

MATHEMATICAL MODELING FOR FARM IRRIGATION WATER MANAGEMENT

BY

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B.Sc.Agric.Sc. (Rural Engineering) , Damascus University, ٢٠٠٠

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ABSTRACT

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This study was carried out in Irrigation Laboratory at Agricultural Engineering Department, Faculty of Agriculture, Ain Shams University located at Shoubra El-Kheima, Kaliobia Governorate, Egypt. A type of porous pipe " recycled automobile tyres " or leaky pipe with ١٠ mm internal diameter and ١٥ mm outer diameter was used in this study.

The objectives of this study are: to develop two-dimensional computer driven model to simulate water movement and its distribution under subsurface line-source (porous pipe), study the wetting front movement in both sandy and loamy soils for subsurface porous pipe and to determine the hydraulic performance of the porous pipe.

The partial differential equation of water flow is solved by the Explicit Finite Differences Method (EFDM).

Results indicated that the highest discharge rate in this study produced the largest wetting front, and the wetting front in the sandy soil was bigger than in the loamy soil at the same depth and operating pressure because the granules of loamy soil are smaller than the sandy soil and may close some holes of porous pipe.

Also, results indicated that the discharge of porous pipe at the same operating pressure is higher in the air than that in case of porous pipe buried under soil surface. This may be due to that the granules of soil close some holes of porous pipe.

It is recommended to test the porous pipe before using because there are no universal standard for making it and because its holes are very small.

This model can be used to predict the two-dimensional water movement from subsurface line source in sandy soils, and this model can be extended to predict the two-dimensional water content in sandy soil from surface or subsurface point source or for surface line source.

KeyWords: Subsurface line source, Mathematical model, Porous pipe Simulation water content, ∇ -dimensional flow, Explicit Finite Differences Method.

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INTRODUCTION

Due to climatic changes and population pressure, water resources are becoming a scarce resource. Water demands for different sectors in Syria, as it is throughout the Middle East, have been increasing steadily and at a high rate, and generally it is considered not enough to cover all human necessities. Syria's agricultural sector is the backbone of the economy, and the sustainability of this sector is vital for the overall development of the country. Syria is divided to 5 zones according to the rainfall. Zone 1 receives an average of rainfall of more than 700 mm/year, zone 2 receives an average of rainfall between 500- 700 mm/ year , zone 3 receives an average of rainfall 500 mm/year , zone 4 receives an average of rainfall between 400- 500 mm/year and zone 5 receives less than 400 mm/year, and this zone is the steppe lands that make up 20,1 % of the total area of the country . The big part of the zone 5 is sandy soil, so that the Ministry of Irrigation conducted a study about the future of water in Syria. It includes several measurements and recommendations. One of that is using classic and new techniques such as agricultural cycles, improved seeds, genetic engineering, intensive agriculture, fertilizers, new techniques in irrigation, modernizing the irrigation networks (Alshami, 2000).

The development of irrigation systems in Syria is very important because the water will be the biggest problem in the world and especially in the Middle East.

Trickle irrigation systems either surface or subsurface can be used because it is considered as highly efficient system.

To develop and manage the irrigation trickle systems, we should know some important considerations such as irrigation time, water application rates and the frequencies necessary to irrigate the plants, but the advances in trickle irrigation management rely on knowledge of the distribution and dynamics of soil water within the wetted soil volume (Coelho and Or , 1996).

There are four main topics to be addressed regarding water management. The first topic is timing of the irrigation (In other words, how dry or moist should the medium be, or at what frequency or time interval should water be applied?) , the second topic is the volume of water to be applied at any one irrigation (What amount of water is needed to moisten the root medium? is leaching necessary?), The third topic is the importance of the temperature of the irrigation water, and the fourth and final topic is the method of application (What is the most efficient and economical way to get water to all the plants?).

The mathematical sciences can be very useful to answer the previous questions.

There are many tools to predict soil moisture movement and distribution in the soil profile. One of the efficient tools is the mathematical modeling of the soil and the surrounding boundaries (Marcos et al ,۱۹۹۴ a).

A mathematical model is the use of mathematical language to describe the behaviour of a system. Mathematical models are used particularly in the sciences such as biology, electrical engineering, physics but also in other fields such as economics, sociology and political science. So it is necessary to introduce this scientific technique in agriculture and irrigation management because the use of mathematical modeling to design future plans for irrigation development which can be a powerful tool to ensure efficient use of these irrigation systems.

In the last two decades, a large number of mathematical models have been developed and used for simulating and predicting flow in the unsaturated soils.

The main objectives of this study are:

- ۱- Develop two-dimensional computer driven model to simulate water movement and distribution under subsurface line-source (porous pipe).
- ۲- Studying the wetting front movement in both sandy and loamy soils for subsurface porous pipe.
- ۳- Studying the hydraulic performance of the porous pipe.

REVIEW OF LITERATURE

Understanding the movement of water through soils is of great importance in managing, utilizing and designing irrigation networks. These processes are very dynamic, changing dramatically over time and space. Soil properties and water application rates interact in complex ways within the soil system to determine the direction and rate of movement of the water. Researchers have worked many years to understand the physical mechanisms responsible for the movement of the water in the soils and they have attempted to simulate the soil water dynamics around emitters. They have developed mathematical models for describing these processes and comparing the predictions of these models with field and laboratory measurements. The results of the mathematical models form a basis for predicting the behavior of water in soils.

۲-۱- Irrigation:

۲-۱-۱- Definition:

Izuno and Haman (۱۹۹۵) defined the following:

Irrigation: It is a application of water by artificial means. Purposes for irrigating may include, but are not limited to, supplying evapotranspiration needs, leaching of salts, and environment control.

Irrigation Uniformity: It is a measure of the spatial variability of applied or infiltrated waters over the field. Several indicators can be used to place a numerical value on the irrigation uniformity by statistically representing the deviations in water applied, or stored in the crop root zone, from the field average. The irrigation uniformity is generally expressed as a percent with ۱۰۰% representing the perfect uniformity.

Drip: It is a category of trickle irrigation in which water is applied to the soil surface in discrete or continuous drops, or tiny streams through emitters. The terms drip and trickle irrigation are often used interchangeably. However, the American Society of Agricultural Engineers Practice ASAE-EP۴۰۵ makes the distinction that trickle

irrigation includes systems with higher discharge rates than most drip systems. To be classified as drip irrigation, point source emitters should have discharge rates less than 1 l/h/m and line source emitters less than 1 (l/h/m) of lateral.

Trickle: It is a low pressure system where water is distributed through closed pipelines. Water is applied directly or very near to the soil surface, either above or below the ground surface, in discrete drops, continuous drops, small streams, or spray. Flows and pressures are typically low. A wide variety of emitters are available to dissipate pressures at points, allowing water applications to the soil in small amounts with little force.

Subsurface: It is a low pressure system that falls into the trickle category with the defining characteristic being that the laterals, emitters and line source tubes are buried beneath the soil surface, thereby applying water directly to the root zone. Discharge rates are of the same magnitude as drip rates.

Subirrigation: It is a water table control system that uses the raising of the water table to add water to the root zone. Water is introduced into parallel open ditches and flows under the root zone through the soil profile to raise the water table to a level that allows for sufficient wetting of the root zone from the water table aquifer below. Closely spaced tile, perforated pipe, or mole drains that run perpendicular to the field ditches are often used to aid in the lateral spreading of water beneath the root zone.

ASAE Standards (1998) defined the following:

Microirrigation: It is the frequent application of small quantities of water as drops, tiny streams, or miniature spray through emitters or applicators placed along a water delivery line. Microirrigation encompasses a number of methods or concepts such as bubbler, drip, trickle, mist, or spray.

Trickle irrigation: It is the method of micro-irrigation where in water is applied to the soil surface as drops or small streams through emitters. Discharge rates are generally less than 1 lph for single outlet emitters and 12 lph per meter for line-source emitters.

Subsurface trickle irrigation: It is the application of water below the soil surface through emitters, with discharge rates generally in the same range as trickle irrigation. This method of water application should not be confused with **sub-irrigation**, which is defined as application of irrigation water below the ground surface by raising the water table to within or near the root zone.

Emitter: It is a small microirrigation dispensing device to dissipate pressure and discharge a small uniform flow or trickling of water at a constant discharge, which does not vary significantly because of minor differences in pressure head.

Line source : It is continuous source of water emitted along a line.

Porous trickle tubing: It is tubing with a uniformly porous wall. The pores are small and ooze water under pressure.

2-1-2- Advantages and disadvantages of subsurface trickle irrigation:

Qassim (2003) reported the subsurface irrigation covers all methods that distribute water through underground emitters. He listed the advantages of subsurface trickle irrigation as follow:

- 1- Subsurface trickle irrigation (SDI) maintains soil moisture around the roots at an optimum level and thus reduces crop stress at critical growth stages.
- 2- It improves disease control by allowing foliage and fruit to be kept dry.
- 3- It reduces water losses through evaporation, run-off and deep percolation as a result of improved application efficiency.
- 4- Fertilizers can be applied through the irrigation system directly to the root zone when and where the plant needs them (fertigation).

- 5- In orchards, it provides precise control of water stress, which can reduce unwanted vegetative growth and improve fruit quality.
- ٦- SDI allows access to the field during irrigation giving flexibility to conduct other cultural practices.
- ٧- Systems can be automated, thus saving labour.
- 8- Pumping head and energy requirements are reduced through low application rates and operating pressure, thus saving the operation costs.
- 9- Weed control is improved because most of the soil surface is kept dry.

Also he listed the disadvantages of subsurface trickle irrigation as follow:

- ١- Line damage more difficult to repair.
- 2- High initial capital cost.
- ٣- Root intrusion and blockage of emitters.
- 4- Germination and crop establishment might require additional sprinkler or surface irrigation.
- ٥- Soil structure may decline around emitters after trickle systems are used for successive years.
- ٦- Salt and nutrients can accumulate on the soil surface and be flushed to roots by rainfall, stimulating unwanted growth.
- ٧- Restriction of root development by small wetted volume.

٢-٢- Evaluation of Trickle Irrigation System:

٢-٢-١- Pressure-flow characteristics:

Keller and Karmeli (١٩٧٤) and **Smajstrla et al. (١٩٩٠)** described the relation between emitter flow rates vs. pressure as follows:

$$q = k H^x \dots\dots\dots(١)$$

Where:

q = emitter flow rate, (lph) ;

K = emitter discharge coefficient (is a constant of proportionality which characterizes each emitter) ;

H = operating pressure (m), and

X = emitter discharge exponent .

To determine k and x values, the discharges for at least two different operating pressure heads must be known for each emitter. The various types of emitters and the " x " values are shown in Table ۱. (Kimura, ۱۹۸۷).

Table ۱: The various types of emitters and the " x " value.

Emitter Type	x-value	Emitter type
Variable	۰,۰	Pressure compensating emitter
	۰,۱	
	۰,۲	
	۰,۳	
Vertical flow	۰,۴	Vortex emitter
Fully turbulent flow	۰,۵	Orifice flow, tortuous path
	۰,۶	Average
	۰,۷	Long or spiral path
Line Source (drip tubes)	۰,۸	
Mostly turbulent flow	۰,۹	Micro tube
Fully laminar flow	۱,۰	Capillary flow

The value of x characterizes the flow regime of emitters. The coefficient and exponent for this equation will normally be given by the emitter manufacturer or from an independent testing laboratory. The emitter discharge exponent " x " is a measure of the sensitivity of the emitter flow rate to changes in pressure. This exponent is dimensionless and it is independent of the units used to measure flow rate and pressure.

Low values of "x" (below 0.5) indicate emitters that are relatively insensitive to changes in pressure (pressure compensating emitters), while large values of "x" indicate that emitters have larger changes in flow rate as pressure changes (laminar flow emitters).

2-2-2- Emitter manufacturing variation (Cv) :

Smajstrla et al . (1990) found that flow variations due to pressure variations between emitters of the same type also occur due to manufacturing variations in the tiny plastic components, because their orifice diameters are very small, microirrigation emitters are easily plugged or partially plugged from particulate matter, chemical precipitates and organic growths. For these reasons, water application uniformity may be greatly affected by the emitter performance. The manufacturing coefficient of variation is defined as the statistical coefficient of variation (standard deviation divided by the mean discharge rate) in emitter discharge rates when new emitters of the same type are operated at identical pressures and water temperatures.

ASAE (1998) described the manufacturing coefficient of variation (Cv) as a measure of the variability of discharge of a random sample of a given make, model and size of emitter as produced by the manufacture and before any field operation or aging has taken place.

$$C_v = \frac{S}{X} \dots\dots\dots(2)$$

Where:

X = the mean discharge of emitters in the sample , (l/h/m) ; and

S = the standard deviation of the discharge of the emitters in the sample.

$$S = \left[\frac{\sum_{i=1}^n (X_i - \bar{X})^2}{n-1} \right]^{1/2} \dots\dots\dots(3)$$

Where:

Xi = the discharge of line source ,(l/h/m); and

n = the number of emitters in the sample.

If a line-source is used, the individual discharge from holes on a one-meter or other specified length of emitter tape are used. This term can also be used to describe the variability in the downstream pressure from pressure control valves or the variability in discharge from flow control valves or orifices. Classifies point source (drip emitters and microsprinklers) and line source (drip tubing) emitters based on manufacturing variation are shown in Table 2.

Table 2: Classifications of manufacturer's coefficient of variation (Cv) for emitters ASAE (1998).

Emitter Type	Cv range (%)	Classification
Point source (drip emitters and microsprinklers)	below 5%	Excellent
	5% to 7%	Average
	7% to 11%	Marginal
	11% to 15%	Poor
	above 15%	Unacceptable
Line source (drip tubes)	below 10%	Good
	10% to 20%	Average
	above 20%	Unacceptable

2-2-3- Friction losses:

Bombardelli and Garcia (2003) described many equations that approximate the friction losses associated with the flow of a liquid through a given section. Commonly used methods include : Hazen-Williams equation and Darcy-Weisbach equation.

Larock et al. (1999) showed that the Hazen-Williams equation is the most frequently used in the design and analysis of pressure pipe systems. The equation was developed experimentally, and therefore should not be used for fluids other than water (and only within