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Creating Software to Design a Low-Head Bubbler Irrigation System as an Alternative to Traditional Furrow Irrigation

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ABSTRACT

Freshwater scarcity has become a global issue, and agriculture is the major water consumer, pushing researchers to look for methods to improve water usage efficiency. The research aims to create design software for a simple low-head bubbler as a water-saving alternative to a traditional furrow irrigation system. The specified bubblers, having an inside diameter *(ID)* of *8.8* to *13.6 mm* and a height of *0.5 m*, were hydraulically evaluated in the lab at low effective pressures ranging from *1 to 13 kPa*. There are two methods for estimating bubbler discharges (q_b) by the design model: using equation from the laboratory bubblers evaluation (*E1*) or using theoretical calculations (*E2*). The model calculates discharge uniformity (*CU*) until it is *≥ 85 %*, at which point it stops and displays determining the lateral flow rate (Q_T), pressure (H_T), and length (L_L) for each value of *CU ≥ 85 - 90, ≥ 90 - 95,* and *≥ 95 %*. The correlation factor (R^2) between measured and estimated q_b by (*E1*) and (*E2*) was *0.98* and *0.93 %* for *ID 8.8 mm* and *(0.76* and *0.81 %)* for *ID 13.6 mm*, respectively. Although the R^2 between measured and predicted q_b was reduced by *ID* increasing, the correlation remained high. As a result, an *ID* of *13.6 mm* or less is often recommended. According to the results, using this model to design a simple low-head bubbler irrigation system is both effective and reliable. In terms of water conservation, it could be a viable alternative to traditional furrow irrigation. conservation, it could be a viable alternative to traditional furrow irrigation.

Keywords: Design Software, low-head, Bubbler, Discharge, Uniformity.

INTRODUCTION

With the increasing demand for freshwater around the world, the agricultural sector is the most consuming water. Traditional irrigation systems will be replaced with modern irrigation systems as part of a global goal to rationalize the use of water resources. Almost all modern irrigation systems, which are known for their high water-use efficiency, consume significant input energy. To achieve high water-use efficiency with consuming low energy, innovative irrigation systems are still required (Nogueira *et al*., 2021).

Micro-irrigation is a modern system that applies water slowly to only a portion of the soil volume. Surface or subsurface drip, bubbler, small-tube, and small-sprinkler are some of the techniques used. Water is provided through emitters, porous tubing, small-tube or sprayers as discrete or continuous drips, tiny streams, or a fine mist, and then runs through the soil by capillary and gravity (Ullah *et al.*, 2021 and Al-Omran *et al.*, 2021).

Water is supplied to the soil surface as a little stream using a small diameter tube (*1 to 13 mm*) or a commercially available device in bubbler irrigation. Small basins or furrows are required to control water distribution on the land to save water near the plant root zone since application rates typically exceed soil infiltration rates. High and low pressurized systems are the two main types of bubbler irrigation systems available. Low head bubblers operate at *10* to *50 kPa*, based on gravity flow systems, and *50* to *150 kPa* in pressurized systems (Hills & Yitayew, 2007).

In general, the techniques for designing pressurized bubbler systems are like those for most microirrigation systems. Gravity irrigation design procedures have been developed over several years and are relatively unique to this type of irrigation. The lateral line, delivery tube, and bubbler outlet height must all be designed when creating a low head bubbler irrigation system (El-Meseery, 1999 and Waller & Yitayew, 2016a).

Microirrigation is commonly made using smooth plastic tubes to reduce head friction losses. Friction losses along the lateral line can be calculated using the Darcy-Weisbach equation and the empirical Hazen-Williams equation; these equations are presented further below. (Waller & Yitayew, 2016b).

Low-pressure gravity-flow systems with pockets of air at the crest of pipe undulations are susceptible to airlocks. These air pockets absorb energy and can sometimes prevent water flow. No water will be discharged until the air is removed from the passage. Maintaining pipe velocities greater than *0.3 m/s* is a more cost-effective approach than using an air-lock removal technology. Water turbulence at these velocities keeps air from accumulating in the pipes. To achieve these hydraulic conditions under low-pressure operation, emission tubes with a diameter of less than (*13 mm*) are recommended (Reynolds & Yitayew, 1995).

The American Society of Agricultural Engineers (ASABE EP458, 1999) set up microirrigation uniformity classifications ranging from poor to excellent for point source emitters. Low, poor, fair, good, and excellent uniformity are defined as uniformity below *60 %,* between *60* and *70 %,* between *70* and *80 %,* between *80* and *90 %,* more than *90 %*, respectively. For standard design requirements, a system with a uniformity coefficient of at least *85 %* is considered suitable (Ella *et al.*, 2009).

