



**UNIVERSITI PUTRA MALAYSIA**

**WATER REQUIREMENTS, WATER DISTRIBUTION PATTERN AND  
POTASSIUM SUBSTITUTION WITH SODIUM FROM SEAWATER  
FOR PINEAPPLE CULTIVATION ON BRIS SOIL**

**MD. NIAZUDDIN**

**FP 2007 8**



**WATER REQUIREMENTS, WATER DISTRIBUTION PATTERN AND  
POTASSIUM SUBSTITUTION WITH SODIUM FROM SEAWATER FOR  
PINEAPPLE CULTIVATION ON BRIS SOIL**

**By**

**MD. NIAZUDDIN**

**Thesis Submitted to the School of Graduate Studies, Univerisiti Putra Malaysia  
in Fulfilment of the Requirements for the Degree of Philosophy**

**May 2007**



**DEDICATED  
TO  
MY MOTHER AND FATHER  
MY GRAND FATHER  
AND  
MY WIFE FARZANA AFROSE (ASHA)  
MY SON FAHIM SHAHRIAR  
DAUGHTER NILIMA FARZANA (MIHI)**



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

**WATER REQUIREMENTS, WATER DISTRIBUTION PATTERN AND  
POTASSIUM SUBSTITUTION WITH SODIUM FROM SEAWATER FOR  
PINEAPPLE CULTIVATION ON BRIS SOIL**

**By**

**MD. NIAZUDDIN**

**May 2007**

**Chairman: Professor M. M. Hanafi, PhD, AMIC**

**Faculty: Agriculture**

Pineapple is one of the most traded tropical fruit in Malaysia; mostly planted on peat soil. However, Malaysia has a vast area of sandy fallow beach ridges interspersed swales (BRIS) soil. Due to lack of cultivable land, increasing populations, and urge to improve the standard of living of inhabitants of in this area, there is a need to develop a viable commercial-oriented agriculture. Therefore, the objectives of the study were to estimate the crop water requirements, water distribution patterns, and K substitution with Na from seawater for cultivation of pineapple on BRIS soil. A series of experiments including soil temperature, water distribution, and crop water requirements of the BRIS soil were determined in the glasshouse and field. Water distribution patterns were determined using water application rates of 2, 4, and 8 l/h emitters at different times of duration using a specially designed apparatus. Crop water requirements of 'N-36' of pineapple were estimated by planting of different stages of plants on the lysimeters and using the CROPWAT model. Pineapple stages were adjusted according to their length of growth on the lysimeters and in the model. The estimated crop water requirements was applied in the field at BRIS soil area,

Terengganu using Na from seawater for substitution of K requirements of pineapple (based on 300 kg K ha<sup>-1</sup>) at 15, 30, and 60% in comparison to the control (100% K) using fertigation techniques for 4 months with irrigation water. Pineapple growth, development, and yield were measured. With the exception in the morning, the topsoil temperature of BRIS soil was higher than the subsoil. The temperature gradually increased from 08:00 up to 14:00 hr of a day then decreased. On normal soil temperature and heated soil, the shape of water distribution of the wetted fronts was spherical or ellipsoidal. The higher discharge rate in short duration, the lateral movement was more as compared with the vertical movement. But the opposite was observed when lower discharge rate was applied in long time of duration. Wetted waterfronts were increased with increasing soil temperature in both horizontal and vertical directions. The average calculated crops reference evaporation (ET<sub>c</sub>) at the respective stages was 0.83, 0.73, 0.68 and 0.61 mm/day. The calculated average ET<sub>o</sub> was 1.99 mm/day. The estimated pineapple crop coefficient (K<sub>c</sub>) value (0.50) was the highest at the early growing stage 1 because of the maximum ET<sub>c</sub> occurred from the bare soil and young pineapple with limited transpiration rate. The K<sub>c</sub> value for pineapple was 0.30 at stage 2 to 4. The average depth of fertigation in the field using CROPWAT model was 1.67 mm/day. Application of 0, 15 and 30% Na from seawater substitution for K on plant height, number of leaf per plant, D-leaf length, and area, fresh and dry weight was not significantly different. Fruit length, diameter, and weight obtained from Na application at 15, and 30% Na for K substitution were not significantly different from 0% Na (100% K) treatment. The results indicate that up to 30% of pineapple K requirement can be substituted by Na obtained from seawater. Knowing the emitter size and soil water movement could ensure precise placement of water and nutrients in the active roots zone.

