UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF AN INTEGRATED COMPUTER AIDED DESIGN TOOL FOR MICROIRRIGATION SYSTEMS

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By

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Thesis Submitted in Fulfilment of the Requirement for the Degree of Master of Science in the Faculty of Engineering Universiti Putra Malaysia

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To my parents

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

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January 2001

Chairman: **Associate Professor Ir. Mohd. Amin Mohd. Soom, Ph.D**

Faculty: **Engineering**

Planning, design and management of microirrigation systems require extensive numerical calculations. The introduction of computers in these processes removes much of the complications in calculation and results in more accurate analysis. Not many of the available software can be used to deal with an overall irrigation system implementation. Usually, separate software are used for irrigation planning and irrigation systems design. Consequently, this increases the investment cost for using the software in irrigation schemes. Hence, an integrated approach for both planning and system design is required.

In this study, an integrated computer aided design for microirrigation systems was developed. The program was written in Visual Basic (version 6.0) and it runs in Windows environment. A user-friendly interface is provided to give more flexibility to the user. This program uses menu bar and toolbar which takes the user to all data entry and results dialogs. Additionally, it is designed in such a way that extensive use of tables

tables and graphics will be provided. This program also provides a help file that can be used as a guide for selecting the appropriate data during data entry processes.

The developed program has the ability to estimate crop water requirements and design of microirrigation system pipelines. The computation of reference crop evapotranspiration from the available climatic data can be done for daily and monthly time steps, using FAO Penman-Monteith method. Crop water requirement during the whole crop growing season can be calculated. Using these data, the program estimates irrigation requirement taking into consideration the available rainfall. All the inputted data and the obtained results can be displayed in tabular or graphical forms.

The program is also capable of performing analysis of either lateral or submain unit. All the emitter flows along a lateral or in a submain unit can be determined. Additionally, maximum and minimum emitter flows and their locations can also be determined. Finally, emitter flow variation and pressure variation along a lateral or in a submain unit are computed. In this stage, tables and graphics are also provided. The overall laterals' layout and emitter flows profile can be displayed in the screen.

The developed program can be considered as a tool for preliminary design of microirrigation systems. It is recommended to extend it to more powerful software by including the design of all irrigation system.

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

PEMBANGUNAN KAEDAH BERSEPADU MEREKABENTUK SISTEM PENGAIRAN MIKRO TERBANTU KOMPUTER

Oleh

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Januari 2001

Pengerusi: **Profesor Madya Ir. Mohd Amin Mohd Soom, Ph.D.**

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Perancangan, rekabentuk dan pengurusan sistem pengairan mikro memerlukan pengiraan yang banyak. Penggunaan komputer dalam proses tersebut mengelakkan banyak kesulitan dalam pengiraan dan keputusan analisis yang lebih tepat boleh diperolehi. Tidak banyak perisian yang terdapat di pasaran boleh digunakan untuk merancang dan merekabentuk sistem pengairan. Biasanya dua program berlainan diperlukan untuk merancang dan satu lagi untuk merekabentuk. Ini akan memerlukan kos pelaburan perisian yang lebih besar. Oleh yang demikian satu pendekatan bersepadu bagi merancang dan merekabentuk amatlah diperlukan.

Dalam kajian ini, satu kaedah merekabentuk sistem pengairan mikro dengan bantuan komputer telah dibangunkan. Program ini ditulis dalam Visual Basic (Versi 6.0) dalam persekitaran Windows. Satu antaramuka mesra pengguna disediakan untuk keanjalan penggunaan. Palang menu dan palang alat digunakan untuk mencapai semua dialog untuk memasukkan data dan keputusan. Rekabentuk program juga membolehkan

penggunaan meluas jadual dan grafik. Fail pertolongan membantu pemilihan data yang bersesuaian semasa proses memasukkan data.

Program tersebut boleh menganggar keperluan air tanaman dan rekabentuk saluran paip sistem pengairan mikro. Pengiraan sejatpemeluhan tanaman rujukan daripada data cuaca yang ada boleh dilakukan dalam tingkatan masa harian atau bulanan menggunakan kaedah Penman-Monteith. Keperluan air tanaman bagi sepanjang musim boleh dikira. Dengan data tersebut program ini dapat menganggar keperluan air pengairan dengan mengambil kira hujan berkesan. Semua data yang dimasukkan dan keputusan boleh dipaparkan dalam bentuk jadual atau grafik.