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Khedr *et al.* (2015) developed a computer model to determine the ideal lateral length in microirrigation systems. The model was developed with flow variations *(q_{var})* of *10*, *15*, and *20 %*, or a coefficient of uniformity *(CU)* of over *85 %*. To validate the model, an actual experimental study was conducted with in-line, on-line, and microtube emitters for various lateral lengths and operating pressures. The correlation coefficient *(R^2)* between the model and the real experiment was between *0.80* and *0.95*.

Yurdem *et al.* (2015) provide a simplified empirical model for predicting the optimal lateral length for uniform water distribution. The created model applies to a *16 mm* nominal pipe diameter, cylindrical co-extruded emitters, and emitter spacing ranging from *0.2 m* to *1 m*. A total of *26* drip irrigation pipes were used to determine the best lateral length. The resulting model explained *98.3 %* of the variation in optimal lateral lengths.

Rashad (2013) developed a computer program that design a typical low head bubbler lateral with full application uniformity. the variables must be specified are including, water temps, bubbler length and diameter, lateral diameter, lateral upstream pressure, and soil surface slope. The output design model will estimate bubbler heights, lateral length, and lateral flow.

The main objective of this research is to create design software for a simple low-head bubbler irrigation system that has constant lengths and heights as well as uniform water application. This system can be used to replace traditional gravity furrow irrigation systems with a modern, water-saving alternative.

MATERIALS AND METHODS

A suggested Low Head Bubbler system

The schematic diagram of a suggested Low Head Bubbler Irrigation system in the field is shown in Figure (1). Water is transported from the source to the bubblers through a subsurface pipe network. a furrow was formed on the lateral pipe and the bubblers were placed on the upper furrow. The bubbler discharges at several points in each of the furrow's two bottoms, then each lateral irrigate two farrows.

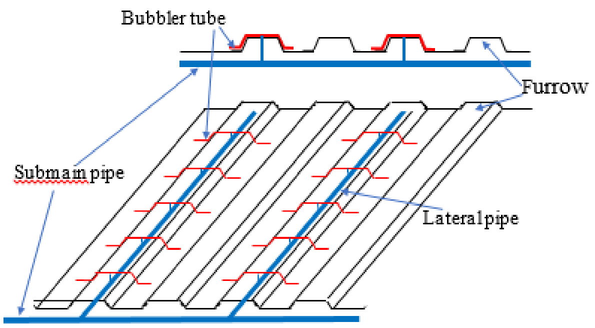

Figure 1. Irrigation with a low head in the field for furrow-planted intensive crops.

Calibrating Bubblers Hydraulically

To evaluate the Bubblers' Hydraulic Properties, the discharge of water from the two tested bubblers, *ID* (inside diameter) *8.8* and *13.6 mm*, was measured in the lab at various pressures.

Figure 2 shows a schematic diagram of one lateral in the bubbler hydraulic properties calibration experiment. In the calibration experiment, there are two laterals, each with ten bubblers that can be tested simultaneously. The water is pumped into a *0.80 m^3* cylindrical plastic tank with a height of *1.0 m* and a diameter of *0.50 m*. By increasing the inflow over the outflow and using a *50 mm* diameter overflow tube near the tank's upper lip, the water level in the tank was kept constant. The effective pressure head from the tank's water level to the bubbler level, on the other hand, is controlled by the tank's adjustable base height.

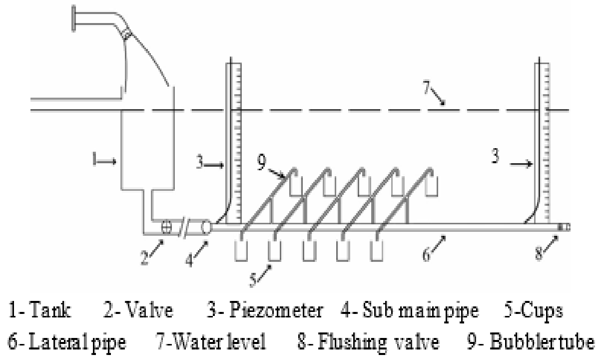

Figure 2. A schematic diagram of one lateral pipe in the calibration experiment of bubbler hydraulic properties.

