
WBC	Water buffering capacity
WC	Water collected
WEDE	Wick emitter discharge equation
WHC	Water holding capacity
WRC	Water retention Curve
WL	Water level
x	Exponent
α,n.m	Van Genuchten fitting parameters
θ	Water content
θ_r	Residual water content
θ_S	Saturated water content
dSm^{-1}	deciSiemens per meter

CHAPTER 1

INTRODUCTION

1.1 Background

Water shortage today has become a pressing issue of global concern. It is hard to fulfill the food requirements of the increasing world population by providing available fresh water resources using traditional irrigation systems. Therefore, there is a crucial requirement to investigate, develop and implement efficient irrigation techniques and effective irrigation management strategies. Among micro-irrigation systems, drip irrigation has been proven to save both significant amounts of water and labor costs, increase yield, and frequently also enhance the product quality. However, the high investment and energy costs are obstacles that hamper efforts to develop low-cost irrigation systems for subsistence farmers. There is therefore much interest in the design and development of novel micro-irrigation systems to address the rising water crisis

Greenhouse plant production plays an important role in agriculture and helps to meet the food demands of today's world population but it has undergone dramatic change from the use of mineral soils to new soilless growing media in the last few decades as a result of developments in the growing media system. Many different types of growing media are produced by various manufacturers. Peat-based substrates are frequently used in the growing systems, but sometimes inorganic substrates like perlite and rock wool are used in potted plant production. These growing media can differ in their physical and chemical properties. It is important to optimize the conditions in the root zone of potted medium. Although researchers have paid much attention to the chemical and physical nature of the substrates in the past, there is still a knowledge gap that exists in modeling water in the root zone of potted plants to achieve high yields with minimal waste of water and fertilizer. The water movement in potted plants should be known to set the adequate discharge as per crop water requirement. As the laboratory and greenhouse experiments are costly and time consuming, the numerical models are mostly used to predict water movement. Recently the two- and/or three-dimensional simulation model HYDRUS 2D/3D, which provides a numerical solution to the Richard's equation for saturated-unsaturated water flow and the convection-dispersion equation for solute flow has been used in micro-irrigation systems and emerged as a dependable indicator of modeling water (Gärdenäs et al., 2005).

The uniform distribution is also a crucial parameter in the development, control and adoption of micro-irrigation. A properly-designed irrigation system provides the approximately equal amount of water distributed to every plant and is economically viable. The uniform nature of the system ensures that an irrigation system's distribution of water is even over the root zone. Excess irrigation applications to the potted plants cause disease, contamination of ground water and low yield (Klock-Moore and Broschat, 2001b). Many studies have been conducted to find efficient water application approaches to potted plants (Dole et al., 1994). A drip irrigation system is a widely-used method to irrigate crops efficiently under protected cultivation. The sub-irrigation system is an efficient water application model to save labor costs, time and water compared to other methods (Dole et al., 1994). Unfortunately, due to the high start-up costs smallholder farmers have not been able to afford the installation and use of the drip irrigation system (Wesonga et al., 2014). However, advanced irrigation systems with improved performance are still needed, especially to apply water to potted plants. Among smart irrigation systems, wick irrigation system is a promising irrigation method.

Capillary Wick Irrigation System (CWIS) is a sub-irrigation system that utilizes a device that provides water through capillary movement from a reservoir to the plant growing medium. Sub-irrigation systems are economical in terms of labor, time and water costs in comparison with overhead irrigation systems for potted plants (Dole et al., 1994; Klock-Moore, 2001; Son et al., 2006). Capillary Wick Irrigation System is ideal for greenhouse production as it is water and nutrient efficient for crop plants production (So et al., 2003). The system produces better quality produce with less water loss in the absence of runoff, lower labor costs, and decreased cases of diseases besides saving time and costs operation. This irrigation innovation also offers easy and economy of installation and operation (Bainbridge, 2002).

Myung et al. (2007) analyzed the water contents of root media for various wick lengths, pot sizes and media compositions to establish the proper irrigation requirements in a nutrient-flow wick culture (NFW) system. This study found that water content fluctuated more with reduced pot size in the NFW system. Factors, like wick length, pot size, and medium composition, affected the water contents of the medium in the NFW system. The water contents in the media were reduced by more than 8% and 5% in 2 cm and 3 cm wick lengths within 15 minutes respectively.