Program ini boleh melakukan analisis sama ada bagi satu unit saluran subutama atau saluran sisi sahaja dimana semua kadar luahan dari penyebar dapat dipastikan. Kadar luahan maksimum dan minimum dan lokasi juga boleh dikenalpasti. Akhirnya, variasi luahan dan variasi tekanan sepanjang saluran sisi atau unit subutama dapat dikira. Jadual dan grafik disediakan untuk memaparkan susunatur keseluruhan saluran paip dan profil luahan penyebar.

Program yang dibangunkan ini boleh dianggap sebagai satu alat untuk rekabentuk awal sebuah sistem pengairan mikro. Kajian seterusnya boleh menjadikan program ini satu perisian yang lebih berkuasa dengan memasukkan rekabentuk untuk semua jenis sistem pengairan.

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I certify that an Examination Committee met on 13th January 2001 to conduct the final examination of Abdelouahid Fouial on his Master of Science thesis entitled "Development of an Integrated Computer Aided Design Tool for Microirrigation Systems" 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:

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DECLARATION

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

ABDELOUAHID FOUIAL

Date: January 20, 2001

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABREVIATIONS AND NOTATIONS

CWR	Crop Water Requirement.
FAO	Food and Agriculture Organization.
IWR	Irrigation Water Requirement.
USDA	United State Department of Agriculture.

a_s	Fraction of extraterrestrial radiation reaching the earth on overcast days
$a_s + b_s$	Fraction of extraterrestrial radiation reaching the earth on clear days
C	Pipe roughness coefficient.
c_p	Specific heat at constant pressure = 1.013×10^{-3} kJ Kg^{-1} $^oC^{-1}$.
CV	Coefficient of variation.
D	Day in the month.
D_p	Pipe diameter [m].
D_e	Emitter diameter [m].
D_l	Inside diameter of lateral [cm].
D_s	Submain diameter [cm].
d_r	Relative earth-sun distance.
e_a	Actual vapour pressure [kPa].
e_s	Saturated vapour pressure [kPa].
e_a	Actual vapour pressure [kPa].
$(e_s - e_a)$	Saturated vapour pressure deficit [kPa].
$e^o(T)$	Saturated vapour pressure at the air temperature [kPa].
$e^o(T_{min})$	Saturated vapour pressure computed at T_{min} [kPa].
$e^o(T_{max})$	Saturated vapour pressure computed at T_{max} [kPa].
EC_w	Electrical conductivity of the irrigation water [dS m^{-1} or mmhos cm^{-1}].
ET_0	Reference crop evapotranspiration [mm day^{-1}].
ET_C	Crop water requirements [mm day^{-1}].
ET_{CP}	Average daily consumptive use during the peak use period [mm day^{-1}].
EU	Emission uniformity [%].
f	Friction factor.
G	Soil heat flux density [MJ m^{-2} day^{-1}].
G_{SC}	Solar constant =0.0820 MJ m^{-2} day^{-1}.
H	Inlet or operating pressure [m].
H_l	Operating pressure at the inlet of lateral [m].
H_s	Operating pressure at the inlet of submain [m].
H_{var}	Pressure variation

H_f Friction loss [m].
i Day number within the growing season.
i Ratio of a given length from the inlet l to the total length L.
M_l Minor loss [m].
IR Irrigation water requirement [mm period^{-1}].
IR_m Maximum gross daily irrigation [mm].
J Number of day in the year.
K Discharge coefficient
$K_{C,i}$ Crop Coefficient on day i.
$K_{C,next}$ Crop coefficient at the beginning of the next stage.
$K_{C,prev}$ Crop coefficient at the end of the previous stage.
K_e Soil water evaporation coefficient
K_{cb} Basal crop coefficient (describes crop transpiration).
L Lateral or Submain length [m].
L_l Total length of lateral [m].
LR Leaching requirement ratio under microirrigation.
L_{stage} Length of the stage under consideration [days].
$\sum(L_{prev})$ Sum of the length of all previous stages [days].
M Month number.
$\max EC_e$ Electrical conductivity of the saturated soil extract [dS m^{-1} or mmhos cm^{-1}].
n Actual duration of sunshine [hour].
N Maximum possible duration of sunshine or daylight hours [hour].
n/N Relative sunshine duration.
n Total number of emitters along a lateral.
N Number of emitters in a submain unit.
N_e Number of emission per plant.
P Atmospheric pressure [kPa].
P_C Percentage of soil surface shaded by crop canopies at midday.
Q Total discharge [l/s].
Q_o Total discharge determined by the operating pressure [l/s].
q_i Emitter flow at a given length ratio [l/s].
q_{ij} Emitter flow at a location i of a j^{th} lateral in a submain unit [l/s].
q_{oo} Emitter flow resulted from the operating Pressure H and is considered as the flow from the first emitter of the first lateral line [l/s].
q_o Emitter flow at the inlet determined by the operating pressure [l/s].
$q_{\max}$ Maximum emitter flow [l/s].
$q_{\min}$ Minimum emitter flow [l/s].
$\bar{q}$ Average emitter flow [l/s].

q_{var} Emitter flow variation [%].