The main pipe transported water from the supply tanks to two laterals, each with two valves at the entrance and end for flow control and air flushing. The lateral pipe was smooth *PVC* with a slope of zero and a length of *1.2m* and *61.8 mm ID*. Where every lateral pipe had ten smooth polyethylene bubbler tubes, each two of those were joined by a T connector and mounted by a five-riser tube (*0.5 m* height and *13.6 mm ID)* at *20 cm* intervals. The bubbles (*1.0 m* length) were placed on a metal test bench and discharged into plastic containers (*ID 0.25 m* and *0.30 m* length) at pressures of *1.0 to 13.0 kPa* in *1 kPa* increments. To measure the pressure, piezometers were mounted at the start and end of the lateral pipe.

As a result of the relationship between bubbler discharge and operating pressure, the bubbler discharge equation is as follows:

$$q_b = k\ h^x \qquad (1)$$

Where *k* is the dimensionless bubbler constant, *h* is the pressure head at the bubbler (*m*), and *x* is the dimensionless bubbler discharge exponent.

Calculating the manufacturer's coefficient of variation C_v from the lab experiment is also possible. It is among the most important factors affecting the microirrigation system uniformity. C_v is classified as unacceptable *(> 0.15)*, poor *(0.11 to 0.15)*, marginal *(0.07 to 0.11)*, average *(0.05 to 0.07)*, and excellent *(<0.05)* by the ASABE Standards (2008), and is given by the equation:

$$C_v = \frac{S_q}{q_{av}} \qquad (2)$$

Where C_v is the discharge coefficient of variation *(%)*, S_q is the standard deviation of discharge rates of the emitters in the sample (*L h^{-1}*) and q_{av} is the mean of emitter discharge rate (*L h^{-1}*).

The Design Model of Bubbler's Lateral

A mathematical model of the bubbler system based on a series of algebraic equations was proposed, and a program written in *MATLAB (R2015a)* was created to solve such equations and predict discharge and uniformity. Step-by-step (*SBS*) hydraulic calculations are used in this analysis. Starting at the lateral downstream end and moving upstream, the *SBS* procedure was initiated. Assume the bubbler discharge rate is constant and the lateral pipe slope is level. Bernoulli's equation describes energy conservation between two consecutive outlet positions in lateral construction (*n* and *n -1*).

$$\frac{P_n}{\gamma} + Z_n + \frac{V_n^2}{2g} = \frac{P_{(n-1)}}{\gamma} + Z_{(n-1)} + \frac{V_{(n-1)}^2}{2g} - \sum h_{f\ell} - \sum h_{m\ell} \quad (3)$$

$$h_n + Z_n + \frac{V_n^2}{2g} = h_{(n-1)} + Z_{(n-1)} + \frac{V_{(n-1)}^2}{2g} - \sum h_{f\ell} - \sum h_{m\ell} \quad (4)$$

Where P is the lateral pipe pressure (N/m^2), The character n is assigned to the lateral's last bubble. while the one before it is given *n-1*, γ is the specific weight of water (N/m^2), h is the pressure head, Z is the lateral elevation (*m*), V is the water flow velocity (*m/s*), g is the acceleration of gravity constant (*9.81 m/s²*), $h_{f\ell}$ is the friction head loss in a lateral pipe (*m*) and $h_{m\ell}$ is minor losses at pipe fittings (*m*).

The lateral pressure head at the bubbler (*n-1*) point is as follows:

$$h_{(n-1)} = h_n + \sum h_{f\ell} + \sum h_{m\ell} \quad (5)$$

The basic formulas for friction and other minor pipeline losses were used to calculate the discharges and total head in the lateral in this analysis. In small diameter and smooth pipes, the Darcy Weisbach equation was employed to compute friction head loss (Rashad, 2013 and Waller & Yitayew, 2016b) as follows:

$$h_f = f\,\frac{LV^2}{D2g} \quad (6)$$

Where, h_f is the friction head loss (*m*), L is the bubbler length (*m*), D is the bubbler tube inside diameter (*m*), V is the average flow velocity (*m/s*), g is the acceleration of gravity (*9.81 m/s²*), and f is the friction factor for pipe flow calculated as:

For laminar flow $Re \leq 2000 \quad f = 64/Re \quad (7)$

For turbulent flow $4000 \leq Re \leq 100000 \quad f = 0.3164/Re^{0.25} \quad (8)$

The hydraulic flow regime in this model was specified using the Reynolds number (R_e), which was developed by Boor et al. (1968) to show the impact of water temperature as follows:

$$R_e = 198.7\,Q\,(1 + 0.03368T_w + 0.000221T_w^2)/d \quad (9)$$

Where Q is the total flow rate (*ℓ/h*); T_w is the water temperature (*ºC*), and d is the internal pipe diameter *(mm)*.

