UNIVERSITI PUTRA MALAYSIA

HYSTERESIS OF COCOPEAT-PERLITE MIXTURE UNDER ROOT ZONE COOLING SYSTEM FOR GROWING BUTTERHEAD LETTUCE

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By

WAN FAZILAH BINTI FAZLIL ILAHI

Thesis Submitted to the school of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

June 2017

To my loving parents Fazlil Ilahi & Noraizan,
beloved husband Zahhid,
and my wonderful son Fatih,
Thank you for your continuous support
.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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June 2017

Chairman : Professor Ir. Desa Ahmad, PhD
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Cocopeat is one of the leading coconut by-products known for its special characteristics; high water holding capacity, excellent drainage and absence of weeds and pathogen, however it has high water holding capacity which may not provide adequate aeration for plant root. It is common in soilless culture to mix perlite with cocopeat on order to improve aeration. The ratio of mixing these two materials needs to be determined in order to provide a better cocopeat-perlite mixture for plants. Moreover, little attempts had been made to observe the hysteretic phenomena in cocopeat medium and the theory used in soil physics cannot be directly applied for container medium. Plant heat stress is more economically reduced by root zone cooling (RZC) method compared to other environmental technique such as air temperature cooling. This study focuses on the water retention curve (WRC) and hysteresis for the cocopeat-perlite mixture in two conditions; with and without RZC. The aim is to understand the behaviour of the hydraulic properties of cocopeat-perlite mixture so that the irrigation schedule for butterhead lettuce can be established.

An extensive study on physical properties of the cocopeat-perlite mixture were analysed in the laboratory for its particle size distribution, bulk and particle densities, porosity, water holding capacity, wettability and hydraulic conductivity. These properties were analysed to choose the most suitable ratio of cocopeat-perlite mixture as a growing medium. Available water content derived from WRC and hysteresis retention curves measurements were used to estimate irrigation scheduling for butterhead lettuce. Irrigation interval was calculated from the crop water requirement and the medium available water. In order to determine the effectiveness of RZC, comparisons of butterhead lettuce growth grown in the selected cocopeat-perlite mixture with and without RZC treatments were conducted.

Results had shown that the best cocopeat-perlite mixture was 3 cocopeat: 1 perlite. This ratio had the highest porosity (63.22%) and water holding capacity (920%), and lowest hydraulic conductivity (0.09 cm/s) compared to other ratios. These properties are significant in providing suitable environment for plant growth. From the hysteresis curve, the first main drying and wetting cycle of cocopeat-perlite mixture (3:1) without RZC, showed an unclosed hysteretic loop in term of water retention properties with a gap of 16% (0 kPa) and 9% (10 kPa) of water ratio. However, reversible and closed hysteretic loop was observed for the second drying and wetting cycle. Under RZC treatment, retention and hysteresis curves shifted upward from the normal curves which resulted in an increase in volumetric water content for suction 0 to 10 kPa. The hysteresis loop of the first cycle was anticlockwise which was contradictory with the normal clockwise hysteresis loop obtained earlier. The first main drying and wetting cycle showed a closed hysteretic loop in terms of water retention properties with a maximum gap of 15% at 5 kPa. The optimum temperatures in the medium with RZC treatment were between 12°C and 19°C at 10 cm below the medium surface during hot ambient temperatures between 10 am and 4 pm daily. Medium temperatures remain below 22.8°C after this period. Irrigation management without considering hysteresis had resulted in three days of irrigation interval for both medium treated with and without RZC. However, when hysteresis was considered in the irrigation management, the irrigation interval reduced to two days for medium without RZC and one day for medium with RZC treatment. Considering hysteresis in the irrigation management is significant to estimate the accurate irrigation interval. In this study, yields were found greatest for butterhead lettuce grown in RZC compared to those grown in ambient temperatures without RZC. The cocopeat-perlite mixture (3:1) had provided an optimum growth condition for butterhead lettuce with RZC treatment at low temperatures (between 12 and 19°C).

