

**USING PULSE DRIP IRRIGATION TO IMPROVE MOISTURE
DISTRIBUTION AND DEVELOPING MATHEMATICAL
MODEL FOR IRRIGATION MANAGEMENT**

By

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**A Thesis Submitted in Partial Fulfillment
Of**

The Requirements for the Degree of

**DOCTOR OF PHILOSOPHY
in**

**Agriculture sciences
(Agricultural Engineering)**

**Department of Agricultural Engineering
Faculty of Agriculture
Ain Shams University**

2017

Approval Sheet

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Date of examination: / /2017

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ABSTRACT

Walied Morsy Ibrahim Hassan: Using Pulse Trickle Irrigation to Improve Moisture Distribution and Developing Mathematical Model for Irrigation Management. Unpublished Ph. D. Thesis, Department of Agricultural Engineering, Faculty of Agriculture, Ain Shams University, 2017.

Numerical model was developed for predicating wetting front movement and soil moisture distribution from point source under continuous surface and pulse trickle irrigation was using Visual Basic of Applications 2013. The model combines the alternate direction implicit method (ADI) of solving two dimensional linear partial differential equations with the iterative Newton-Raphson method to advance through variable time. To validate the simulation model was divided into two steps. The first step, tested the validity of the model under the wetted front movement at selected times (120 min continuous, 180 min pulse 30 on/ 15 off, 240 min pulse 15 on/ 15off, and 360 min pulse 15 on/ 30 off), movements were compared between the predicted and observed results with discharge rates (1, 1.5, 2, 3, 4, 5, 6 and 8 l/hr).

The second step was testing the validity of the model under the soil moisture distribution, and comparing between the predicted and measured results at the previous selected times with the same discharge rates. The difference percent between the observed and predicted with a range of (-12.66 % to 19.2 %) for radius, depth of a range was (1.91 % to 17.22 %) and the coefficients of correlation of linear regression analysis between predicted and measured soil water content ranged from (0.7284 to 0.9333). The numerical model could be satisfactorily used to find out soil moisture movement and distribution under different conditions of continuous and pulse trickle irrigations.

Keywords: Continuous and pulse trickle irrigations, Numerical model, ADI finite difference, Newton-Raphson method, Two dimensional flow model, Soil moisture movement.

ACKNOWLEDGMENT

I wish to express my special appreciation and sincere gratitude to prime supervisor **Dr. Mahmoud Mohamed Hegazi** Professor of Agricultural Engineering, Ain Shams University, for sincere supervision, valuable guidance and suggestion during this study.

I would express my thanks and sincere appreciation to **Dr. Khaled EL-Bagoury** Assoc. Prof. of Agricultural Engineering, Ain Shams University, for his encouragement and help in this work.

I express my deep appreciation and sincere gratitude to **Dr. Mohamed Adel EL-Saadawy** Professor of Agricultural Engineering, Agric. Eng. Res. Inst., Agric. Res. Center, for his supervision, valuable guidance in the field work.

Finally, thanks to **My Family** for support and attention during this investigation.

INTRODUCTION

Some properties of trickle irrigation, such as low economic cost, the ability to apply fertilizers, reduced water stress, increased irrigation efficiency, ease of automation, that have contributed to the increased popularity in the last few decades, if the system is designed to meet water requirements.

Pulse trickle irrigation technique helps in reducing clogging of emitters, increasing yield, saving water, improving quality of crop, reducing energy consumption ...etc. So that it is applied all over the world.

Wan and Kang (2006) intermittent irrigation is one of the most important factors in trickle irrigation scheduling, and the conditions in the root zone throughout the crop period from oxygen and moderate moisture can be achieved with proper pulse trickle irrigation to employ enough oxygen and moisture .

El-Abedin (2006) mentioned that during the on time of the pulse drip irrigation technique, the water enters the soil, while during the off time, soil moisture redistributed and more uniform distribution pattern results.

Bakeer et al. (2009) mentioned that amount of applied water and number of pulses effect on the soil moisture distribution under trickle irrigation systems.

Design of trickle irrigation systems must consider a combination of discharge rate and spacing between emitters for any given set of crop, soil and climatic conditions, according to understanding the wetted zone pattern around the plant.

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The wetted zone pattern around the emitter depends on physical soil properties, initial moisture content, evapotranspiration, root characteristics of plant, discharge rate and application frequency. Modelling soil moisture dynamics from trickle irrigation is very complex because of water flow in multi-dimensional, plant uptake, and high frequency of water application.