R_e Effective rainfall [mm period^{-1}].

R_T Total amount of rainfall [mm period^{-1}].

R_a Daily total extraterrestrial radiation [MJ m^{-2} day^{-1}].

R_n Net radiation at the crop surface [MJ m^{-2} day^{-1}].

R_{ns} Net shortwave radiation [MJ m^{-2} day^{-1}].

R_{nl} Net longwave radiation [MJ m^{-2} day^{-1}].

R_s Incoming solar short wave radiation [MJ m^{-2} day^{-1}].

R_{so} Shortwave solar radiation for a clear sky day [MJ m^{-2} day^{-1}].

R_i Friction drop ratio = $\Delta H_i / \Delta H$.

R_j Friction drop ratio; $R_j = \Delta H_{sj} / \Delta H_s$.

R_i' Energy gain (or loss) ratio.

R_j' Energy gain (or loss) ratio along a submain with respect to the length ratio j .

RH_{max} Maximum daily relative humidity [%].

RH_{min} Minimum daily relative humidity [%].

RH_{mean} Mean relative humidity [%].

S_p Spacing between plants in the row [m]

S_r Spacing between plant rows [m]

S_o Lateral (or submain) slope.

T Mean daily air temperature at 2m height [^{o}C].

T_{dew} Dew point temperature [^{o}C].

T_{max} Maximum daily temperature [^{o}C].

T_{min} Minimum daily temperature [^{o}C].

$T_{max,K}$ Maximum daily air temperature [^{o}K].

$T_{min,K}$ Minimum daily air temperature [^{o}K].

$T_{month,i}$ Mean air temperature of month i [^{o}C].

$T_{month,i-1}$ Mean air temperature of previous month [^{o}C].

T_i Irrigation application time required during peak use period [hr day^{-1}].

T_d Average daily transpiration rate during the peak use month [mm day^{-1}].

u_2 Wind speed measured at 2m height [m s^{-1}].

u_z Measured wind speed at z_m above ground surface [m s^{-1}].

V Flow velocity [m/s].

x Emitter discharge exponent.

z Elevation above sea level [m].

z_m Height of measurement above ground surface [m].

ΔH_i Total friction drop at a given length ratio, i [m].

ΔH_s	Total friction drop at the end of a submain [m].
ΔH_{sj}	Total friction drop at a given length ratio along a submain [m].
$\Delta H'$	Total energy gain or loss by uniform slope at the end of lateral [m].
$\Delta H_i'$	Energy gain (or loss) at i.
$\Delta H_s'$	Total energy gain or loss at the end of the submain [m].
$\Delta H_l'$	Total energy gain or loss by uniform slope condition at the end of the lateral connecting submain at its mean pressure location [m].

Δ	Slope vapour pressure curve [kPa $^oC^{-1}$].
γ	Psychrometric constant [kPa $^oC^{-1}$].
ε	Ratio molecular weight of water vapour /dry air = 0.622.
λ	Latent heat of vaporization [MJ Kg^{-1}].
α	Albedo or canopy reflection coefficient
φ	Latitude [Rad]. (Negative when referring to Southern Hemisphere).
δ	Solar declination [Rad].
ω_S	Sunset hour angle [Rad].
σ	Stephan-Boltzmann constant =4.903x 10^{-9} MJ K^{-4} m^{-2} day^{-1}.
$\forall_G$	Gross volume of water required/plant/day during the peak use period [l day^{-1}].
ν	Kinematic viscosity of water [m^2/s].

CHAPTER I

INTRODUCTION

Since past centuries, irrigation has been used for crop production during periods where rainfall was not available. Irrigation has played a strategic role in the continuous process of human evolution and cultural development (Phene and Phene, 1987). With water scarcity and population expanding in regions where rainfall is not sufficient, the development of an irrigation system which increases water use efficiency and water conservation became necessary.

In the beginning of the 1960's, a new irrigation method using porous pipes appeared. Microirrigation attracted many researchers. Extensive research started trying to develop the new approach. The results showed the potentialities to conserve water, since the ability of the new method to control water application. Additionally, it provided high application uniformity, hence uniform yield productivity. The development of this method passed through many stages in which it was increasingly ameliorated. During the earlier period of its development, microirrigation systems was not as widely used as surface and sprinkler systems due to many problems related to its operation and its relatively high cost compared with the others. Nowadays, with the introduction of new technologies, many of those problems have been overcome. Trickle irrigation does offer many unique agronomic, agrotechnical and economic advantages for the present and future irrigation technologies (Bucks an Davis, 1986).

