

## **SIMULATION OF THE WETTING PATTERN UNDER SURFACE DRIP IRRIGATION AND GRAVEL\_GROOVE**

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**ABSTRACT:** - A groove filled with gravel under the soil surface is presented in this research to study the influence of groove's dimensions and emitter's discharge on the wetting pattern directions in the heavy soil under surface drip irrigation systems. Dimensional analysis techniques were used for predicting the wetting pattern directions functions and the comparison with the experimental work was carried out. The laboratory tests were conducted in a clay loam soil steel container using groove filled with gravel under the soil surface of width 10 cm and 20 cm and at emitter's discharge 1.3 l/hr and 2 l/hr. The results showed that the groove's width has effected on dimensions of the wetting patterns front. The increasing of the groove's width caused increase in the soil water movement in downward and horizontal directions by an average value of 19.1% and 8.9%, respectively. Also, the increasing of the groove's width had an inverse effect on the water upward direction; the average value dropped by 19.9%. Moreover, increasing value of the emitter's discharge influenced on the increasing and decreasing of the upward, horizontal and downward water directions. Increasing of the emitter's discharge, saturation state was taken place inside the groove due to the clay particles in the soil. The statistical analysis for the comparison among the predicted wetting patterns equations developed by the dimensional analysis techniques with the experimental measured data showed a good agreement. The RMSE and R<sup>2</sup> were varied from 1.18 cm to 1.847 cm and from 0.98 to 0.99, respectively.

**Keywords:** *Drip irrigation, groove, wetting front, dimensional analysis*

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### **1. INTRODUCTION**

Improving water use efficiency is very important for agriculture in arid and semi-arid region. Surface and subsurface drip irrigation system may achieve high field application efficiency with minimum runoff and deep percolation losses and with a proper wetting pattern

A mathematical model <sup>(1)</sup> is used to estimate the dimension and volume of the wetting area at the end of irrigation cycle and comparison between the properties and dimensions of the wetted area under the surface and subsurface drippers is conducted. The volume of the processed water is (4.33 L) with flow rate of (2.6 L/hr) through irrigation cycles, and the soil water movement is observed by using the tensiometers and is measured before irrigation and through irrigation cycles. The results demonstrated that the soil moisture content in the wetted zone under subsurface drip irrigation system is ranged from 44% to 29% at the end of irrigation cycles and it is larger than the moisture content under surface drip irrigation. In addition, the model results demonstrated that there is a good convergence with laboratory data.

A theoretical method is submitted <sup>(2)</sup> as a study to prevent the increasing the positive pressure at the emitter soil surface. The proposed method included digging a trench in the soil, fill it with gravel, and then the drip tube is placed near the bottom of the trench. This method has been tested in the field for seven years and has been compared with the surface drip irrigation. Also, it is tested using the numerical simulation model Hydrus-2d to assess the impact of soil texture and trench dimensions on the distribution of soil water for buried drip line under soil surface. It is found by the numerical simulation model that in soils with low hydraulic conductivity value requires increasing the size of the trench to ensure the growth of a positive pressure in the soil. Also it has been found that in the case when the depth of the drippers is reduced with a saturated zone near the soil surface by increasing the width of the trench.

The simulation of the water content from the subsurface line source in sandy soil is predicted <sup>(3)</sup> by using a mathematical model. The partial differential equation in a Cartesian coordinate system (plane flow model) in two dimensions in unsaturated soil is solved by the Explicit Finite Differences Method (EFDM). The results are indicated that EFDM for solving the partial differential equation can yield accurate results of soil water flow. This model can be used to predict the two dimensional water contents from subsurface line or point source in sandy soils.

A dimensional analyses model is implemented <sup>(4)</sup> to describe the subsurface water distribution under sub-irrigation by using a porous pipe. The sub-irrigation experiment was carried out in a greenhouse by using porous pipes with dimensions of 6 m length and 16 mm inside diameter that installed at depth of 15 cm. Three types of soils are used clay, loamy sand and loam soil. Statistical analysis showed that this model has a high degree of accuracy in simulating a wet soil, indicating that there is no significant difference between predicted and observed soil wetted. They proved that the model could also be used to modelling soil wetting dimensions under sub irrigation with porous pipe.