Equations (2, 3, and 4) can be combined to obtain the equations for laminar (Eq. 6) and turbulent (Eq. 7) flows, respectively as follows:

For laminar flow $$h_f = 408.4479\,\frac{LQ^2}{R_e d^5} \quad (10)$$

For turbulent flow $$h_f = 2.01926\,\frac{LQ^2}{R_e^{0.25}\,d^5} \quad (11)$$

The emitter barb causes minor friction losses (E_ℓ), which are expressed as an equivalent length of lateral pipe (Watters & Keller, 1978). The following losses for bubbler barbs are shown for various pipe diameters and barb dimensions:

$$E_\ell = 0.25 d_b (19 d_L^{-19}) \quad (12)$$

Where E_ℓ is the corresponding pipe length (*m*), d_b is bubbler barb diameter (*mm*) and d_L is the lateral pipe diameter (*mm*).

As a result, the distance between bubbler (S) in the lateral frictional head loss equation was substituted by S_ℓ after adding the equivalent length (E_ℓ):

$$S_\ell = (S + E_\ell) \quad (13)$$

The system's velocity and other minor losses are generally expressed as:

$$h = k\frac{V^2}{2g} \quad (14)$$

Where, k is the head loss coefficient, which is divided into two minor loss coefficients as $k_e = 1.2$ to calculate the entrance head loss h_e, and $k_v = 1$ to calculate the velocity head loss.

As a result, Eq. (14) can be rearranged as follows to account for these two minor losses:

$$h_e = 0.0077\frac{q^2}{d^4} \quad (15)$$

$$h_v = 0.0064\frac{q^2}{d^4} \quad (16)$$

A schematic diagram of the hydraulic grade and energy line along the lateral pipe is shown in Figure (3). It describes its elements, such as the lateral upstream head (H_T), lateral and bubbler Hydraulic Gradient Line (*HGL*), lateral and bubbler friction losses (h_{fL}, h_{fb}), entrance head loss h_e, velocity head (h_v), and bubbler heights (h_h) along with the horizontal low head bubbler irrigation lateral.

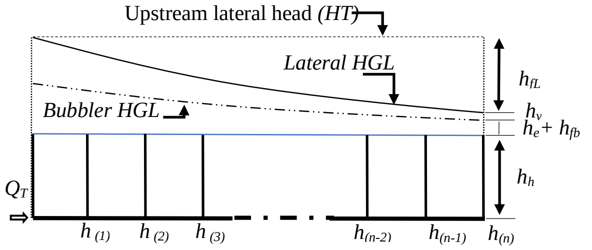

Figure 3. A schematic diagram of the hydraulic grade and energy line along the lateral pipe.

As a result, the upstream lateral head (H_T) equation is:

$$H_T = h_e + h_V + h_{fb} + h_h + h_{fL} \pm S\delta_L \quad (17)$$

Where, h_h is the bubbler height *(m)* and h_{fL} is frictional head loss of lateral at the distance before outlet point one *(m)*.

The downstream end bubbler (q_n) is specified in the input data, and (q_{n-1}) and preceding ones were estimated in the design model using the practical equation (*E1*) or theoretical equation (*E2*). *E1* estimation using the lateral section frictional head loss, h_{fL}, and (q_n) as follows:

$$q_{n-1} = q_n + k\,h_{fL}^x \quad (18)$$

Where q_{n-1} is current bubbler discharge (*ℓ/h*) and q_n is previous bubbler discharge (*ℓ/h*).

The model can use the alternate estimate equation *E2* based on the bubbler flow regime to calculate the bubbler discharges:

For bubbler laminar flow

$$q_{n-1} = \left(\frac{h_{fb} + h_{fL}}{408.4479 \text{ x } b_\ell \times Re_b \times {b_d}^5}\right)^{0.5} \quad (19)$$

For bubbler turbulent flow

$$q_{n-1} = \left(\frac{h_{fb} + h_{fL}}{2.01926 \text{ x } b_\ell \times Re_b^{0.25} \times {b_d}^5}\right)^{0.5} \quad (20)$$

Where, q_{n-1} is current bubbler discharge (*ℓ/h*), h_{fb} is previous bubbler friction loss (*m*), h_{fL} is previous lateral friction loss (*m*), b_ℓ is bubbler length (*m*), Re_b is previous bubbler Reynolds number (dimensionless) and b_d is bubbler diameter (*m*).

The total number of bubblers b_N, lateral length L_L *(m)*, and lateral upstream discharge, Q_T *(ℓ/h)* calculated as follows:

$$b_N = o_n \times Number\ of\ bubbler\ per\ outlet\ point \quad (21)$$

$$L_L = o_n \times \delta \quad (22)$$

$$Q_T = \sum_{i=1}^{i=n} q_b \quad (23)$$

Where, O_n is outlet point numbers, δ is the interval distance between bubblers (*m*) and q_b is the bubbler discharge, (*ℓ/h*).