Researchers applied numerical analysis for solving Richards' equation with certain initial and boundary conditions to simulate the water movement from emitter to obtain model in design and management of trickle irrigation systems due to its merit over direct measurements.

Consequently, the main objectives of this study are:

- 1- Developing a mathematical model under point source (cylindrical flow) to simulate soil water movement and moisture distribution in the soil profile for continuous and pulse trickle irrigation systems, for design, installation, and management of systems.
- 2- Comparing between the predicted and measured moisture distributions in the soil profile for continuous and pulse trickle irrigation to check the model validity.

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2-1- Concept of trickle irrigation

Trickle irrigation, is a method of irrigation that saves water and fertilizer by transmitting water slowly to the roots of plants, either on the surface of soil (surface trickle irrigation) or directly on the root zone (subsurface trickle irrigation), through a network of an emitters, pipes and valves. (Awady et al., 1997) and (Al-Amoud, 1997).

2-2- Definition of pulse trickle irrigation

Pulse irrigation is an irrigation technique to obtain low application rate from using an irrigation device with a higher application rate. A complete pulse irrigation is consist of a series of irrigation cycles where each cycle includes two phases, the operating and the resting phases, one after the other. The variables of the pulse technique are the operating irrigation time, the resting time, and the total time of a single pulse (*David and Gideon, 1974*) as:

$$f_{(t)} = \frac{Q_p t_{op}}{t_{op} + t_r} \dots \dots \dots (2.1)$$

The average pulsed discharge ($f_{(t)}$) is equivalent to a continuous discharge (Q_p), (t_{op}) is time of an operating phase, (t_r) is time of a resting phase, over the irrigation period ($t_{op} + t_r$).

Eric et al. (2004) showed that pulse trickle irrigation is the technique of irrigating composed of a short period then waiting for another short period, and repeating this cycle to reach the irrigation time.

Dole (1994) pointed out that Pulse irrigation or watering is a modern concept where small frequent irrigation applications are used to meet the requirements of plant from water and fertilizers while reduced deep percolation and run-off.

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Feng-Xin et al. (2006) showed that scheduling of trickle irrigation depends on irrigation intermittent as one of the most important factors. The yield was different when the same amount of water is used under different irrigation intermittance, Due to the differences in moisture distribution and wetted pattern of the soil.

2-3-Importance of pulse trickle irrigation

2-3-1- Emitter clogging

Zhou et al. (2015) pointed out that when increased number of pulse of trickle irrigation decreased, the degree of emitter clogging. After 540 h from operating time, the variation discharge ratio and uniformity coefficient of highest pulsed irrigation treatment reached 30.98 and 31.97 %, respectively.

Elbegawy et al. (2012) studied the effect of clogging ratio of emitters on pulse trickle irrigation. They measured the discharge of used emitters after two years and compared them with the discharge of new emitters for calculated clogging ratio of emitters. Increasing the number of irrigation pulses under trickle irrigation (surface and subsurface) decreased clogging ratio of emitters, because the flow was troubled preventing particles suspended from accumulation inside emitters.

Al-Naeem. (2008) showed that reduced the emitter clogging by increase pulsing discharges but the cost of the system also increase due to used large pipes and automatic sequencing valves. Moreover, could be offset the high cost of this technique by reduction in replacing emitters, cleaning and maintenance of the system.

2-3-2- Performance of irrigation systems

Eid et al. (2012) investigated the effect of pulse (long period) and continuous irrigation. (two times per day, three times per day and four

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times per day under interval between pulses 30 minutes) and two types of trickle irrigation systems (surface and subsurface) and three rates of water application (100, 75, and 50 %) from actual irrigation requirements on emission uniformity. Maximum and minimum values of emission uniformity were (90.48 and 81.37 %) under (4 pulses with 50% from actual irrigation requirements under SDI) and (continuous with 100% from actual irrigation requirements under SSDI), respectively. From the results, the emission uniformity increased by increasing the number of irrigation pulses due to reducing clogging ratio of emitters.

El-Abedin (2006) found that distribution efficiency(Ed) and emission uniformity (Eu) recorded the highest values under pulse trickle irrigation technique compared with continuous trickle irrigation as shown in fig (1).