The evolution of a half-spherical cavity around the emitter under the soil surface is studied <sup>(5)</sup>. The cavity development is measured on different emitter discharge in laboratory tests carried out on containers by using homogeneous clay soils. The results showed that the shape of the cavities formed around the drippers in the drip irrigation systems under the soil surface is spherical in recent releases. Horizontal cracks observed in the beginning when using high-discharge, but fills up slowly in soil, which eventually resulted in a spherical cavity.

The soil water patterns in the surface and subsurface drip irrigation system is studied <sup>(6)</sup> by using the statistical distributions approach. Laboratory tests are conducted in a container with a transparent face, where the drippers are buried at depths (15, 30 and 45 cm) with discharge (2.4, 4, and 6 L/h). The soil water front data are divided into three time lengths (2, 4, 6 hours). Data are analyzed by using the time-series in accordance with the (HYFA) software (Hydrological Frequency Analysis) and is evaluated according to suitable function of frequency distribution at different conditions. The results showed that the best statistical distribution to describe surface and subsurface drip irrigation system is the normal distribution and the distribution of the Pearson type three depending on relative frequency.

## 2. MATERIALS AND METHODS

### 2.1 Laboratory work

#### 2.1.1 Soil container

The soil container consists of a cuboid-shaped structure of net dimensions 140 cm\*100 cm\*5.5 cm (length\*height\*thickness) made from iron steel bars jointed together horizontally and vertically for strengthening purposes and opened from the top. The front facade made of a transparent slab of hard plastic sheet of 9 mm thick to follow up the front-wetting pattern, the back view made of steel sheet. Figure (1) showed the layout of the soil container with the water supply system.

### 2.1.2 Water applying system

The system used for applying water to the soil container consists of two cylindrical steel tanks of total capacity 20 liters provided with calibrated manometer installed on its side for measurement the water level and quantity. The upper reservoir at the bottom level provided with plastic hose connected at a certain level with the lower cylinder tank to ensure a constant water level in the lower tank. The lower cylinder was supplied the emitter with water through flexible plastic pipe provided with control manual valve and with the flexible plastic tube. The emitter consists of three capillary spiral tubes inside a piece of a plastic, installed 1 cm height above the soil surface level. Figure (2) showed the type of the emitter which was used. The process of adding water was prepared to adjust the rate of water in each test to ensure a regular and consistent flow processing of drip line source where the discharge was applied along 5.5 cm.

### 2.1.3 Type of the Soil

Clay loam soil was used in the experiments was taken from Al- Rashidiya district, which located north of the City of Mosul by about 5 km. A weight of 1000 kg of the soil was used. Physical properties analysis was carried out to indicate the soil texture and the bulk density. Table (1) showed the physical properties of the soil samples.

### 2.1.4 Soil stratification

The bed and the vertical steel sides in the steel container were leveled then the soil was added to the container by using plastic funnel connected with a plastic hose to the bed level of the container to decrease the separation of the soil particles. Then, the soil was compacted in layers of thickness of 5 cm for each layer. The above procedure was repeated many times until the total thickness of the compacted soil was reached to 65 cm, between each compacted layer the soil surface was brushed roughly. Steel screen was installed in a depth of 35 cm in the compacted soil of width equal to 10 and 20 cm filled with gravel of diameters ranged between 1 cm to 1.5 cm. The soil in the side of the steel screen was compacted in layers until to reach the surface screen level.

### 2.1.5 Measurement of the wetted front patterns

After the soil was prepared for the stratification, the water was added to the groove from the lower water cylinder through the emitter, which installed above the soil surface. The drops of the water were penetrated through the groove and distributed through the soil layers. The wetting front pattern was followed from the front transparent plastic face of the container as showed in figure (3). Measurements of the water downward and horizontal movement directions were started from the center of the groove bottom, while the measurement of the upward direction was started from the bottom of the groove at the side edge of the groove as showed in figure (4). The wetted front pattern was fixed as a figure at the selected time interval. The test was ended when the volume of the added water was reached the required quantity. The initial soil water content was 9.58 % (by volume), and groove's width 10 and 20 cm was used at emitter's discharge 1.3 l/hr and 2.0 l/hr.

## 2.2 Dimensional analysis model

The dimensional analysis model is a numerical method to create forms, based on Buckingham's  $\pi$ -theorem, which is used for analysis of consistency in dimensions. In general, Buckingham theorem states that the total number of these relevant dimensional parameters (n) can be grouped into n-m independent dimensionless groups <sup>(7)</sup>. The number (m) was usually equal to the minimum of independent dimensions required to specify the dimensions of all relevant parameters.