It is unfortunate that there have been very few studies, regarding the optimal moisture contents of soilless substrates in pots, the hydraulic characteristics and water contents of growing medium in capillary wick irrigation systems (CWIS). On the other hand, Kirkham and Powers (1972) stated that ideal level of moisture for plant growth in mineral soils is 25% of the soil volume. Son et al. (2006) indicated that water content ranging from 30% to 60% in growing medium provided good growth in Kalanchoe. The CIWS consists of a fabric strip, which is put on the pots from the bottom and absorbs water from a water reservoir delivering to the root zone. Research has already been carried out on a capillary wick irrigation system for potted plants in Japan and South Korea (Kwon et al., 1999). This system cannot raise water to more than 20 cm. In relation to this issue, Wesonga et al. (2014) reported that the maximum capillary height of wick materials ranged from 14 to 19 cm. Therefore, the precise water application will remain greatly important and societies worldwide need to develop strategies by designing efficient techniques for agricultural irrigation. This current research was conducted to determine the hydraulic characteristics of the capillary wick irrigation system from the top. This theme was adopted bearing in mind the coefficient and distribution uniformity as the relevant parameters for irrigation management. The other reason for adopting this topic was, negligence, as very limited attention has been given to the hydraulic characteristics and water contents of different growing media for potted plants cultivation under CWIS. However, the algae growth in wick irrigation has been recorded and is now a major hurdle in practicing the wick irrigation system widely. Therefore, it is required to make agricultural water useful and more efficient through the enhancement and application of the current irrigation science and technologies (Hsiao et al., 2007). Therefore, in this study available local materials are compared with commercially available non-woven cotton wick, while hydraulic characteristics and irrigation efficacy are also carried out and a comparison made between hanging and buried wicks by using Peat Grow (soilless media) under laboratory conditions. Furthermore, the capillary wick irrigation is designed to minimize algae growth and evaporation. An experiment was conducted in a greenhouse with potted tomatoes and evaluated CWIS's performance for the best management practices in smallholders greenhouse production.

1.2 Problem Statement

Agricultural producers worldwide are facing massive challenges in producing enough to feed the 9.6 billion global population that the FAO projects by 2050. Increasing world population will increase the demand for food production which must be raised by 70%. It seems quite impossible to meet the food demand of around 10 billion people because of limited available arable lands and the competitive demand for limited fresh water, among other factors.

In today's globalized and wired world, over half of the worldwide population (54%) resides in urbanized areas even though there are still significant differences in the levels of urbanization from country to country. The decades ahead there will bring even more significant changes to the size and spatial distribution of the human population. The ongoing urbanization and overall increase of the world's population is expected to add 2.5 billion people to the urban population by 2050, with almost 90 % of the increase in Asia and Africa (Brenner and Schmid, 2014). Therefore, smallholders have to play a key role to produce more with less input. Drip irrigation is the method mostly used by smallholder greenhouse farmers to save water and reduce fertilizer losses, but this still needs energy for operation, lots of tools and cost of installation, making it difficult and putting it out of reach of the majority of low-income farmers.

Lee et al. (2010) investigated sub-irrigation using capillary wick system for a specialized pot with a wick in the bottom (13.5 cm diameter x 10.5 cm height).

The results revealed that the height of the pots was limited to the wick's ability to irrigate the upper part of the pots due to the limit of rising water. Wesonga et al. (2014) conducted research on capillarity action, water holding capacity and maximum capillary height for five types of wick materials. They concluded that the maximum height of capillarity is less than 20 cm. The wick irrigation system can be applied to the bottom and from the top of the pot. Only a few researches have been undertaken to measure the results of CWIS, and no one has yet tried to develop a systematic wick irrigation system. However, a research recorded algae growth as a serious problem in wick irrigation. Irrigation efficiency by wick is related to proper water distribution in growing medium, minimizing algae growth and limited capability of rising water when irrigated from the bottom of the pot. Therefore, this study focuses on improving wick irrigation system to maximize the application of water and fertilizers using experiment and 2D-HYDRUS simulation for smallholder greenhouse production.

1.3 Aim and Objectives

The aim of this study is the modeling of the capillary wick irrigation system (CWIS) to characterize the principle components and to determine the best management practices of water and fertilizers for the smallholders' crop production. The specific objectives are:

1. To develop the equation for compensating wick emitter discharge;
2. To determine the optimum water and nutrients use for tomato grown in different pot sizes;
3. To minimize algae growth and evaporation losses WIS
4. To determine the optimum pot size and zero leachates for potted crops in greenhouse; and
5. To evaluate two dimensional water distribution pattern in potted growing media using HYDRUS 2D simulation

1.4 Significance of the Study

The modified design for wick irrigation system will enable the wide adoption of this irrigation system and prove the equation for cotton-bonded non-woven wick material, which will help to establish the discharge rate of the wick material. By measuring hydraulic characteristics of the wick materials, the most suitable wick material for capillary wick irrigation system was determined. The best size of the pot and enough discharge were known to manage nutrients in potted tomatoes for wick irrigation. Moreover, simulation of water movement under wick irrigation enables farmers and researchers to schedule irrigation for the best management practices.

1.5 Scope of Work

The research approach includes modification in the design of capillary wick irrigation system to minimize the algae growth and evaporation, modification of wick emitter discharge equation and produce an effective low-cost irrigation system for smallholders' greenhouse production. This is achieved as follows:

1. Conduct laboratory experiments to identify best material as wick emitter and develop the equation for wick emitter discharge.
2. Finding the correlation of controlling factors affecting the capillary wick discharge rate.
3. Evaluating the best size of pot for potted tomatoes in CWIS.
4. Managing nutrients and water discharge application in CWIS
5. Simulation of 2D-water movement using HYDRUS 2D/3D in different size pots at different discharge rate under CWIS.

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