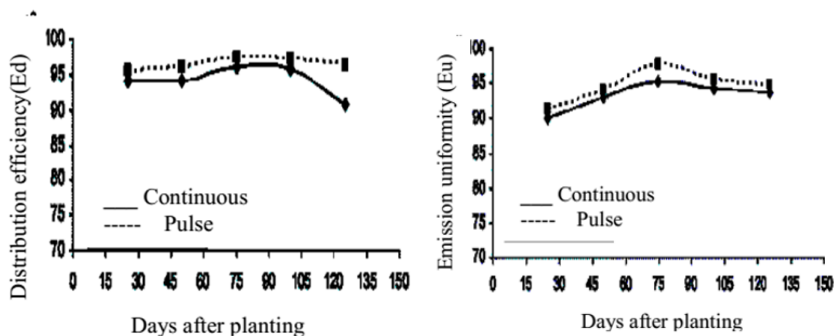


Fig. (1): Distribution efficiency(Ed) and emission uniformity (Eu) for continuous and pulse (5/5) trickle irrigations at all irrigations.

(El-Abedin, 2006)

2-3-3- Soil moisture distribution

Bakeer et al. (2009) indicated that wetting soil volume more than or equal to 100 % of field capacity ($WSV \geq 100\%$ FC) increased by increasing number of pulsations and enhancement in moisture distribution inside root zone. The value of ($WSV \geq 100\%$ FC) recording an increase by 48 % between continuous and pulse trickle irrigation where were 9617 and 14272 cm³, respectively.

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El-Abedin (2006) illustrated that the soil water depletion for pulse trickle irrigation technique ranged from 96 % to 48.5 % and from 84.4 to 55 % at soil depths (0-15 cm) and (15-30 cm), and for continuous trickle irrigation ranged from 94 to 49% and from 74.6 to 50.9 % at same soil depth. The results indicated that the best uniform moisture distribution pattern for both soil depths and higher moisture content level were with pulse trickle irrigation technique.

Feng-Xin et al. (2006) showed that soil water distribution in the root zone changed by different treatments of irrigation intermittent where, the matric potential in the root zone decreased when irrigation intermittent decreased. And the domain contains of the dry soil become larger. Moreover, difference between the matric potential at depth (0 to 50) cm after and before irrigated increased with decreased irrigation intermittent.

2-3-4- Yield and water use efficiency

El-Mogy et al. (2012) Studied the effects of subsurface pulse trickle irrigation on yield and water use efficiency of green beans, treatments of irrigation were (t1: one pulse, t2: two pulses, t3: three pulses, and t4: four pulses). yields increased from 3.78 t/fed to 4.83 t/fed in the experimental year 2008 and increased from 4.06 t/fed to 4.73 t/fed in the experimental year 2009 when the treatments were from t1 to t4, respectively, and also increased water use efficiency from 4.59 kg/m to 6.84 kg/m and from 4.44 kg/m to 6.64 kg/m in the first and second experimental year, respectively.

Feng-Xin et al. (2006) Studied the effect of pulse trickle irrigation (p1: once every day, p2: once every 2 days, p3: once every 3 days, p4: once every 4 days, p6: once every 6 days and p8: once every 8 days) on yield, root distribution of potato and water use efficiency in two

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experiments. With total amounts of water was equal for the different pulses. The results indicated that the higher pulses, the lower was the root mass density in 10 cm depth from soil surface, and the higher was the root length density in 60 cm depth from soil surface. When the irrigation intermittent was reduced from p1 to p8, the yield decreased by 33.4 and 29.1 % in the first and second seasons.

Panagiotis and Makrantonaki (2005) stated that sugar beet yield improved by used the pulse trickle irrigation technique. The results prove that root yield and sugar content increased with pulses irrigated compared with continuous irrigation.

2-3-5- Plant growth characteristics and quality

Elbegawy et al. (2013) investigated the effect of trickle irrigation frequency on area of leaves per plant (A/P) and dry weight of plant (W/P). The results indicated improved A/P and W/P by increasing number of pulses, when using four pulses increased W/P from 38.22 g to 46.12 g compared with continuous trickle irrigation. Also under previous conditions, A/P increased from 1668 cm² to 1875 cm².

Khondaker et al. (2007) studied the effect of pulsing trickle irrigation on root developments. When using the treatment, one pulse per day increased the root biomass compared by treatment of five pulse per day.

Feng-Xin et al. (2006) investigated the effects of intermittent trickle irrigation on quality and growth of radish. Treatments of irrigation were once every (1, 2, 3, 4, 6, and 8) days. The results indicated that the treatment of once every three days was the best in developed roots throughout the season and lowest cracking rate in radishes.