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

**KEPERLUAN AIR, PATEN TABURAN AIR DAN PENGGANTIAN KALIUM  
OLEH NATRIUM DARIPADA AIR LAUT UNTUK PENANAMAN NANAS  
PADA TANAH BRIS**

OLEH

**MD. NIAZUDDIN**

**Mei 2007**

**Pengerusi: Profesor M. M. Hanafi, PhD, AMIC**

**Fakulti: Pertanian**

Nenas merupakan salah satu buahan tempatan yang paling laris di Malaysia, yang mana ianya di tanam di tanah gambut. Namun begitu, Malaysia mempunyai kawasan tanah 'sandy fallow beach ridges interspersed swales (BRIS)' yang begitu luas. Dengan kawasan tanaman yang terhad, peningkatan populasi, dan usaha untuk menambah 'standard of living for BRIS area', ini memerlukan pelaksanaan ke arah orientasi pertanian yang mantap dan berdaya maju. Satu siri kajian di makmal lapangan telah di lakukan dengan menggunakan tanah BRIS untuk menanam nenas. Contoh-contoh tanah Bris telah dikumpul dan untuk menentukan suhu, taburan air keperluan airnya. Satu peralatan khas telah direkabentuk untuk digunakan untuk mengkaji kesan kadar penggunaan air, isipadu air, dan tempoh pembasahan permukaan tanah BRIS. Penggunaan air dengan kadar 2,4 dan 8 liter/ jam telah digunakan bagi tempoh masa yang berbeza. Bagi menentukan pekali tanaman untuk nenas pada tanah BRIS, lisimeter dan panci penyejatan Kelas A telah digunakan untuk menganggar penyejatan rujukan tanaman ( $ET_c$ ) dan penyejatan rujukan ( $ET_o$ ) dalam rumah kaca. Model CROPWAT pula telah digunakan untuk mengira

keperluan air tanaman (CWR) bagi nenas. Tiga kadar Na dari gantian air laut bagi K pada 15, 30 dan 60% telah dibandingkan dengan kawalan 0% Na (100% K) berdasarkan 300 kg/hektar pada pertumbuhan nenas. Pembangunan dan hasil penggunaan tanah BRIS dengan menggunakan teknik titisan fertigation dan larutan ini telah diaplikasikan selama 4 bulan dengan penggunaan air pengairan. profil suhu tanah BRIS menunjukkan suhu tanah atas adalah lebih tinggi dari suhu tanah bawahnya, kecuali pada waktu pagi. Meskipun begitu, suhu ini meningkat dengan mendadak sehingga 14.00 jam untuk satu hari dan kemudian suhunya mula menurun. Eksperimen pergerakan air pada tanah normal dan panas pula menunjukkan bentuk permukaan basah adalah bulat atau bujur. Dengan meningkatnya kadar air dalam tempoh yang singkat, pergerakan sisi lebih banyak berlaku jika dibandingkan dengan pergerakan menegak. Dari pemerhatian, pergerakan bertentangan pula akan berlaku apabila kadar air yang rendah dilakukan bagi tempoh masa yang panjang. Keputusan ini akan memastikan kedudukan air dan nutrient berada pada zon akar aktif. Permukaan air akan meningkat dengan pertambahan suhu tanah bagi kedua-dua arah menegak dan mendatar. Tahap pertumbuhan nenas 'N-36' telah diperbetulkan mengikut panjang pertumbuhannya pada lisimeter. Kedalaman purata pengairan air bagi tahap pertumbuhan 1,2,3 dan 4 adalah 2.43,1.56,1.54 dan 1.55 mm/hari dan purata penyejatan rujukan tanaman ( $ET_c$ ) yang dikira adalah 0.83,0.73,0.68 dan 0.61 mm/hari. Nilai bagi penyejatan rujukan ( $ET_o$ ) pula adalah 1.99 mm/hari. Nilai pekali tanaman nenas ( $K_c$ ) pula menunjukkan bacaan tertinggi pada iaitu 0.50 di mana ia berlaku pada tahap pertumbuhan awal kerana  $ET_c$  maksimum berlaku dari tanah atas dan nenas yang mengalami proses transpirasi yang terhad. Nilai  $K_c$  untuk nenas pula adalah 0.30 pada tahap 2 dan 4. penggunaan Na sebanyak 0,15 dan 30% dari gantian air laut untuk K pada ketinggian tumbuhan, bilangan daun, panjang D-daun, dan

keluasan, kesegaran dan berat kering adalah tidak banyak berubah. Pangang buah, diameter dan beratnya diperolehi dari penggunaan Na sebanyak 15 dan 30% untuk penggantian K juga tidak banyak berubah daripada 100% rawatan K. Keputusan menunjukkan sebanyak 30% keperluan K nenas boleh digantikan dengan Na yang diperolehi dari air laut.