### 2.2.1 Model Development

In this study, the dimensional analysis model was used for predicting the wetted patterns functions for three directions (upward, downward and horizontal) in the case when the groove was used. Table (2) showed the experimental measuring wetting front in the downward, horizontal, and upward directions for different groove's width, emitter's discharge, and time. The wetted area was assumed to be depending on emitter's discharge,

groove's width and irrigation time. The relationships between parameters that describe the volume of wetted area assumed to be written as follow:

$$f(q, w, t, d, x, z) = 0 \quad (1)$$

Where:

$f$  = function relationship,  
 $d$  = depth of wetted pattern (L),  
 $x$  = width of wetted pattern (L),  
 $z$  = rising of wetted pattern (L),  
 $q$  = discharge ( $L^3/T$ ),  
 $w$  = width of groove (L), and  
 $t$  = irrigation time (T).

The basic dimensions of each variable can be expressed as follows:

$q = L^3T^{-1}$ ,  $t = T$ ,  
 $d = L$ ,  $x = L$ ,  $w = L$ , and,  
 $z = L$ .

The number of variables ( $n$ ) = 6, and the number of depended variables ( $m$ ) = 2. The  $\pi$  terms number (independent variables) was equal to ( $n-m$ ). So, numbers of  $\pi = 6-2 = 4$ , and,

$$f(\pi_1, \pi_2, \pi_3, \pi_4) = 0 \quad (2)$$

Two variables ( $q$  and  $w$ ) were selected as depended variables. Starting with independent variables ( $t$ ), the first  $\pi$  term formed was written as follows:

$$\pi_1 = q^{a_1} w^{b_1} t \quad (3)$$

Where:

$a_1$  and  $b_1$  were estimated as follow:

$$(L^3T^{-1})^{a_1} (L)^{b_1} T = L^0 T^0$$

$$3a_1 + b_1 = 0 \text{ (for L)}$$

$$-a_1 + 1 = 0 \text{ (for T)}$$

Therefore:

$$a_1 = 1 \text{ and } b_1 = -3$$

The  $\pi_1$  term became:

$$\pi_1 = \frac{q \cdot t}{w^3} \quad (4)$$

In order to convert the emitter's discharge ( $q$ ) from (l/hr) into ( $cm^3/hr$ ) (where  $q$  was applied along 5.5 cm in width), and the time ( $t$ ) from (min.) into (hr), Eq. (4) was rewritten as follows:

$$\pi_1 = \frac{q t 100}{w^3 6} \quad (5)$$

Similarity, others  $\pi$  terms were formed in the same procedure as conducted for  $\pi_1$ :

$$\pi_2 = \frac{d}{w} \quad (6)$$

$$\pi_3 = \frac{x}{w} \quad (7)$$

$$\pi_4 = \frac{z}{w} \quad (8)$$

### 2.2.2 Modelling steps

In order to build the model, the parameters ( $\pi$ ) should be joined together. Figure (5) showed the relation among parameters  $\pi_1$  and  $\pi_2$ . The following equation for the downward water direction was predicted from the figure (5):

$$\pi_2 = 1.141\pi_1^{0.359} \quad (9)$$

By substituting Eq. (5) (for  $\pi_1$ ) and Eq. (6) (for  $\pi_2$ ) into Eq. (9), the following equation was predicted for downward water direction:

$$d = 3.133 \frac{(qt)^{0.359}}{w^{0.077}} \quad (10)$$

Figure (6) showed the relation between parameters  $\pi_1$  and  $\pi_3$ :

$$\pi_3 = 1.758\pi_1^{0.324} \quad (11)$$

By substituting Eq. (5) (for  $\pi_1$ ) and Eq. (7) (for  $\pi_3$ ) into Eq. (11), the following equation was predicted for the horizontal water movement:

$$x = 4.372 \frac{(qt)^{0.324}}{w^{0.028}} \quad (12)$$

For predicting the upward water movement, relationship between  $\pi_1$  and  $\pi_4$  was plotted as showed in figure (7) and the following equation was conducted:

$$\pi_4 = 1.211\pi_1^{0.515} \quad (13)$$

By substituting Eq. (5) (for  $\pi_1$ ) and Eq. (8) (for  $\pi_4$ ) into Eq. (13), the following equation was predicted for upward water movement in clay loam soil:

$$z = 5.162 \frac{(qt)^{0.515}}{w^{0.546}} \quad (14)$$

### 2.3 Statistical analysis

Statistical analysis was used to verify the performance of the dimensional analysis models by comparing the predicted data resulted from the dimensional analysis models with the measuring data from the laboratory experimental. Coefficient of determination ( $R^2$ ) and the root mean squared error (RMSE) <sup>(4)</sup> were used in this comparison and as follow:

$$R^2 = \left( \frac{\sum_{i=1}^N (Y_o - \bar{Y}_o)(Y_c - \bar{Y}_c)}{\sqrt{\sum_{i=1}^N (Y_o - \bar{Y}_o)^2 \sum_{i=1}^N (Y_c - \bar{Y}_c)^2}} \right)^2 \quad (15)$$

$$RMSE = \sqrt{\frac{(Y_c - Y_o)^2}{N}} \quad (16)$$

Where:

- $Y_o$  = observed value,
- $Y_c$  = simulation value,
- $\bar{Y}_o$  = mean of observed value,
- $\bar{Y}_c$  = mean of simulation value, and
- $N$  = number of data.

## 3. RESULTS AND DISCUSSION

The wetting front in the upward, horizontal and downward directions was measured in the experimental laboratory for different groove's width and emitter's discharge as showed in table (3). Groove's width and emitter's discharge had an influence on the all wetting directions.

### 3.1 Influence of the groove's width

Increase in the groove's width from 10 to 20 cm at emitter's discharge of 2 l/hr, tends to increase in water downward direction from 28.9 cm to 36.1 cm, with increasing value by about 25%. Additionally, the increasing in the groove's width from 10 to 20 cm at emitter's discharge of 1.3 l/hr tends to increase in water downward direction from 29.4 cm to 33.3 cm with increasing value by about 13.3%. Also, in the horizontal wetted directions, the increasing values was 1.66% and 16.1%, for emitter's discharge of 1.3 l/hr and 2 l/hr, respectively. On the other hands, in the upward wetted direction the factor of the groove's width was inversely affected on the value of the upward water direction. So, when the groove's width increased from 10 to 20 cm the values of upward direction dropped by about 9.82% and 29.9% for emitter's discharge of 2 l/hr and 1.3 l/hr, respectively. The downward and horizontal water movements directions were increased when the groove's width increased from 10 cm to 20 cm at the same emitter's discharge. But the water depth was decreased on the groove's sides when the groove's width increased from 10 cm to 20 cm. The reason for this fluctuation was due to when the groove's width was 10 cm, the bed of the groove was filled with water by a time less than for the groove's width of 20 cm. Additionally, for the groove's width of 10 cm, the water movement was reached to the side's edge of the groove faster than for the groove's width of 20 cm. Therefore, the water

movement was increased in the downward and horizontal directions and decreased greatly toward upward direction due to the gravity action. This conclusion was also confirmed by <sup>(4)</sup>.

### 3.2 Influence of emitter's discharge

When the emitter's discharge was dropped from 2 l/hr to 1.3 l/hr at groove's width of 20 cm, the downward wetting front directions were dropped by about 8.4%. While, at groove's width 10 cm the downward wetting front directions were increased by about 1.73%. For the horizontal direction, and when the emitter's discharge was dropped from the 2 l/hr to 1.3 l/hr for groove's width 10 cm, the horizontal wetted directions was increased by about 8.4% and dropped by about 5.27% for groove's width 20 cm. In the upward direction, when the emitter's discharge dropped from 2 to 1.3 l/h, the upward directions were also dropped by 0.67% and 19.05% at groove's width 10 and 20 cm, respectively. Therefore, when the emitter's discharge increased and the groove's width decreased, this will cause rising in the water depth inside the groove and the saturation state will occurred. This was due to the existing of the fine particles of the clay in the soil.

### 3.3 Water rising inside the Groove

The rising of the water inside the groove filled with gravel was taken place during the test period as showed in table (4). The highest depth of water inside the groove was 16.8 cm when the flow rate was 2 l/hr and groove's width was 10 cm. When the groove's width increased to 20 cm, the depth of water inside the groove was dropped by an average value of 110.5%. For the same groove's width and when the emitter's discharge increased, the average rising of the water depth was an average value of 47.2%. Therefore, when the emitter's discharge increased and the groove's width decreased, this will cause rising in the water depth inside the groove and the saturation state will occur due to the existing of the fine particles of the clay in the soil.

### 3.4 Verification performance of the dimensional analysis model

Dimensional analysis technique was used for predicting the downward, horizontal and upward wetting front directions function. The performance of the dimensional analysis models were tested by comparing the prediction equations with the experimental measured data. Statistical analysis parameters was carried out, RMSE and  $R^2$  for the verification performance were used. Table (5) showed the statistical comparison among the predicted wetting pattern directions and the experimental measured data. The RMSE values were less than 2 cm; additionally  $R^2$  values were ranged among 0.98 and 0.99. According to <sup>(7)</sup> and <sup>(8)</sup>, no significant difference was indicated.

## 4. CONCLUSIONS AND RECOMMENDATIONS

According to the results from the present study, the following conclusions and recommendations were withdrawn:

- 1- The groove's width has effected on dimensions of the wetting patterns front. The increasing of the groove's width was caused to increase the soil water movement in downward and horizontal directions by an average value of 19.1% and 8.9%, respectively. On the other hands, the increasing of the groove's width was an inverse effect on the upward direction. So, when the groove's width increased the upward direction was dropped by an average value of 19.9%.
- 2- Increasing value of the emitter's discharge was influenced on the increasing and dropping of the upward, horizontal and downward water directions.
- 3- When the groove's width increased to 20 cm, the depth of water inside the groove was dropped by an average value of 110.5%. For the same groove's width and when the emitter's discharge increased, the average rising of the water depth was 47.2%. In the case of increasing the emitter's discharge, saturation state was taken place inside the groove due to the clay particles.
- 4- The statistical analysis for the comparison among the predicted wetting patterns equations developed by the dimensional analysis techniques with the experimental data showed a

good agreement. The RMSE and  $R^2$  were varied from 1.18 cm to 1.847 cm and from 0.98 to 0.99, respectively.

- 5- Comparison among using the groove filled with gravel under drip irrigation system and without groove to draw down the influence on the wetting fronts is recommended.
- 6- Using different types of heavy soil textures in the comparison.
- 7- Using subsurface drip irrigation system combined with the groove to describe the wetting front patterns.

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Table (1). Some physical properties of the soil samples.

Soil texture	Clay (%)	Silt (%)	Sand (%)	Bulk density (gm/cm <sup>3</sup> )
Clay loam	38	37	25	1.25

Table (2). Laboratory measured the wetting patterns directions for different groove's width, emitter's discharge, and time.

Groove's width (cm)	Emitter's discharge (l/hr)	Time (min)	$d$ (cm)	$x$ (cm)	$z$ (cm)
20	2	15	6.5	13.65	4.3
20	2	30	8.9	18.05	8.6
20	2	45	11.1	20.20	12.8
20	2	60	13.6	22.40	15.0
20	2	75	15.7	23.85	16.2
20	2	90	17.9	25.90	18.2
20	2	105	19.4	27.60	20.1
20	2	120	21.3	29.40	21.8
20	2	150	24.4	32.70	23.5
20	2	180	27.5	35.95	25.2
20	1.3	30	7.6	14.8	4.1
20	1.3	60	11.3	19.35	8.9
20	1.3	90	14.3	22.4	11
20	1.3	120	17.7	25.00	13.0
20	1.3	150	19.7	27.35	15.2
20	1.3	180	21.4	29.30	16.3
20	1.3	210	23.3	31.05	17.4
20	1.3	240	25.3	32.80	19.0
20	1.3	277	26.9	34.75	20.5
10	1.3	30	6.3	12.25	8.3
10	1.3	60	9.0	16.90	12.6
10	1.3	90	11.2	19.50	16.2
10	1.3	120	13.1	22.05	18.7
10	1.3	150	14.9	24.75	20.0
10	1.3	180	17.1	27.05	23.0
10	1.3	210	19.0	28.95	24.8
10	1.3	240	20.9	31.50	26.6
10	1.3	277	22.6	33.00	28.0

Table (3). Maximum dimensions for soil wetting front.

Groove's width (cm)	10		20	
	Emitter's discharge (l/hr)		Emitter's discharge (l/hr)	
Max. downward movement (cm)	1.3	2	1.3	2
Max. upward movement (cm)	29.4	28.9	33.3	36.1
Max. horizontal movement (cm)	30	30.2	23.1	27.5
Max. horizontal movement (cm)	39.15	36.1	39.8	41.9

Table (4). Emitter's discharge, groove's width and water rising depth.

Groove's width (cm)	10		20	
Emitter's discharge (l/hr)	1.3	2	1.3	2
Water rising depth (cm)	13	16.8	5.5	9.1

Table (5). Statistical comparison among experimental measured data and the dimensional analysis model of the wetting pattern directions.

Equation	(10)	(12)	(14)
RMSE (cm)	1.7	1.18	1.847
R <sup>2</sup>	0.98	0.99	0.99



Figure (1). Layout of the soil container and the water supply system.

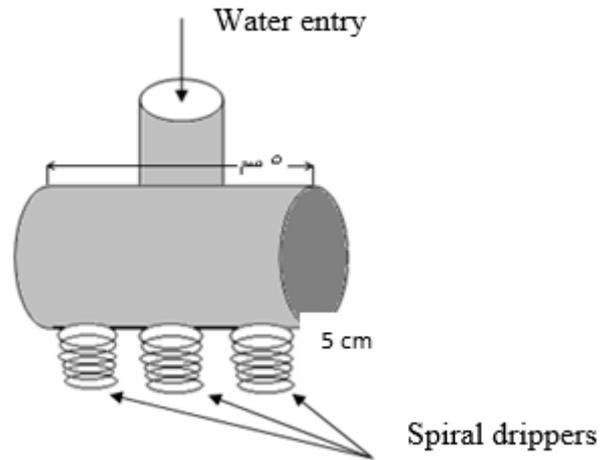


Figure (2). Type of the emitter used.



Figure (3). Shape of the wetting front pattern for  $q=1.3$  l/hr and  $w = 10$ cm.

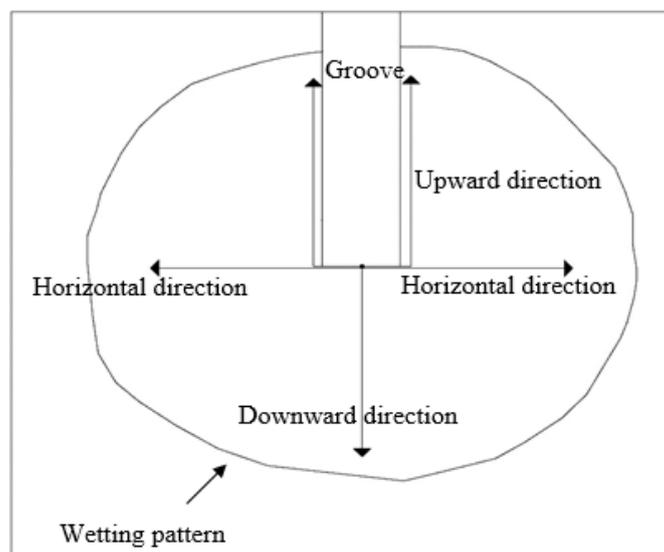


Figure (4). Measurements of the wetting front patterns.

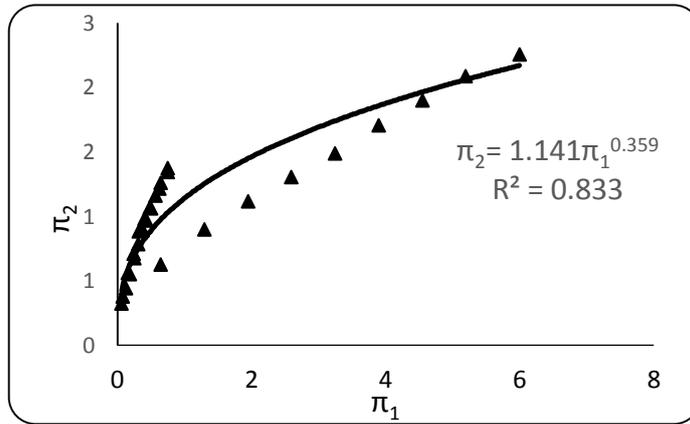


Figure (5). Relationship among dimensionless parameters  $\pi_1$  and  $\pi_2$ .

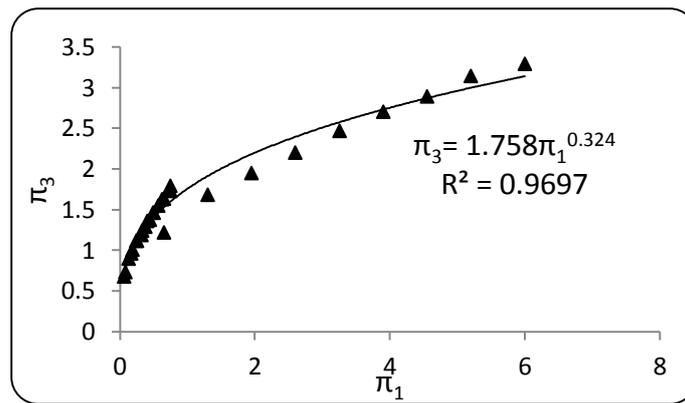


Figure (6). Relationship among dimensionless parameters  $\pi_1$  and  $\pi_3$ .

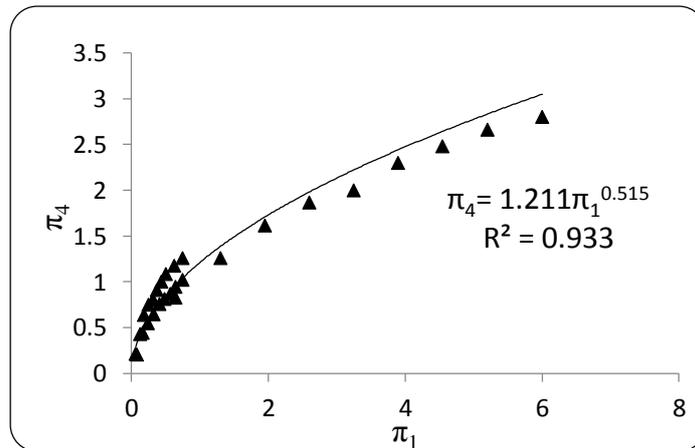


Figure (7). Relation between dimensionless parameters  $\pi_1$  and  $\pi_4$ .

## محاكاة لجبهة الابتلال تحت الري بالتنقيط السطحي وبأخدود مملوء بالحصى

يونس محمد حسن ، احمد شهاب احمد ، صباح أنور داوود المصرف

### الخلاصة

أستعرض في هذا البحث أستعمال أخدود مملوء بالحصى تحت سطح تربة مزيجية طينية تحت نظام الري بالتنقيط السطحي لغرض دراسة تأثير أبعاد الاخدود وتصريف المنقطات على أتجاهات جبهة دالة الابتلال في التربة الثقيلة. أستخدمت تقنية التحليل البعدي لاستنباط دالات أتجاهات جبهة الابتلال ومقارنة ذلك مع العمل المختبري. أجريت الاختبارات المختبرية في حاوية مصنوعة من الحديد مملوءة بالتربة الطينية المزيجية وبأستخدام أخدود مملوء بالحصى بعرض 10 و 20 سم وتصريف عند المنقط 1.3 و 2 لتر. ساعة<sup>-1</sup>. أظهرت النتائج بأن عرض الاخدود له تأثير على تقدم جبهات الابتلال. حيث أن الزيادة في عرض الاخدود أثرت في زيادة حركة دالة التقدم بالاتجاه نحو الاسفل والافق وبمعدل 19.1% و 8.9% على التوالي. كما كانت الزيادة في عرض الاخدود له الاثر المعاكس على حركة أتجاه المياه نحو الاعلى وبمعدل نقصان قدره 19.9%. أضافة الى أن الزيادة في تصريف المنقط له تأثير على زيادة ونقصان أتجاهات دالة التقدم نحو الاعلى والافق والاسفل. أن هذه الزيادة ستجعل من حالة التشبع هي الحالة السائدة داخل الاخدود وذلك نتيجة وجود حبيبات الطين داخل التربة. أظهر التحليل الاحصائي للمقارنة بين المعادلات المستنبطة لدالة الابتلال لكافة الاتجاهات وبأستخدام تقنية التحليل البعدي مع البيانات المختبرية المقاسة بأنه تطابق جيد، حيث كانت قيم معدل الجذر المربع للخطأ ومعامل الارتباط بين 1.18 الى 1.847 سم وبين 0.98 الى 0.99 على التوالي.