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2-3-6- Run off, deep percolation and application efficiency

Bakeer et al. (2009) said that, under surface and subsurface trickle irrigation, increasing number of pulses increased the application efficiency (AE). Application efficiency increased by 5.5% between continuous and pulse trickle irrigations, where it was 88.6 % under continuous trickle irrigation, and 93.5 % under pulse trickle irrigation.

Elmaloglou and Diamantopoulos (2009) studied the deep percolation under root zone of plants by using discharge rates 1, 2 and 4 l/h, soil textures were silt loam and loamy sand, with continuous and pulse trickle irrigation. The deep percolation was higher in loam sand compared with silt loam, and was lower with pulse trickle irrigation compared with continuous trickle irrigation.

Kassem (2008) studied the deep percolation under 60 cm depth for irrigation intervals (0.5, 1, 2, 3, 4, 6, and 8) day. Decreased number of pulses increased the water losses by deep percolation. Where the maximum value of 195 mm was for irrigation interval 8 day amounting to 44.72 % of irrigation water, while the minimum value was 5.3 mm for irrigation interval of .5 day. This indicated that increasing irrigation pulsing reduces the deep percolation and keeps irrigation water within the root zone.

Panagiotis and Makrantonaki (2005) showed that discharge rate from emitters decreases by using the pulse trickle irrigation, and this reduces the percolation and the hydraulic conductivity of soil. The field experiment included surface and subsurface trickle irrigations with pulses and without pulses to study the effect on wetted patterns. The results indicated that the wetted patterns were wider in surface and subsurface trickle irrigations with pulses.

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2-3-7- Fertilizer efficiency

Abdallah et al. (2012), Hillel. (1987) and Van Loon (1981) studied fertilizers use efficiency under continuous and short cycles trickle irrigation. The results indicated that Nitrogen use efficiency of potato increased from 21.12 to 29.53 kg/kg-N, Phosphate use efficiency of potato increased from 22.38 to 31.29 kg/kg-P and Potassium use efficiency of potato increased from 20.89 to 29.20 kg/kg-K under continuous and short cycle irrigation, respectively. This mean that the short cycle irrigation increased wetted pattern of soil under emitters and increased the ability of plants to absorb fertilizers.

2-4-Some methods to improve the soil water distribution under trickle irrigation

2-4-1-Using synthetic soil conditioner

Zin El-Abedin (2006) used the layer of polymer at 30 cm depth with subsurface trickle irrigation when operating pressure 1 bar with 15 cm depth. The soil moisture distribution was the best in uniformity compared with different depths and without polymer layer, the yield increased due to moisture distribution improvement. But one should study the profit and expenses for used synthetic soil conditioner.

2-4-2-Using solid barriers

Barth (1995) laid polyethylene layer under the lateral pipes at 30 to 40 cm depth, the wide and thick of plastic sheets were 60 cm and 0.06 mm, respectively. Plastic sheet limited the deep percolation and increased the amount of water in the root zone. He developed a special equipment to release the lateral pipes and plastic sheet simultaneously into the soil without disturbing profile of soil.

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2-4-3-Using pulsating irrigation

Elnesr et al. (2015) investigated the effects of three trickle irrigation techniques on yield of the tomatoes. The three techniques were pulse trickle irrigation. The dual lateral trickle one was at 15 cm under the soil surface, another at 25 cm depth, and the third technique was the physical barrier at 30 cm depth. The results indicated that the physical barrier increased the water use efficiency to 54 % and increased the yield to 50 %. The pulse trickle technique improved the qualities of yield such as size of fruit and vitamin c. The physical barrier technique had no effect on yield and quality.

2-5-Development flow governing equations

2-5-1-Generalization of Darcy's law

In three-dimensional flow, there are three velocity vectors at any point of fluid for certain discharge will be given according to **Gupta (2008)** as:

$$V = IV_x + JV_y + KV_z \dots\dots\dots (2.2)$$

Where I, J and K represent three standard unit vector in the X, Y and Z directions. The velocity component in three directions depends on Darcy's equation as:

$$V_x = -K \frac{\partial H}{\partial x}, V_y = -K \frac{\partial H}{\partial y}, V_z = -K \frac{\partial H}{\partial z} \dots\dots\dots (2.3)$$

$$H = h + z \dots\dots\dots (2.4)$$

H: Total head, h: pressure head, z: gravitational head which has a negative sign for z direction, and is zero in both x, y directions.

From equations (2.2), (2.3) and (2.4) one can obtain the expression: