UNIVERSITI PUTRA MALAYSIA

EVALUATION OF ROOT ZONE COOLING SYSTEM FOR STRAWBERRY (FRAGARIA X ANANASSA DUCHESNE) CULTIVATION IN TROPICAL LOWLANDS

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By

MOHD ASHRAF ZAINOL ABIDIN

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

September 2015

I wish to dedicate this thesis to Allah, his messenger Muhammad S.A.W. and my beloved family

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

EVALUATION OF ROOT ZONE COOLING SYSTEM FOR STRAWBERRY (*FRAGARIA X ANANASSA* DUCHESNE) CULTIVATION IN TROPICAL LOWLANDS

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September 2015

Chairman : Desa Ahmad, PhD

Faculty : Engineering

Strawberry prices have increased significantly due to high demand. In Malaysia's tropical climate, strawberries are only able to grow in highland areas which have low environmental temperatures. However, the areas are limited and strawberries are now can be grown inside greenhouses under a controlled environment in lowland areas. This has a high cost of production, thus reducing profits. Since root zone temperature (RZT) manipulation provides more benefits than environment temperature manipulation, a root zone cooling (RZC) system integrated with multi-tier cultivation technique (MCT) under fluctuating environment temperature located in lowland areas was proposed as an alternative method to cultivate strawberries. To evaluate the efficiency of the system proposed, three different treatments were set up. Treatment 1 and Treatment 2 were set up in lowland areas with and without the integration of RZC system. Treatment 3 was located in highland area without RZC system. All treatments were left to undergo fluctuating environmental conditions. On average, the environment temperature in lowland and highland areas were 28.91 °C and 20.71 °C respectively. For relative humidity, those values were 75.01% and 75.79%. Both areas experience around twelve hours of day light. However, lowland areas receive lower ventilation rates than highland areas. The use of RZC system reduced RZT down to 9.48% and increased the root zone moisture content (RZMC) up to 30.36%. The cooling system also was able to highly standardize the RZT at various points of the cultivation structure. Aside from potential evaluation, a mathematical model for predicting RZT using minimum input data (environment temperature and chilled pipe temperature) was proposed and validated. The constants *a* and *b* were 2.83 x 10^{-8} W/K4 and 1.52785 W/K respectively. Though the treatment in the highland areas obtained better results in terms of fruit size, RZC system significantly increased the fruit's diameter and weight up to 8.85% and 21.60% respectively for lowland productions. Moreover, 70.00% of the strawberries produced were of marketable size (> 5 g) compared to 46.67% of the strawberries produced by the treatment without RZC system. The lowland areas also produced more than 70.00% of the strawberries that above the average sweetness of the *Festival* variety (brix index: > 8 °Bx), compared to approximately 50.00% of the strawberries produced in the highland areas. In conclusion, the RZC system was found to significantly reduce RZT, and increase the RZMC. It also produces better fruit yield in strawberry cultivation in lowland areas, thus providing an alternative solution that can comply with the growing strawberry demand.

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

PENILAIAN SISTEM PENYEJUKAN ZON AKAR BAGI PENANAMAN STRAWBERI (*FRAGARIA X ANANASSA* DUCHESNE) DI TANAH RENDAH TROPIKA

Oleh

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Harga strawberi telah meningkat dengan ketara disebabkan oleh permintaan yang tinggi. Berdasarkan iklim tropika Malaysia, strawberi hanya sesuai ditanam di kawasan tanah tinggi yang mengalami suhu persekitaran yang rendah. Walau bagaimanapun, kawasan pertanian tersebut adalah terhad. Namun, strawberi boleh ditanam di dalam persekitaran terkawal rumah hijau di kawasan tanah rendah. Akan tetapi, kosnya adalah tinggi, justeru boleh mengurangkan keuntungan. Berdasarkan teori yang menyatakan manipulasi suhu akar (RZT) lebih berkesan daripada manipulasi suhu persekitaran, sistem penyejukan akar (RZC) telah digabungkan dengan teknik penanaman secara bertingkat (MCT) di kawasan tanah rendah sebagai alternatif untuk penanaman strawberi. Untuk menilai kecekapan sistem, tiga rawatan berlainan diuji. Rawatan 1 dan Rawatan 2 terletak di kawasan tanah rendah dengan dan tanpa sistem RZC. Manakala Rawatan 3 terletak di kawasan tanah tinggi tanpa system RZC. Semua rawatan dibiarkan mengalami keadaan persekitaran yang asal. Purata suhu persekitaran di kawasan tanah rendah dan tinggi masing-masing 28.91 °C dan 20.71 °C. Bagi kelembapan udara, nilainya adalah 75.01% dan 75.79%. Selain itu, kedua-dua kawasan mengalami siang sekitar 12 jam. Walau bagaimanapun, kawasan tanah rendah menerima kadar pengudaraan yang lebih rendah berbanding kawasan tanah tinggi. Penggunaan sistem RZC menurunkan RZT sehingga 9.48% dan meningkatkan kelembapan zon akar (RZMC) sehingga 30.36%. Sistem penyejukan itu juga mampu menyeragamkan RZT di pelbagai lokasi pada struktur penanaman bertingkat itu. Selain kajian terhadap potensi, model matematik untuk meramalkan RZT menggunakan data input yang minimum (suhu persekitaran dan suhu paip sejuk) turut dibangunkan. Pemalar *a* dan pemalar *b* masing-masing adalah 2.83 x 10^{-8} W/K^4 dan 1.52785 W/K. Walaupun kawasan tanah tinggi menghasilkan saiz buah yang lebih baik, secara puratanya sistem RZC meningkatkan diameter and berat buah sehingga 8.85% dan 21.60% bagi penanaman di kawasan tanah rendah. Malah, menghasilkan sehingga 70.00% saiz buah yang boleh dipasarkan (> 5 g) berbanding cuma 46.67% yang dihasilkan tanpa sistem RZC. Kawasan tanah rendah juga menghasilkan lebih dari 70.00% strawberi di atas purata kemanisan varieti *Festival* (brix index: > 8 °Bx) berbanding lebih kurang 50.00% sahaja yang dihasilkan di tanah tinggi. Kesimpulannya, sistem RZC dapat menurunkan RZT and menaikkan RZMC secara ketara. Selain itu, dapat menghasilkan buah yang lebih baik bagi penanaman strawberi di tanah rendah. Secara tidak langsung, ia mampu memberi penyelesaian alternatif bagi memenuhi permintaan strawberi.

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I certify that a Thesis Examination Committee has met on 10th September 2015 to conduct the final examination of Mohd Ashraf Zainol Abidin on his thesis entitled "Evaluation of Root Zone Cooling System for Strawberry (*Fragaria x Ananassa* Duchesne) Cultivation in Tropical Lowlands" 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 degree of Master of Science.

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LIST OF ABBREVIATIONS

RZC	Root zone cooling
RZT	Root zone temperature, °C
RZMC	Root zone moisture content, %
E	Ratio of evapotranspiration to solar radiation
F	Decimal representing the portion of greenhouse space in plant production
τ	Transmittance of greenhouse glazing to solar radiation, %
I	Solar intensity on a horizontal surface, $W.m^{-2}$
U	Heat transmission coefficient, $W.m^{-2}.K^{-1}$
A_f	Area of greenhouse glazing, m^2
T_o	Environment temperature outside greenhouse, °C
T_i	Environment temperature inside greenhouse, °C
V	Ventilation rate, $m^3.s^{-1}$
ρ	Air density, $m^3.kg^{-1}$
C_p	Specific heat of dry air, $kj.kg^{-1}.K$
η	Pad efficiency, %
eps	Surface emissivity
σ_{SB} / σ	Stephan-Boltzmann constant, $W.m^{-2}.K^4$
T_{in}	Environment temperature inside greenhouse, °C
T_4	Growth media temperature between surface area and chilled pipe, °C
T_2	Chilled pipe temperature, °C
R_{42}	Growth media resistance, °C/W
CEC	Cation Exchange Capability, cmol(+)/kg
EC	Electrical conductivity, mho
pH	Nutrient solution acidity
K_c	Crop coefficient
Q_{rad}	Rate of heat gain through solar radiation on growth media, W
ε_T	Total emissivity
ε_{pp}	Surface emissivity of pillow polybag
ε_{peat}	Surface emissivity of growth media
A_{pp}	Area of pillow polybag, m^2
T_{envi}	Environment temperature, K
T_{peat}	Growth media temperature, K
a_{pp}	Major width of pillow polybag, m
b_{pp}	Minor width of pillow polybag, m
L_{pp}	Length of pillow polybag, m
$Q_{cond,pipe\rightarrow peat}$	Rate of heat loss through conduction from chilled pipe to growth media, W
S	Conduction shape factor, m
L_{pipe}	Length of chilled pipe, m
z	Distance between growth media surface and centre of chilled pipe, m
D_{pipe}	Diameter of chilled pipe, m
y	Dependent variable

x	Independent variable
m	Coefficient of the independent variable
c	Constant term
K_{peat}	Thermal conductivity of growth media, W/m.K
MC	Moisture content, %
$Q_{cond,water \rightarrow pipe}$	Rate of heat loss through conduction from chilled water to chilled pipe, W
R_{pipe}	Resistivity of chilled pipe, °C/W
r_2	Outer radius of chilled pipe, m
r_1	Inner radius of chilled pipe, m
K_{pipe}	Thermal conductivity of chilled pipe, W/m.K
T_{pipe}	Chilled pipe temperature, K
T_{water}	Chilled water temperature, K
$T_{initial\ water}$	Initial chilled pipe temperature, K
a	Constant *a*
b	Constant *b*
ANOVA	Analysis of variance
SPSS	Statistical package for the social science

CHAPTER 1

INTRODUCTION

1.1 General

Malaysia is a tropical country located in the equatorial region between latitudes 1° – 7° North and longitude 100° – 119° East. It is divided into Peninsular and East Malaysia, and is mostly surrounded by the sea. This influences the climatological properties in Malaysia. Generally, Malaysia undergoes a uniform environmental temperature with high relative humidity, and experiences copious rainfall throughout the year. The environment temperature varies from 21 °C to 34 °C and its mean yearly is around 27 °C. The mean values of relative humidity and evaporation rates were around 80% and 3 to 4 mm/day respectively. Most of the rain is the result of convection precipitation, with annual rainfall up to 2,500 mm per year. Typically, highland areas experience higher rainfall than lowland areas. The wind speeds are generally light. Besides that, it is hard to experience a full day with completely clear skies even during severe drought periods. Conversely, it is also rare to have several days without sunshine except during the northeast monsoon season. On average, Malaysia experiences photoperiods that are about 12.5 hours long per day (Malaysian Meteorological Department, 2012; Razak & Roff, 2011).

With this tropical weather, the main crops cultivated in Malaysia are oil palms, rubber, paddy, and cocoa (Mahmudul Alam et al., 2011; Tunku Mahmud Tunku Yahya, 2001). However, Malaysia also has agricultural highland areas such as Cameron Highlands, Kundasang, and Lojing that experience low environmental temperature all year round. In Cameron Highlands, the environment temperature is always less than 25 °C, sometimes dropping below 12 °C (Eisakhani & Malakahmad, 2009). Most of these agricultural areas cultivate temperate crops such as vegetables, tea, flowers, and fruits.

Although the main crops in Cameron highlands are vegetables, strawberries have long been known as an iconic crop of Cameron Highlands. In accordance with this status, strawberries were chosen by the government as a product in 'one district, one industry' campaign for Cameron Highlands. Strawberries are cultivated in high density using a multi-tier cultivation system as shown in Figure 1. This system consists of five crop growing containers placed on different tiers, constructed in the 'A' shape design. The structure system is placed under a rain shelter equipped with fertigation system to reduce fruit damage, and infestation from pests and disease due to copious rainfall and high relative humidity (Mohd Ridzuan et al., 2011).

Figure 1: Multi-tier structure in Cameron Highlands
(Source: Mohd Ridzuan, 2011)

The total strawberry production area in Cameron Highlands increased from 14 ha in 2008 to 30 ha in 2010, with an estimated production of fresh fruit worth RM 60 million to RM 70 million per annum, and downstream products worth RM 12 million to RM 18 million a year. The production of this popular high-value crop (Folta et al., 2010) is expected to rise due to a significant number in demand (Mohd Ridzuan et al., 2011). The price of strawberries can reach up to RM 25 /kg. Hence, strawberries have been listed as the temperate crop with the most potential in the global market by the Ministry of Agriculture and Agro Based Industry Malaysia (MOA).

Technology that controls the environment in a crop protection structure (as shown in Figure 2) can meet the suitable crop growth requirements for temperate crops (Al-Shamiry et al., 2006) such as strawberries and tomatoes, so that they can be grown optimally in tropical lowlands. Tropical crop protection structures experience extreme environment temperature without the controlled system due to the high intensity of solar received, which may stunt crop growth (Chen et al., 2011). Hence, the system becomes more important (Mattas et al., 1997) in cultivating temperate crops in the tropics.

The integration of aerial cooling system with root zone cooling (RZC) system instead of cooling the aerial environment of the controlled environment structure alone has proven to raise the performance of temperate crops in controlled environment greenhouses (Mohammud et al., 2012). The comparative effects of root zone temperature (RZT) and environment temperature were examined in the past for crop growth, yield, and crop value of several crops cultivated under a crop protection structure. Most results indicate that RZT manipulation is beneficial to crop growth performance (Dodd et al., 2000; Gosselin & Trudel, 1984). However, the crop protection structure equipped with the environmental control system demands a high cost of production especially the initial cost, thus reducing the profit (Ahmad Syafik et al., 2010; Gosselin & Trudel, 1984; Santamouris et al., 1995).

Figure 2: Controlled environment greenhouse

1.2 Problem Statement

Supply of strawberries will probably be limited due to limited arable land in highland areas, coupled with the government's strict policy against the opening of new agricultural areas in the highlands. The opening of new agricultural land in highland areas requires high initial cost, especially in providing roads for transportation. In recent years, concerns have been raised about potential sustainability problems and the impact on the environment caused by agricultural activities, especially in the highland areas (Barrow et al., 2009). Problems such as soil erosion caused by water runoff and water pollution were caused by those activities. Apart from those, the immediate and most serious risk faced by most agricultural productions in highland areas is water deficit, especially during the drought season. However, tropical lowlands do not provide a suitable climate for strawberry cultivation due to the tropical weather that affect the soil temperatures, extreme rainfall, and the threats from insect pests (Mat Sharif, 2006; Rerkasem, 2005).

An alternate idea is to bring the RZC technique to an open space under a rain shelter structure to cultivate the strawberries. This leaves the environment to experience natural ventilation with no energy required and maintenance input (Al-Shamiry & Ahmad, 2010). The chilled pipe act as cooling mechanism was buried around the root zone area and used to chill the temperature. The RZC system will also be integrated with the multi-tier cultivation technique (MCT) to maximize the use of cultivation area. With the normal temperature for growth media in lowland areas varying between 27 °C – 30 °C (Mohammud et al., 2011) and without exact references on growth media temperature pattern in Cameron Highlands, the growth media temperature was assumed to vary around 25 °C. This estimated temperature was based on the optimum RZT suggested by Angelina (2012) to grow tomatoes inside the controlled environment greenhouses.

Generally, most of the temperate crops are less tolerant to the high environment temperature (Mat Sharif, 2006) experienced in tropical regions. This is a huge challenge because the environment temperature in tropical lowlands is normally very high compared to tropical highlands. Also, very limited study and data for the efficiency of RZT manipulation are available for a tropical country like Malaysia (Angelina, 2012).

The hypothesis of this study was a RZC system integrated with MCT in tropical lowlands is suitable for strawberry cultivation requirements without the presence of aerial cooling system.

1.3 Objectives of Study

The main objective of this research was to evaluate the root zone cooling system for strawberry cultivation in tropical lowlands. The specific objectives were:

1. To determine the climatological properties difference between tropical lowlands and highlands.

2. To evaluate the root zone cooling system integrated with multi-tier cultivation technique in tropical lowlands.

3. To establish a prediction model for root zone temperature chilled by root zone cooling system.

4. To assess the quality of strawberry grown using the root zone cooling system in tropical lowlands.

1.4 Scope of the Study

The proposed research of investigating root zone cooling system for strawberry cultivation in tropical lowlands was carried out in four stages; determination of climatological properties difference between tropical lowlands and highlands, evaluation of RZC system integrated with MCT in tropical lowlands, prediction model of RZT chilled by RZC system, and assessment on the quality of strawberry grown in tropical lowlands. The details scope for each objective is stated below:

1.4.1 Determination of Climatological Properties Difference between Tropical Lowlands and Highlands

The determination focused on the comparison of climatological properties experienced in tropical lowlands and highlands besides evaluating their influence on other climatological and growth media properties. The climatological properties such as environment temperature (°C), relative humidity (%), solar radiation (kW/m^2) and wind speed (km/h) in both areas were examined. The statistical software such as Statistical Package for the Social Science (SPSS) and Microsoft Excel 2010 were used to perform the analyses.

1.4.2 Evaluation of the Root Zone Cooling System Integrated with Multi-tier Cultivation Technique in Tropical Lowlands

The evaluation focused on the efficiency of the cooling system to suit strawberry growth in tropical lowlands, and the compatibility of RZC system integrated with multi-tier structure. Data such as RZT (°C) and growth media moisture content (%) were collected and analysed. The statistical analyses were performed using SPSS and Microsoft Excel 2010.

1.4.3 Prediction Model of Root Zone Temperature Chilled by Root Zone Cooling System

A mathematical model was established to predict the RZT at different parts of a multi-tier structure without calculating the rate of electricity consumption. The minimum input data such as environment temperature (°C) and chilled pipe temperature (°C) were used to propose the model. The MATLAB software was used to solve the mathematical model.

1.4.4 Assessment on the Quality of Strawberry Grown Using the Root Zone Cooling System in Tropical Lowlands

The crop performance was focused on the quality of strawberry fruit grown using the RZC system excluding the crop growth performance. Samples of fruits were collected and tested. The scope of strawberry quality will be limited to size (diameter, mm and weight, g) and brix index or sweetness of the strawberry (°Bx). The SPSS and Microsoft Excel 2010 were used to perform all the statistical analyses. The influencing factors on the quality of the fruit and the reliability of the RZC system based on analyses and reviews were also discussed.

1.5 Limitation

1. Data such as solar radiation and wind speed for the site in Cameron Highlands (tropical lowlands) could not be recorded due to the lack of sensors and data loggers available. Both data were extracted from previous study.

2. The availability of multi-tier cultivation structure is limited. This led to non-replicable treatments being conducted. However, the replication problem was dealt with by extending the data collection period for several harvest periods.

3. The optimum RZT ranges for strawberry cultivation in tropical lowlands could not be determined due to the RZC system design that was not capable of providing a range of different water temperatures at the same time. Furthermore, there was no RZT manipulation carried out to assess its effects on the strawberry yield in tropical highlands.

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