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

HISTERESIS CAMPURAN DEBU SABUT KELAPA-PERLIT DI DALAM SISTEM PENYEJUKAN ZON AKAR UNTUK TANAMAN SALAD BUTTERHEAD

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Debu sabut kelapa adalah salah satu keluaran utama kelapa yang dikenali dengan ciri-ciri khasnya; kapasiti pegangan air yang tinggi, saliran yang baik serta tiada rumpai dan patogen, namun ia mempunyai kapasiti pegangan air yang tinggi yang tidak dapat memberikan pengudaraan yang mencukupi untuk akar tumbuhan. Adalah perkara biasa dalam budaya tanaman tanpa tanah untuk mencampurkan perlit dengan debu sabut kelapa untuk meningkatkan pengudaraan. Nisbah pencampuran kedua-dua bahan ini perlu ditentukan untuk menyediakan campuran debu sabut kelapa-perlit yang lebih baik untuk tumbuh-tumbuhan. Selain itu, usaha yang kecil telah dilakukan untuk memerhatikan fenomena histeretik di dalam medium debu sabut kelapa dan teori yang digunakan dalam fizik tanah tidak boleh digunakan secara langsung untuk medium di dalam kontena. Tekanan haba tumbuhan dapat dikurangkan secara ekonomi dengan kaedah penyejukan zon akar (RZC) berbanding dengan teknik penyejukan persekitaran lain seperti penyejukan udara. Kajian ini memberi tumpuan kepada keluk pengekalan air (WRC) dan histeresis untuk campuran debu sabut kelapa-perlit dalam dua keadaan; dengan dan tanpa RZC. Matlamat kajian adalah untuk memahami sifat hidraulik campuran debu sabut kelapa-perlit supaya jadual pengairan untuk salad butterhead dapat ditentukan.

Kajian meluas tentang sifat-sifat fizikal campuran debu sabut kelapa-perlit dianalisis di makmal untuk menentukan pengasingan saiz zarah, ketumpatan pukal dan zarah, kadar keliangan, kapasiti pegangan air, kebolehbasahan dan kekonduksian hidraulik. Ciri-ciri ini dianalisis untuk memilih nisbah yang paling sesuai untuk campuran debu sabut kelapa-perlit sebagai medium tanaman. Kandungan air yang diperoleh daripada WRC dan lengkung pengekalan heteresis digunakan untuk menganggarkan penjadualan pengairan untuk salad butterhead. Selang pengairan dihitung dari keperluan air tanaman dan air yang tersedia di dalam medium. Untuk menentukan

keberkesanan RZC, perbandingan pertumbuhan salad butterhead yang ditanam di dalam medium campuran debu sabut kelapa-perlit yang dipilih dengan dan tanpa rawatan RZC dijalankan.

Keputusan telah menunjukkan bahawa campuran debu sabut kelapa-perlit terbaik adalah 3 debu sabut kelapa: 1 perlit. Nisbah ini mempunyai kadar keliangan tertinggi (63.22%) dan kapasiti pegangan air tertinggi (920%), serta kekonduksian hidraulik terendah (0.09 cm/s) berbanding nisbah campuran lain. Sifat fizikal ini adalah penting untuk menyediakan persekitaran tanaman yang sesuai. Dari lengkung histeresis, kitaran pertama pengeringan and pembasahan utama campuran debu sabut kelapa dan perlit (3:1) menunjukkan gelung histeresis tertutup dari segi sifat-sifat pengekalan air dengan jurang 16% (0 kPa) dan 9% (10 kPa) daripada nisbah air. Walaubagaimanapun, gelung histeresis boleh balik dan tertutup diperolehi untuk kitaran kedua pengeringan dan pembasahan. Di bawah RZC, lengkung pengekalan air dan lengkung histerisis telah beralih ke atas dari lengkung normal dan hasilnya kandungan isipadu air meningkat untuk tekanan 0 - 10 kPa. Gelung histerisis kitaran pertama adalah arah lawan jam yang bercanggah dengan gelung histerisis arah jam biasa diperoleh sebelum ini. Kitaran pengeringan dan pembasahan utama menunjukkan gelung histeresis tertutup dari segi sifat-sifat pengekalan air dengan jurang maksimum 15% pada 5 kPa. Suhu optimum di dalam medium dengan RZC adalah di antara 12 dan 19°C, 10 cm di bawah permukaan medium pada suhu persekitaran yang panas diantara 10 am dan 4 pm setiap hari. Suhu medium kekal di bawah 22.8°C selepas tempoh ini. Pengurusan pengairan tanpa mempertimbangkan histerisis memberikan selang pengairan tiga hari untuk kedua-dua medium dengan dan tanpa RZC. Walaubagaimanapun, apabila histerisis dipertimbangkan dalam pengurusan pengairan, selang pengairan dikurangkan kepada dua hari untuk medium tanpa RZC dan satu hari untuk medium dengan RZC. Mempertimbangkan histerisis dalam pengurusan pengairan adalah signifikan untuk menganggarkan selang pengairan yang tepat. Dalam kajian ini, hasil didapati paling tinggi untuk salad butterhead yang ditanam dalam RZC berbanding salad yang ditanam pada suhu udara tanpa RZC. Campuran debu sabut kelapa-perlit (3:1) telah memberikan keadaan pertumbuhan yang optimum untuk salad butterhead dengan rawatan RZC pada suhu rendah (antara 12 dan 19°C).

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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LIST OF ABBREVIATIONS

AFP	Air filled porosity
CFD	Computational Fluid Dynamic
CRD	Complete randomized design
EAW	Easily available water
EC	Electrical conductivity
hp	Horsepower
kPa	Kilopascal
LRAW	Less readily available water
MARDI	Malaysian Agricultural Research & Development Institute
MDC	Main drying curve
MWC	Main wetting curve
PDSC	Primary drying scanning curve
PE	Polyethylene
PVC	Polyvinyl chloride
PVDF	Polyvinylidene fluoride
PWSC	Primary wetting scanning curve
RZC	Root zone cooling
SWCC	Soil water characteristic curve
TDR	Time –domain reflectometer
TPS	Total pore space
VWC	Volumetric water content
WBC	Water buffering capacity
WHC	Water holding capacity
WRC	Water retention curve

LIST OF NOMENCLATURE

A	Sample cross section area (cm^2)
d	Core diameter (cm)
h	Pressure head
H	Height of the core (cm) and water level at each piezometric tube levels (cm)
I	Hydraulic gradient
k	Hydraulic conductivity
k_c	Crop coefficient
k_s	Saturated hydraulic conductivity
L	Distance between the lateral outputs from the base plate of the permeability
M_{dw}	Mass of water displaced by soil (g)
M_s	Mass of oven dried soil (g)
M_w	Mass of water retained in the sample (g)
n	Number of samples
Θ	Water content
Θ_s	Saturated water content
ϕ	Porosity
Q	Amount of water (cm^3)
R^2	Coefficient of determination
T	Time (s)
W_b	Weight of medium and core ring after oven dried (g)
W_r	Weight of the core ring (g)
ρ_b	Bulk density (g/cm^3)
ρ_s	Particle density (g/cm^3)
ρ_w	Density of water (g/cm^3)

CHAPTER 1

INTRODUCTION

1.1 Introduction

It is known that water is a major issue in almost all part of the world especially for countries with insufficient water resource. The need to improve crop yield, and in the same time increase irrigation efficiency has been an aim for many growers all around the world to get more crop per drop. For example 85 to 95% of irrigation efficiency was reported for drip irrigation system (Phocaides, 2007). To improve and achieve 100% efficiency and sustain high drip irrigation efficiency while reducing loss of water is by understanding the water retention and hysteresis of a growing medium. A lot of research has been done to optimize water use and this can be done by reducing over-irrigation. Hysteresis represents the history dependence of a physical system. The history of soil wetting and drying as a result of irrigation practice will create this hysteresis phenomenon. Hysteresis can significantly influence water flow in variably saturated porous medium (Russo et al., 1989; Gillham et al., 1979; Vachaud & Thony, 1971). The WRC and hysteresis curves of a medium can be a reference for the irrigation frequency, time and volume planning.

Growing temperate crops in a tropical country such as Malaysia is costly as they require high investment on structures and equipment which provide the cold growing environment. Normal soil temperature condition in Malaysia lowland usually varies between 24-29 ℃ (Nik et al., 1986) and the recommended growth temperature for lettuce is between 15 to 18 ℃ (Sanders, 2001). Despite using cooling structures and equipment for cultivating temperate crops, an approach made by researchers is to cool down the crops by cooling the root zone. The control of root zone temperature is easier and more economical than that of other environmental factors such as air temperature and can be an effective solution to overcome heat stress (Moon et al., 2007). This technique had proven to improve root growth, more leaves, greater leaf area and yield (Moon et al., 2007; He et al., 2001; Dodd et al., 2000; Kosobrukhov et al., 1990).

Soilless culture has long been practiced (Naville, 1913) especially in horticulture production as this culture require less space, labour and use water efficiently. Studies had proved that growing crops in soilless culture gave better yield and more profitable than soil culture (Fontana & Nicola, 2009; Rouphael et al., 2004; Grafiadellis et al., 2000). One of the soilless culture cultivation is by growing crops in growing containers with substrates or growing medium which is widely used for row crops such as vegetable, strawberry, melon and cut flower production. There are wide selections of growing medium to choose from either organic or inorganic materials. However, these medium should guarantee better rooting conditions than agricultural soil. Cocopeat is an organic material which contains short and long fibrous string coconut husk and coconut dust. Cocopeat has a lot of benefits in horticultural usage and had been successfully used as containerized growing medium. Studies had shown that cocopeat or coconut coir dust had given good results in yield and crop performance especially when mixed with other medium such as perlite (Tehranifar et al., 2007; Fascella & Zizzo, 2005). Cocopeat itself as a growing medium has proven that crops can grow and produce yield similar to soils and other growing medium (Grassotti et al., 2003).

Aiming to grow temperate crop and increase yield, the root zone cooling (RZC) practice has shown to play an important role in achieving this aim. By controlling the temperature of the medium with cold water pipes buried along the root zone area of the plants, the warm temperature will be cooled by the heat exchange process. Hereafter, interest arises on the effect of RZC on water retention curve (WRC) and hysteresis for the cocopeat porous medium. The sequence of wetting and drying processes which can be subjected to hysteresis will then influence water content in the medium. Thus, irrigation efficiency can be improved if the water content profiles which depend on the preceding wetting or drying processes in the medium can be determined. In addition, growing lettuce plant in the cocopeat medium under RZC can prove that temperate vegetables can be grown at lowland.

1.2 Problem Statement

The emerged of soilless culture techniques and fertigation in Malaysia had increased the usage of cocopeat (Yaseer Suhaimi et al., 2010). Cocopeat is one of the easily available growing medium products in Malaysia. Its special characteristics; high water holding capacity, excellent drainage, absence of weeds and pathogens are recommended to be used as growing medium in soilless culture. However, due to these special characteristics, cocopeat commonly has high water holding capacity which in some condition could not provide adequate aeration for plant root. Thus cocopeat is usually mixed with other material to improve aeration. The ratio of mixing these two materials needs to be determined in order to provide a better cocopeat-perlite mixture for plants.

The conventional practice to estimate irrigation scheduling is by obtaining the information on medium water availability from a single WRC. The application of WRC is often assumed to be non-hysteretic since the measurement of a complete set of hysteretic WRC is time consuming and costly. However, neglecting the effect of hysteresis in irrigation management may lead to over irrigation which resulted in waste of water and poor aeration in the root zone area of a plant. The knowledge of medium water availability as the result of frequent wetting and drying (hysteresis) is important to specifically estimate the irrigation scheduling. Subsequently applying the accurate amount of irrigation water can increase irrigation efficiency and improved the plant water status.

Hysteresis studies and its application to irrigation management can be found mostly for field soils, while very little information can be found for growing medium particularly when low temperature is applied to the medium. The use of root zone cooling system in the medium arise interest on the effect of temperature on hysteresis. Therefore, the determination of WRC and hysteresis retention curves on growing medium for the irrigation management is needed.

1.3 Objectives of the Study

The main objective of this study was to determine the irrigation scheduling particularly the irrigation interval for butterhead lettuce in cocopeat-perlite mixture medium.

The specific objectives of the study were therefore as follow:

1. To determine the physical and hydraulic properties of different ratio of cocopeat-perlite mixture medium.
2. To determine water retention curve and hysteresis retention curves; main and primary wetting and drying curves for cocopeat-perlite mixture with and without root zone cooling.
3. To determine the temperature profile in water and cocopeat perlite mixture medium as well as establish simulation on the effect of temperature profile in the medium.
4. To evaluate the plant growth of butterhead lettuce with and without root zone cooling.

1.4 Scope of the study

The purpose study of investigating WRC and hysteresis in cocopeat-perlite mixture with and without RZC was to develop a recommended irrigation scheduling for butterhead lettuce. This study involves the scope of work as listed below:

i) A preliminary study on cocopeat-perlite mixture properties for the selection of the best cocopeat-perlite ratio. Later, the best ratio will be used for further study on WRC and hysteresis characteristics.
ii) The relationship of water content and suction in the medium will be studied through WRC and hysteresis phenomena with and without RZC.
iii) A RZC system consists of growing containers, chiller, piping and fertigation system was used to study the temperature effect on the WRC and hysteretic behaviours of the medium under RZC.
iv) Simulation on the temperature profile of cocopeat-perlite mixture under RZC.
v) Study on drip properties and recommendation on irrigation scheduling.
vi) An experimental plant will be grown as a part of the RZC application while comparing the plant growth with and without RZC.
vii) Comparison of the head size produced from the experiment with the commercial product produced from highland.

1.5 Limitations

This study was carried out at a specific condition and criteria. The scope and limitations of this study are as follow:

i) The growing medium used in this study was cocopeat and perlite, other inorganic materials such as zeolite, rockwool and vermiculite were not included.
ii) The WRC and hysteresis retention curves were measured in the fixed container volume (20 cm depth, 30 cm width and 200 cm length) under a rain shelter.
iii) The suction range to determine WRC and hysteresis retention curves in the growing medium were from 0 to 10 kPa only; based on the theory from De Boodt et al. (1973) developed for growing medium.
iv) Environment factors such as relative humidity, wind speed and sunlight were not discussed.
v) The air condition unit used for RZC was 2 hp only.
vi) The climatic data of daily temperature, relative humidity, wind speed, sunshine hours and solar radiation for the calculation of evapotranspiration were obtained from a climatic database, CLIMWAT 2.0 software.

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