A more accurate approach of characterizing the subunit's hydraulic performance was the coefficient of discharge uniformity (*CU*). Christiansen (1942) provided useful assistance in determining irrigation uniformity:

$$CU = 100\left(1 - \frac{\sum_{i=1}^{i=n} |q_i - \bar{q}|}{n\,\bar{q}}\right) \quad (24)$$

Where, $\sum_{i=1}^{i=n} |q_i - \bar{q}|$ is the sum of absolute values of deviations from mean bubbler discharge, q_i and $\bar{q}$ are individual and mean bubbler discharge (*ℓ/h*), and n is the estimated number of bubblers.

Figure 4 is a flowchart of the equations used in this model, and it shows the software output predicted data as, lateral length (L_L), discharge (Q_L), and pressure (P_L) at each predetermined bubbler discharge uniformity (*CU %*).

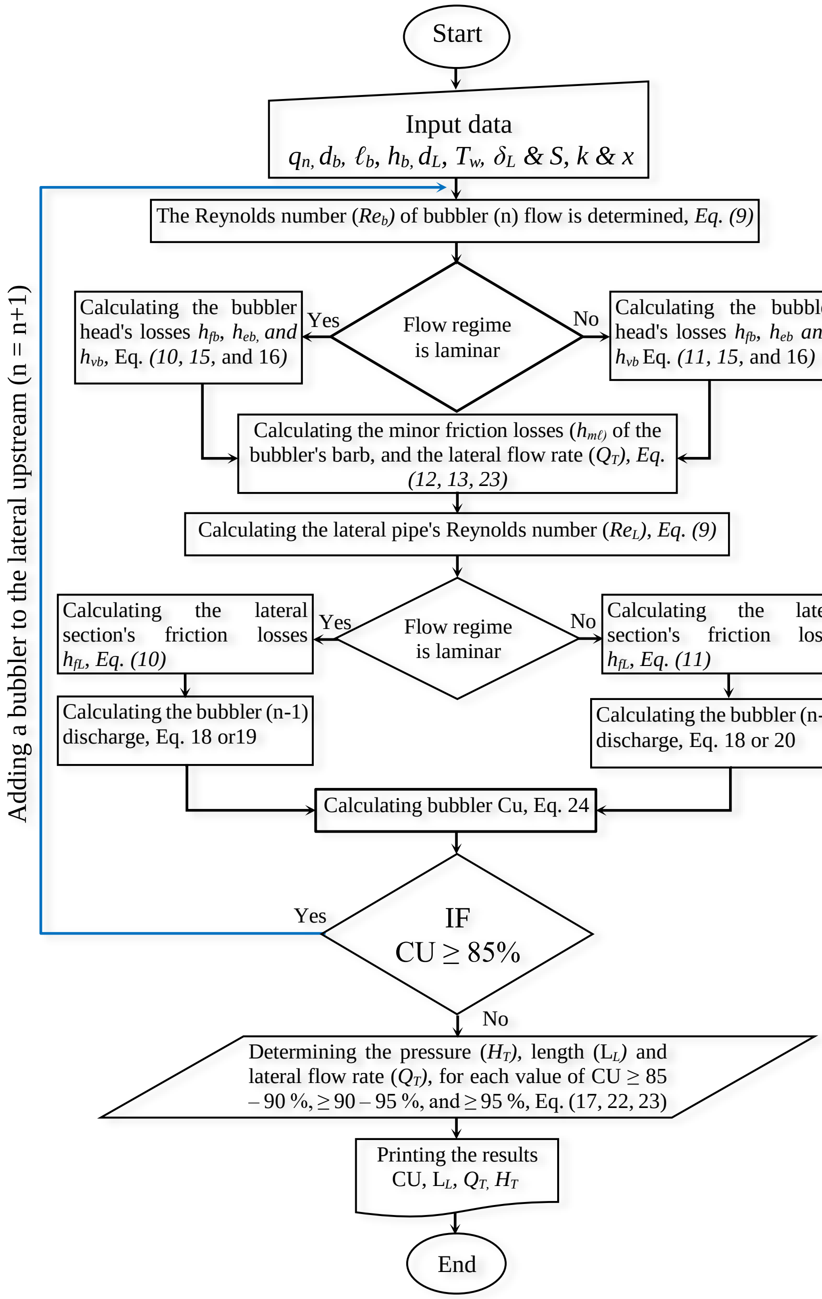

Figure 4. The flowchart of a software model for designing a low-head bubbler lateral pipe.

The Design Model Validation

A low head bubbler irrigation system was established in the field, as described in in Figure (1), to validate the model's various designs through a practical experiment. The main pipe transports water from the source to a *61.8 mm ID* submain pipe, which branches out to laterals *ID 48.8 mm* in a subsurface network. A furrow was formed on each lateral pipe, and two attached bubbler tubes of *1.0 m* length (*ID 8.8 or 13.6 mm*) with *T* connectors were placed on the upper furrow to discharge in the two lower furrow sides. A *0.5m* riser tube linked the bubblers *T* connector to the lateral pipe (*ID 13.6 mm*). The two bubblers were verified at *2* and *4 m* intervals along a constant lateral length of *20 m* under effective pressures of *5.0, 7.5,* and *10.0 kPa*.

RESULTS AND DISCUSSION

The Bubbler's Hydraulic Properties

Table 1 summarizes the characteristics of the two bubblers (*ID 8.8* and *13.6 mm*), including flow versus pressure, bubbler discharge equation constants, and manufacturing variation coefficient (C_v).

The discharge of *ID 8.8* and *13.6 mm* was increased by *124* and *212 %*, respectively, by elevating the effective pressure from (*1* to *13 kPa*). The results revealed that effective pressure and bubbler diameter had a significant impact on the bubbler tube discharges.

The discharge exponents of *ID 8.8* and *13.6 mm* were *0.329* and *0.434*, respectively, indicating that the flow was partially turbulent, according to ASABE Standards (2008).

Table 1. Effective pressures (P_e) versus bubbler discharge (q_b) for various inside diameters (ID), with calculated bubbler constants (k, x), and manufacturer's coefficient of variation (C_v).

P_e	ID (8.8 mm)				ID (13.6 mm)			
(kPa)	q_b (ℓ/h)	C_v (%)	k	x	q_b (ℓ/h)	C_v (%)	k	x
1	91.0	0.06			97.6	0.07		
2	110.3	0.06			127.7	0.11		
3	110.7	0.03			154.4	0.12		
4	143.0	0.09			168.4	0.14		
5	154.8	0.05			192.7	0.06		
6	155.3	0.05			208.2	0.15		
7	163.3	0.07	87.28	0.329	217.7	0.15	94.89	0.434
8	175.2	0.03			223.9	0.16		
9	180.3	0.09			224.3	0.08		
10	179.8	0.07			252.0	0.10		
11	198.1	0.03			271.4	0.12		
12	203.0	0.03			304.3	0.15		
13	203.4	0.03			304.7	0.15		

The C_v of ID 8.8 mm was (0.03 to 0.09), while the C_v of ID 13.6 mm was (0.06 to 0.15), indicating (excellent to marginal) and (marginal to poor), respectively. With increasing effective pressures, cv values fluctuate for all bubblers; these results agreed with Rashad M. A. (2015).

Design Software of Low Head Bubbler

Unlike all other micro-irrigation systems, the bubbler irrigation system's design is dependent on the presence of surface runoff. As a result, the rate of water input exceeds the rate of water absorption by the soil. When entering the program's inputs, this must be considered when selecting the bubbler's lowest discharge at the end of the lateral pipe. As a result, in addition to avoiding air pockets in the bubbler, the bubbler flow rate must be higher than the soil absorption. Consequently, the application calculates and displays the lowest water speed, which must be greater than *0.3 m/s*. Furthermore, to save energy, the water velocity must be less than *1.5 m/s*, however, when it rises, its impact is less since turbulent flow avoids airlocks.

The software interface in Figure (5), requires information on bubbler properties such as diameter and length, as well as the bubbler discharge in the downstream end (q_n). Data on lateral parameters, such as diameter and bubbler interval distances, as well as slope, is also required. the software interface can design the bubbler lateral using the bubbler discharge equation derived from a laboratory experiment (*E1*) by inputting its constants. Alternatively, you can use the theoretical equation *E2*.

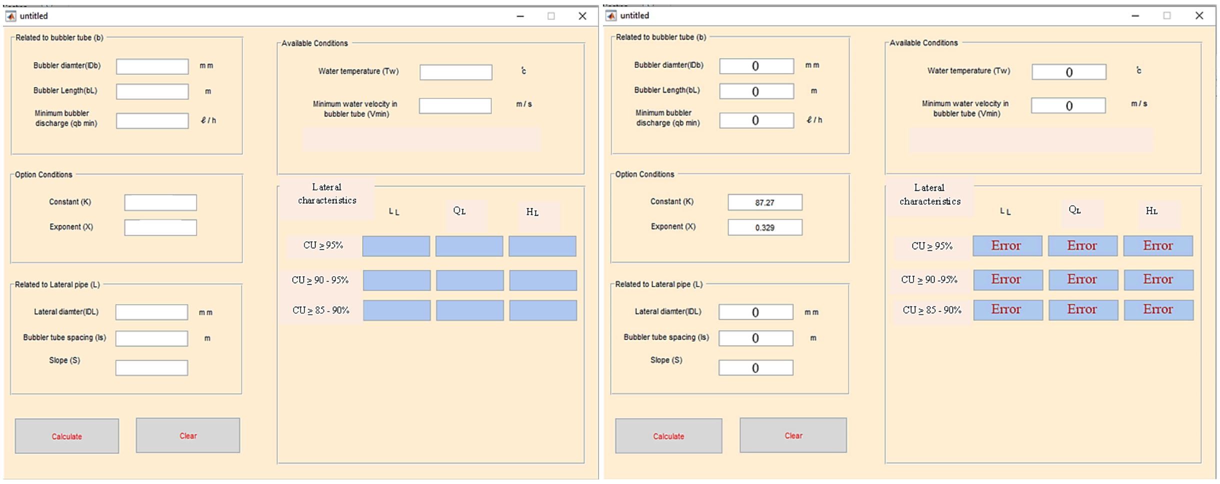

Figure 5. The blank program interface appears first, followed by an error notice if inappropriate data is entered and the design is not achieved.

Evaluation of the Bubbler Lateral Design

The bubbler discharges (q_b) and coefficients of uniformity (*CU*) from the field data are compared to those calculated theoretically by the design software in Table (2) and Figure (6).

The software estimated bubbler discharges based on the two equations that were quite close to those measured in the field, as shown in Figure (6). All *CU* values have been done at *2* and 4 m distances (*Is*) with *ID* of *8.8* and *13.6 mm* were over *90 %*, which was classified as excellent in both field measurements and theoretical estimation.

Consequently, the R^2 correlation factor between observed and estimated discharges using Equation one (*E1*) or two (*E2*) was determined and displayed in Figure (7). The R^2 of measured q_b with *E1* and *E2* was (*0.98* and *0.93 %*) and *(0.76* and *0.81 %)* for *8.8* and *13.6 mm*, respectively.

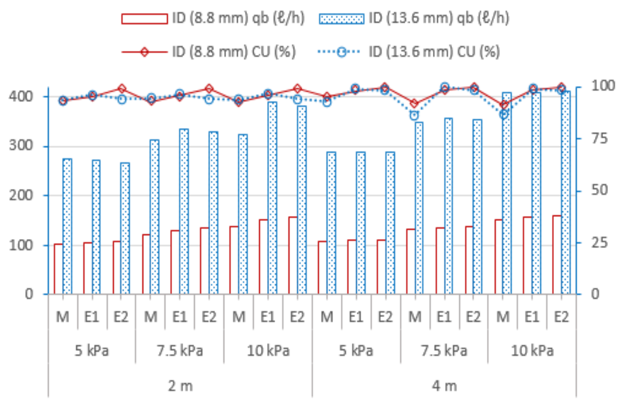

Figure 6. bubbler discharge (q_b) and coefficient of uniformity (CU %) measured (M) and estimated (E1 and E2) for bubbler ID of 8.8 and 13.6 mm at bubbler distances of 2.0 and 4.0 m under different effective pressures (5.0, 7.5, 10.0 kPa).

The correlation R^2 between measured and estimated discharge using *E1* was strong (*98 %*) when the diameter was small (*ID 8.8 mm*), but it declined to *76 %* when the diameter was larger (*ID 13.6 mm*). Furthermore, although R^2 of *E2* follows the same trend as *E1* in reducing correlation by increasing bubbler diameter, there is still a high correlation between measured and predicted discharge when *ID* is increased from *8.8* to *13.6 mm.*

Table 2. Both bubbler discharge (q_b) and coefficient of uniformity (*CU*) were measured (*M*) and estimated (*E1* and *E2*) for interval distances (I_s) and bubbler inside diameters (*ID*) at various effective pressures (P_e).