For proper irrigation water management, one should chose the most appropriate water application method. Some of the conditions which determine the type of irrigation to be used include quantity and quality of available water, cost of water, topography of the area, soil depth and texture, type of crop, salinity problem, frost protection and the overall system cost. Problems arise when irrigation is practiced without restraint of knowledge of basis factors governing soil, irrigation water requirements, salinity and plant-water use (Phene and Phene, 1987).

The first step that should be done for the design of an irrigation system is the evaluation of irrigation water requirements. Microirrigation systems are usually designed and managed to supply frequent light application of water and wet only a portion of soil surface. The system should have a minimum design capacity, sufficient to deliver the peak daily irrigation water requirement in about 90 % of the time available or not more than 22 hours of operation per day (ASAE Standards, 1994). Estimation of irrigation water requirement is mainly depending on crop water requirements that is the crop evapotranspiration (ET_C). Many empirical methods have been developed by specialists worldwide to estimate evapotranspiration from different climatic data. But, advance in research and the use of more accurate assessment of crop water use have revealed weaknesses in these methods. As a result, FAO proposed a new approach for the estimation of reference evapotranspiration (ET_0). The FAO Penman-Monteith method is recommended as the sole method for estimating ET_0 (Allen *et al*., 1998).

Microirrigation is a pressurized pipe network system which is used for its high efficiency and application uniformity. To obtain this objective, the system should be properly designed and managed. One of the most important factors that determine the success or the failure of a microirrigation system is the hydraulic design. The best choice of laterals and submains size and emitters type plays an important role in system operation. The use of large diameter pipe decreases the pressure variation and increases the system performance. Additionally, the use of pressure compensating emitters raises pressure uniformity along the system. Unfortunately, pipes with larger diameter and pressure compensating emitters are usually the most costly. To solve this problem, the combination of different characteristics of those parameters should be selected to optimize the system performance and cost.

The planning, design and management of microirrigation systems require intensive numerical calculations. The introduction of computers in these processes removes much of the complications in calculation and results in more accurate analysis. For this purpose, many software that are aimed to help either designers or farmers in their works have been developed during the last decades. IRRICAD is considered as the premier irrigation software worldwide. It can be used for the design of almost all types of irrigation. However, this software has a graphically based interface which cannot be used easily without a good knowledge in computer. It is relatively an expensive software to be used by small farmers. Several other models are available; many of them are DOS based, and are not interactive for users. Furthermore, a few of the available software can be used when dealing with an overall irrigation system implementation. On the other hand, separate software are used for irrigation planning and irrigation systems design. Consequently, this increase the investment cost for the utilization of software in irrigation schemes. From here the idea to develop a computer program that can be used for the above mentioned purposes emerges.

The main objective of this research is to develop an integrated computer aided design for microirrigation systems. The proposed program is a Windows environment using a user-friendly interface for simple data manipulation. For more flexibility in decision making for microirrigation planning and design, this program has been divided into two integrated models:

- The first model is a decision support system developed for irrigation planning. The main function of this model is the computation of reference crop evapotranspiration, crop water requirements and irrigation water requirement.

- The second model is an aided design system developed for the design of microirrigation pipelines. This model helps user makes decisions when selecting emission devices to be used for appropriate water application. Laterals and submain unit can be designed separately for different field conditions.

CHAPTER II

LITERATURE REVIEW

Introduction

Microirrigation (trickle/drip irrigation) system is a low-pressure and low-volume water application method. This method applies water either onto the ground surface or directly into the root zone. Because of its ability to irrigate only where it is desired, microirrigation system has higher application efficiency and water distribution uniformity compared with conventional systems. Moreover, it can be used for sloping and either regular or irregular field.

Microirrigation system requires lower energy for its operation because less water is used compared with the other systems. Using this system, many experiments have shown the improvement of yields quality and quantity for some crops. Moreover, the use of saline water is possible since water content of the soil is kept at optimal level. This system also minimizes cultural operations interruption, for example, tillage and harvesting can be carried out when irrigating. In a well-designed and installed microirrigation system, wind and undulating/sloping land do not disturb uniformity of water distribution. Despite of its numerous advantages. the system has some disadvantages which can affect either its operation or crop yields if not well managed. The most severe of those disadvantages is the clogging of the system components by particles, chemicals and biological materials. Beside this, the different component of this system increases highly the initial cost of its installation. Furthermore, The limitation of