## ACKNOWLEDGEMENTS

Praise to Almighty Allah for His blessings, kindness and giving the author proper guidance, strength, and will to complete this study.

The author wishes to express his heartfelt gratitude, indebtedness, and deep sense of respect to Professor Dr. M.M.Hanafi, the Chairman of the Supervisory Committee for his sincere support, guidance, constant encouragement, invaluable suggestions and generous help throughout the study period. He provided the author all facilities needed to complete this works. The author also much indebted and grateful to Dr. Abdul Aziz Zakaria and Dr Mohmmud Che.Husain, members of the supervisory committee for their encouragement, constructive advice and guidance in formulation and execution of the research project and critical review of the manuscript.

The author thankfully acknowledges to the UPM for providing financial support and facilitating him to study in Malaysia. The author also expresses his profound appreciation to the Peninsular Pineapple Plant State, Simpang leggam, Johor, Malaysia; Department of Agricultural Extension (DOA) and Malaysian Metrological Service (MMS) for supply of pineapple plants, weather data and allocation of their land to conduct experiments. Furthermore, he is grateful to the Bangladesh Institute of Nuclear Agricultural (BINA) for providing the deputation and all kinds of help to accomplish his degree.

The author feels proud to express his sincere appreciation and indebtedness to Mr Zainudin Bin Mohammad Ali, Mr. Alias Bin Tahar, Mr.Mohamed Shukri bin



Awang, Mr. Altab Hossain and Hartinee bt. Abbas for their cooperation, help and assistance in glasshouse and field experiments. He would like expressing his special thanks to his friends Mr. Abdullah Al Mamun, Dr. Mirza Mofazzal Islam (Apu) and Mr. Asharaful Islam (Belal) for their helps, inspiration and cooperation. He also wishes to express his appreciation to all of his colleagues, friends and well wishers.

The author respectfully acknowledges the blessings and good wishes of his parent; his teachers, uncles-unties, brothers, sisters, and relatives. He is especially grateful to his late father-in law and mother-in law, who provided lots of encouragement, moral support and looked after his wife and children in his absence. Special gratitude must go to his son Fahim Shahriar and daughter Nilima Farzana Mihi who have faced difficult times during his study period. Without their love, great sacrifice, patience, and support this study would not have been possible.

Finally, and above all, the author's wife Farzana Afrose Asha deserves a lot of thanks and appreciation not only for her love and care, but also for bearing the burden and responsibilities of taking care of their children in his absence, in addition, for active cooperation and support to conduct experiments and encouragement for a higher degree. The author really appreciates the hardship she faced due to his absence.



I certify that an Examination Committee has met on 3rd May 2007 to conduct the final examination of Md. Niazuddin on his Doctor of Philosophy thesis entitled “Water Requirements, Water Distribution Pattern and Potassium Substitution with Sodium from Seawater for Pineapple Cultivation on BRIS soil” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

**Y. Bhg. Mohd. Khanif Yusop, PhD**

Professor  
Department of Land Management  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Chairman)

**Jamil Talib, PhD**

Associate Professor  
Department of Land Management  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Internal Examiner)

**Fazlil Illahi Abd. Wahab, PhD**

Department of Agricultural Technology  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Internal Examiner)

**Gabriels Donald, PhD**

Professor  
Department of Soil Management and Soil Care  
Faculty of Agricultural & Applied Biological Science  
Ghent University, Belgium 32-9-264 6036  
(External Examiner)

---

**HASANAH MOHD. BT. GHAZALI, PhD**

Professor/Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date: 03 AGUEST 2007



This thesis 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 are as follows:

**M. M. Hanafi, PhD *AMIC***

Professor  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Chairman)

**Abdul Aziz Zakaria, PhD**

Lecturer  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Member)

**Mohammud Che Husain, PhD**

Deputy Director  
Mechanization and Automation Research Center  
Malaysian Agricultural Research and Development Institute (MARDI)  
(Member)

---

**AINI IDRIS, PhD**

Professor/Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date: 9 August 2007



## **DECLARATION**

I hereby declare that the thesis is based on my original work except for quotation and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

---

**MD. NIAZUDDIN**

Date: 09 July 2007

## TABLE OF CONTENTS

Page

<b>DEDICATION</b>	<b>ii</b>
<b>ABSTRACT</b>	<b>iii</b>
<b>ABSTRAK</b>	<b>iv</b>
<b>ACKNOWLEDGEMENTS</b>	<b>viii</b>
<b>APPROVAL</b>	<b>x</b>
<b>DECLARATION</b>	<b>xii</b>
<b>LIST OF TABLES</b>	<b>xvii</b>
<b>LIST OF FIGURES</b>	<b>xx</b>
<b>LIST OF ABBREVIATION/NOTATION/GLOSSARY OF TERMS</b>	<b>xxvix</b>

## CHAPTER

<b>1</b>	<b>INTRODUCTION</b>	
1.1	Pineapple and BRIS Soil in Malaysia	1.1
1.2	Statement of the Problem	1.2
1.3	Objectives of the study	1.6
1.4	Scope of the study	1.6
<b>2</b>	<b>LETERATURE REVIEW</b>	<b>2.1</b>
2.1	BRIS Soil	2.1
2.1.1	Formation of the BRIS Soil	2.1
2.1.2	BRIS Soil Temperature	2.3
2.2	Water Flow Mechanism	2.6
2.2.1	Water flow in Saturated Soil	2.7
2.2.2	Water Flow in Unsaturated Soil	2.8
2.2.3	Continuity equation	2.10
2.2.4	Richards equation	2.11
2.3	Water Movement and Distribution Patterns Under Drip Irrigation	2.13
2.4	Fertigation	2.17
2.4.1	Advantages of Fertigation	2.18
2.4.2	Fertigation and Crops Growth	2.19
2.4.3	Fertigation Frequency and Plants Growth	2.22
2.4.4	Fertigation vs. Granular Fertilizers	2.23
2.4.5	Problems of Excess and Under Fertigation	2.24
2.4.6	Selection of Fertilizers for Fertigation	2.24
2.5	Irrigation Model	2.25
2.5.1	CROPWAT Model	2.26
2.6	Scheduling	2.28
2.7	Crops Water Requirements	2.31
2.8	Lysimeter	2.33
2.8.1	General Concept of the Lysimeter	2.33
2.8.2	Working Principle of the Hydraulic Weighing Lysimeter	2.35
2.8.3	Types of Lysimeter	2.35
2.8.4	General Design Considerations of a Lysimeter	2.36
2.8.5	Lysimeter and Crop Water Requirements	2.37



	2.8.6	Lysimeter Performance and Limitations	2.40
2.9		Seawater-Nature and It Properties	2.42
	2.9.1	The Saline Agricultural Approach	2.43
	2.9.2	Seawater Based Agriculture	2.44
	2.9.3	Types of Plant Response to Salt	2.45
	2.9.4	Plant Response to Salt	2.46
2.10		Potassium	2.49
	2.10.1	Fixation and Leaching of Potassium in Soil	2.50
	2.10.2	Role of Potassium in Growth and Yield Formation	2.51
	2.10.3	Deficiency Symptoms of Potassium	2.54
	2.10.4	Sodium and Its Relationship with Potassium	2.54
2.11		Pineapple	2.57
	2.11.1	Nutrient Requirement for Pineapple	2.60
2.12		Summary	2.62
<b>3</b>		<b>MATERIAL AND METHODS</b>	<b>3.1</b>
3.1		Determination of BRSI Soil Temperature Profile	3.1
	3.1.1	Collection of BRIS Soil Columns	3.1
	3.1.2	Study Frameworks	3.2
	3.1.3	Measuring the BRIS Soil Temperature	3.3
3.2		Movement and Distribution Pattern of Water in BRIS Soil	3.4
	3.2.1	Construction of the Infiltration Measurement Apparatus	3.4
	3.2.2	Water Application System	3.6
	3.2.3	Measurement of Elapses Depth and Radius	3.9
	3.2.4	Estimation of Wetted Soil Volume	3.12
3.3		The Effect of Temperature on Water Movement in BRIS Soil	3.13
	3.3.1	Description of the Apparatus	3.13
	3.3.2	Determination of BRIS Soil Temperature	3.14
	3.3.3	The Experimental Procedure	3.14
3.4		Determination of Reference Evapotranspiration	3.16
	3.4.1	Pan Evaporation Method	3.16
	3.4.2	“Class A” Pan Evaporation	3.16
3.5		Determination of Cop Water Requirements for Pineapple	3.22
	3.5.1	Design and Construction of the Lysimeter	3.22
	3.5.2	Data Collection	3.32
	3.5.3	Calculation of Crop Evapotranspiration	3.33
	3.5.4	Crop Coefficient	3.33
3.6		Calculation of Crop Water Requirement and Irrigation Scheduling for Pineapple on BRIS Soil Using CROPWAT Model	3.35
	3.6.1	CROPWAT Model	3.35
	3.6.2	Justification of the CROPWAT Model	3.36
	3.6.3	Data Needed for Calculating Crop Water Requirements	3.37
	3.6.4	Pineapple Stages	3.39
3.7		The Effect of Potassium Substitution with Sodium from Seawater on Pineapple Growth, Development and Yield on BRIS Soil under Fertigation Techniques	3.42
	3.7.1	Location of the Experimental Area	3.42
	3.7.2	The Soil	3.42
	3.7.3	Climate of the Area	3.44

	3.7.4	Formation of Stock Solutions for Fertigation	3.46
	3.7.5	Established the drip Fertigation injection systems	3.48
	3.7.6	Planting	3.51
	3.7.7	Method of Fertigation	3.52
	3.7.8	Treatments and Experimental Design	3.53
	3.7.9	Fertilizer Application	3.54
	3.7.10	Calculation of Irrigation Water	3.54
	3.7.11	Flower Induction and other Cultural Practices	3.55
	3.7.12	Determination of Leaf Chlorophyll Content of Pineapple plant	3.56
	3.7.13	Data collection and harvesting	3.57
	3.7.14	Data Analysis	3.58
<b>4</b>		<b>RESULTS AND DISCUSSION</b>	<b>4.1</b>
	4.1	BRIS soil Temperature Profile	4.1
	4.1.1	Soil Temperature Variation at Different Times of a Day vs. Different Depths	4.1
	4.1.2	Mean Monthly BRIS Soil Temperature vs. Different Time a Day	4.4
	4.1.3	Mean Monthly Temperature vs. Various Depth of BRIS Soil	4.5
	4.1.4	Average Monthly BRIS Soil Temperature	4.7
	4.2	Evaluation of Water Distribution under Point Source Drip Irrigation	4.14
	4.2.1	Shape of the Wetting Front	4.14
	4.2.2	Effect of Discharge Rates on Wetting Front Movement	4.20
	4.2.3	Effect of Water Volume on Soil Moisture Distribution Pattern	4.27
	4.2.4	Effect of Water Application Duration on Elapsed Depth and Radius	4.34
	4.3	The Effect of Temperature on Water Movements in BRIS Soil	4.42
	4.3.1	Shape of the Wetting Fronts	4.43
	4.3.2	Effect of Soil Temperature on BRIS Soil Wetting Fronts	4.46
	4.4	Determination of Reference Evapotranspiration	4.55
	4.4.1	Class A Pan	4.55
	4.4.2	Selecting the Pan Coefficient	4.61
	4.4.3	Reference Evapotranspiration	4.62
	4.5	Determination of Crop Water Requirements for Pineapple	4.65
	4.5.1	Lysimeter Experiments	4.65
	4.5.2	Irrigation and $ET_c$ for Pineapple	4.74
	4.5.3	Crop Coefficient for Pineapple	4.78
	4.6	Calculation of Crop Water Requirement and Irrigation Scheduling for pineapples on BRIS Soil Using CROPWAT Model	4.83
	4.6.1	Calculation of Reference Evapotranspiration	4.83
	4.6.2	Crop Water Requirements for PINYR1	4.85
	4.6.3	Crop Water Requirements for PINYR2	4.88
	4.6.4	Total Crop Water Requirement for Pineapple	4.91
	4.7	The Effect of Potassium Substitution with Sodium from Seawater on Pineapple Growth, Development and Yield on BRIS Soil under Fertigation Techniques	4.93



4.7.1	Depth of Fertigation	4.94
4.7.2	Plant Growth	4.95
4.7.3	SPAD Values	4.109
4.7.4	Fruit	4.110
<b>5</b>	<b>CONCLUSIONS AND RECOMMENDATIONS</b>	<b>5.1</b>
5.1	Summary	5.1
5.2	Conclusions	5.4
5.3	Recommendation for Further Work	5.8
	<b>REFERENCES</b>	<b>R.1</b>
	<b>APPENDICES</b>	<b>A.1</b>
	<b>BOIDATA OF THE AUTHOR</b>	<b>B.1</b>



## LIST OF TABLES

<b>Table</b>	<b>Page</b>	
2.1	Summary of differences between saturated and unsaturated flow (adapted from Rattan and Shukla, 2004)	2.13
2.2	Cation Concentrations, pH and EC of Dilute Seawater for small Scale Experiment adapted from Yufdy, 2004	2.42
2.3	Approximate average concentrations of the main solutes in seawater (Source: Allen Cooper (1979)	2.43
2.4	Classification of water (Source: Rhoades et al., 1992)	2.44
2.5	Differences between halophytes and glycophytes with respect to salt tolerance mechanism (Parida, and Das, 2005)	2.46
3.1	Water application duration vs. emitters discharge rates (where, $j = 2l/h$ , $k = 4/h$ , $l = 8l/h$ , $a = 10$ , $b = 20$ , $c = 30$ , $d = 40$ , $e = 50$ and $f = 60$ minutes)	3.8
3.2	Bulk density, Particle density, and porosity and water retention Capacity of BRIS Soil ( Rhu Tapai, Terengganu)	3.43
3.3	Mean fine, medium and coarse sand fractions of Rhu Tapai soil Series (Source: Yeoh, 1986)	3.43
3.4	Average monthly rain days, rainfall and evapotranspiration (1990-2005)	3.44
3.5	Average monthly (1990- 2005) air temperatures at Terrangganue	3.46
3.6	Treatments Summary of Na for K Substitute	3.54
4.1	The BRIS soil temperature at different times of a day vs. different depth	4.2
4.2	Monthly BRIS soil average temperature at different times of a day	4.5
4.3	Monthly BRIS soil average temperatures in different depths	4.6
4.4	Rainfall, ETo and BRIS soil and air temperature at different season	4.9
4.5	Air temperature, ETo, rainfall and R. humidity at UPM	4.9
4.6	Wetting front advances at different discharge rates vs. different	4.21



	applied times of duration on BRIS soil water movement	
4.7	The regression results of the vertical advances of wetting front as a function of the elapsed time, $z = a t^b$	4.24
4.8	Effect of various discharge volume and different application times duration on soil water wetting fronts	4.28
4.9	Increasing rate for discharge volume, wetted soil, radius and elapse depth between 2 l/h and 4 l/h at constant applied time duration	4.30
4.10	Increasing rates for discharge volume, wetted soil, radius and elapse depths between 2l /h and 8l /h at constant applied time duration	4.30
4.11	Parameters for estimation of surface wetted radius	4.33
4.12	The effect of same volume of water applied at different times duration on BRIS soil wetting fronts	4.35
4.13	Applied times duration difference vs. increasing rate of wetting fronts	4.37
4.14	Compared to water infiltration movements between hot and normal BRIS soil at specific (constant, 2 l/hr) discharge rate, but different applied times duration and different soil temperatures	4.46
4.15	Effect of soil temperatures, a constant discharge rate, and different applied time of duration on increasing rate of BRIS wetting fronts	4.50
4.16	BRIS soil temperature distribution patterns during different applied time of duration	4.51
4.17	Effect of BRIS soil temperatures at a constant discharge rate and constant applied time duration on wetting fronts	4.51
4.18	BRIS soil temperature distribution patterns during constant discharge rate and applied time of duration	4.54
4.19	Monthly average weather data from glass house and outside of the glasshouse	4.56
4.20	Summary of the lysimeters experiments	4.82
4.21	Calculated climate data for Terengganu by CROPWAT	4.83
4.22	Calculated ETo and CWR for PINYR1 for pineapple on BRIS soil	4.85

4.23	Calculated SMD for PINYR1 on BRIS soil during pineapple growth	4.87
4.24	Calculated ETo and CWR for PINYR2 for pineapple on BRIS soil	4.89
4.25	Calculated SMD for PINYR2 on BRIS soil during pineapple growth	4.90
4.26	Summary of the fertigation application for pineapple on BRIS soil	4.94
4.27	Influence of Na substitution for K and plant age on plant growth and D- leaf characteristics of pineapple	4.96
4.28	Effects of Na substitution for K from seawater on plant growth and D-leaf characteristics of pineapple	4.97
4.29	Effect of %Na substitute for K from seawater on pineapple Length, diameter and weight	4.111

## LIST OF FIGURES

<b>Figure</b>		<b>Page</b>
2.1	Formation of BRIS soils. (Adapted from Yeoh, 1986)	2.2
2.2	General elevation for unsaturated conductivity ( $K(\theta)$ ) versus suction $h$ for three different soil textured (adapted from James et al., 1999)	2.10
3.1	The Study framework	3.2
3.2	PVC tubes with BRIS soil column and thermometers sensors	3.3
3.3	Water movement and distribution measurement apparatus and its wood sticks for fences of the apparatus	3.5
3.4	Soil water movement and distribution measurement apparatus diagram with dimensions	3.5
3.5	Infiltration measurement instrument was filled with air-dry unsaturated BRIS soil and compacting according to its bulk density	3.6
3.6	Water supply system to the infiltration measurement apparatus	3.7
3.7	Type of emitters (2, 4, and 8 l/hour) used in this study	3.7
3.8	Calibrating the emitters adjusted with water pressure and applied times	3.7
3.9	Emitter was placed geometrically center of the level surface and ensure a constant and continuous supply	3.8
3.10(a)	Soil wetted radius was measuring with a measuring tape	3.9
3.10(b)	Irregular wetting fronts were measuring in different angles	3.10
3.11	Non-wetted soil was removing and only the wetted soil monolith on the open surface	3.10
3.12	The wetted soil monolith (layers) was removed by cutting with a sharp- steel blade from the bottom.	3.11
3.13	The wetted soil monolith (layers) was removed by cutting with a sharp- steel blade from the bottom and throw it to the floor	3.11



3.14	The bottom of the removed layer becomes the surface for the next monolith (layer)	3.11
3.15	The removed soil from the container (box) was placed on the floor of the glasshouse for drying	3.12
3.16	Thermometer sensors were inserting on the surface and different depth of the monolith up to center .	3.13
3.17	Thermometer sensors were inserting on the surface and different depth of the monolith up to center and flash lights were used to heat the soil	3.14
3.18	Floodlights were used to dry the BRIS soil	3.15
3.19	A standard class A pan with its dimension (Adapted from Allen <i>et al.</i> , 1998)	3.17
3.20	A class A pan with a hook gauge mounted on a wooden open frame platform	3.17
3.21	A hook gauge	3.18
3.22	Hook gauge reading was observed with a magnifying glass accurately	3.19
3.23	Two case of evaporation pan sitting and their environment Adapted from Allen <i>et al.</i> , 1998)	3.20
3.24(a)	A weighing hydraulic lysimeter and its dimensions	3.23
3.24 (b)	Foundation of the lysimeters made with bricks and woods pieces	3.24
3.25	Vehicle's tyre's inner tubes were wrapping with tape and used to make Lysimeter	3.24
3.26	The manometer's pipe was easily passed through between plywood's holes and the foundation gap	3.25
2.27	Square size plywood was lain down on each inner tube	3.25
3.28	Manometers and dummy manometers were hanged up to calculated height and red colour was added with water to observe any changed clearly	3.26
3.29	Graph papers were used to make manometers	3.26
3.30	Collecting the percolated water from the lysimeters	3.28

3.31	Tensiometers were put on the lysimeters to measured soil moisture	3.29
3.32	Different stages pineapple plants were planted on lysimeters	3.29
3.33	Each stage has three replications (lysimeter) and each replication have two pineapple plants	3.30
3.34	Pineapple stages on the lysimeters	3.31
3.35	CropWat calculating $ET_o$ using mean maximum, minimum air temperature, humidity, wind speed and sunshine hour	3.38
3.36	Crop data for pineapple PINYR1	3.38
3.37	Crop data for pineapple PINYR2.	3.38
3.38	Duration of pineapple stages, and PINYR1 and PINYR2	3.39
3.39	Soil data for PINYR1	3.40
3.40	Irrigation selecting criteria	3.40
3.41	Soil data for PINYR2	3.41
3.42	Cropping pattern planting	3.41
3.43	Average monthly rainfall of experimental site at Kuala Terrenganu	3.45
3.44	Rainy days of experiment site at Kuala Terrenganu	3.45
3.45	Average (1990-2005) daily rainfall and $ET_o$	3.45
3.46	Seawater was collected and transferred to the filed	3.47
3.47	A special design apparatus was used to mixed fertilizer with seawater	3.47
3.48	Stock fertilizers solution	3.48
3.49	A fertigation system consists with pump, reservoir tanks, injector, main, sub and lateral lines	3.49
3.50	Fertigation main, sub and lateral lines	3.49
3.51	A meter used to control the water pressure	3.50
3.52	Fertilizer Injector	3.50

5.53	Pineapple plants covered by sunshine black plastic mulch	3.51
3.54	Fertigation application phases	3.52
3.55	Depth of fertigation for pineapple on BRIS soil	3.55
3.56	Fertigated days for pineapple on BRIS soil at Terengganu	3.55
3.57	Leaf CM value was recorded ETc for pineapple in the glasshouse	3.56
3.58	Standard curve for total leaf chlorophyll content (mg /l) and CM values (leaf greenness) for pineapple plants	3.57
3.59	Pineapple field	3.58
4.1	BRIS soil temperature at different depths	4.3
4.2	BRIS soil temperature at different times of a day	4.3
4.3	BRIS soil monthly average temperature	4.8
4.4	BRIS soil (T soil) and air temperature (T air)	4.10
4.5	Average BRIS soil temperature flow in different depths at 08:00 (a), 10:00 (b), 12:00 (c), 14:00 (d), 16:00 (e) and 18:00 (f) times of a day in the year	4.12
4.6	Comparative features of water distribution patterns under different discharge rates on BRIS soil for 10 and 20 minutes	4.17
4.7	Comparative features of water distribution patterns under different discharge rates on BRIS soil for 30 and 40 minutes	4.18
4.8	Comparative features of water distribution patterns under different discharge rates on BRIS soil for 50 and 60 minutes	4.19
4.9	Discharge rate vs. wetted radius ( $r = \text{radius}$ )	4.21
4.10	Discharge rate vs. elapsed depth ( $d = \text{depth}$ )	4.22
4.11	Vertical advances of wetting front versus elapsed time for BRIS soil under different application rates	4.24
4.12(a-c)	Observed and predicted vertical advance of wetting front for BRIS soil under various application rate (2, 4, and 8 l/h)	4.25
4.13	Horizontal and vertical advances are a function of discharge rate	4.26



4.14	Discharge volume vs. wetting fronts advances	4.29
4.15	After a certain depth or elapsed time, horizontal movement decreased with increasing elapsed times	4.31
4.16	Surface wetted radius as a function of the cumulative water applied for BRIS soil under different application rates	4.32
4.17(a-c)	Observed and predicted surface wetted radius for BRIS soil under 2, 4, and 8 l/h application rates	3.34
4.18	The lowest application rate at highest applied time duration had a longest elapsed depth and greater spread	4.35
4.19	Wetting fronts vs. elapsed time (for 2l/hr, R = radius, D = depth)	4.38
4.20	Wetting fronts vs. elapsed time (for 4l/hr, R = radius, D = depth)	4.38
4.21	Wetting fronts vs. elapsed time (for 8l/hr, R = radius, D = depth)	4.38
4.22	Wetted depth in different times vs. discharge rates (q1, q2, and q3 are the 2.0,4.0, and 8.0 l/ hr emitters)	4.39
4.23	Wetted radius in different times vs. discharge rates (q1, q2, and q3 are the 2.0,4.0, and 8.0 l/ hr emitters)	4.39
4.24	Wetted soil volumes in different times vs. discharge rates (q1, q2, and q3 are the 2.0, 4.0, and 8.0 l/ hr emitters)	4.40
4.25(a-c)	Water movement patterns (a-c) on different soil temperatures and different applied times of duration at the 2-l/hr-discharge rate	4.43
4.26(d-f)	Water distribution patterns (a-c) on different soil temperatures and a constant applied time of duration at the discharge rate of 2-l/hr	4.44
4.27	BRIS soil temperature increased the advancement of wetted radius compared to the normal soil	4.47
4.28	Vertical wetting front increased with increasing the BRIS soil temperature compared to the normal soil (D hot = depth in hot and D normal = depth in normal soil)	4.47
4.29	Progress of soil water vertical movement on BRIS soil temperature vs. elapsed times	4.48