I_s (m)	P_e (kPa)	Tech.	(ID 8.8 mm) q_b (ℓ/h)	(ID 8.8 mm) CU (%)	(ID 13.6 mm) q_b (ℓ/h)	(ID 13.6 mm) CU (%)
2	1	*M*	103.3	93.5	275.6	93.6
		E1	103.9	95.4	271.4	96.3
		E2	108.9	99.2	265.8	94.3
	3	*M*	122.2	92.9	313.1	94.3
		E1	128.9	95.6	335.7	96.5
		E2	134.9	99.2	327.9	94.3
	5	*M*	137.8	92.8	322.6	93.8
		E1	150.1	95.7	390.2	96.6
		E2	156.8	99.2	380.5	94.3
4	1	*M*	106.4	95.1	286.9	92.6
		E1	109.8	98.1	286.9	98.9
		E2	110.4	99.8	286.9	98.3
	3	*M*	132.7	91.7	348.8	86.3
		E1	135.8	98.2	355.2	99.8
		E2	136.5	99.8	353.7	98.3
	5	*M*	151.9	91.1	407.4	86.6
		E1	157.9	98.3	409.0	98.6
		E2	158.6	99.8	410.2	98.3

In general, the R^2 of the two estimating equations with the measured discharge was high-level when the *ID* was less than *13.6 mm*, which agrees with (Reynolds & Yitayew, 1995; Waller & Yitayew, 2016b).

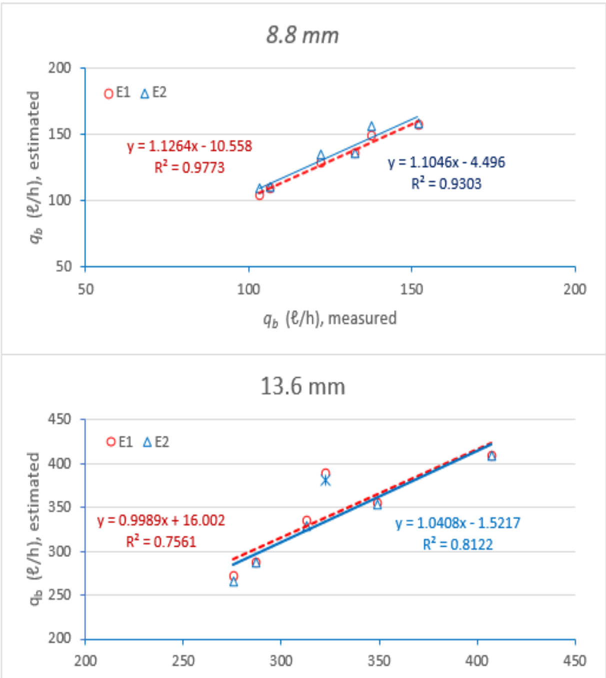

Figure 7. The correlation factor (R^2) between measured and estimated bubbler discharge (q_b) by the model using equations (*E1* and *E2*), for bubbler diameters of *8.8* and *13.6 mm*.

CONCLUSION

Design software for the bubbler irrigation lateral pipe was created using the *MATLAB (R2015a)* program. The design steps include calculating friction losses in the lateral pipe and bubbler tube to determine the pressure at each tube's exit. By employing the obtained pressure, *E1* and *E2* can be used to estimate the bubbler discharge. The software interface was designed to show the essential inputs in calculations and outputs. The calculations were done step by step from the bubbler at the downstream end of the lateral pipe to the one at the upstream end. The calculation of bubbler discharges will continue until the *CU* is reduced to ≥ *85 %*, with three options: ≥ *85-90 %*, ≥ *90-95 %, and* ≥ *95 %*. The total length, discharge, and pressure of the lateral will be presented at each *CU %*.

A low-head bubbler irrigation system was installed in the field to evaluate the designs. The bubblers were mounted on lateral pipes and placed on the top furrows that formed above each lateral as part of the subsurface pipe network. *20 m* lateral designs with two bubblers (*ID 8.8* and *13.6 mm*) at (*2* and *4 m*) intervals were evaluated under varied effective pressures (*5*, *7.5*, and *10 kPa*). The bubbler discharges (q_b) and coefficients of uniformity (*CU*) calculated by the design software are compared to those obtained from field data. The correlation factor (R^2) between measured and estimated discharges by *E1* and *E2* was *0.98 and 0.93 %* for *ID 8.8 mm* and (*0.76* and *0.81 %*) for *ID 13.6 mm*, respectively. R^2 was strengthened (*98 %)* when *E1* has been used in the design with a small diameter (*8.8 mm*), but it was lowered to *76 %* when the diameter was expanded to (*13.6 mm*). R^2 of *E2* also reduced as *ID* increased from *8.8* to *13.6 mm*, but there is still a high correlation between measured and predicted discharge. *ID* of less than or equal to *13.6 mm* is generally recommended since the R^2 between the estimated and measured discharges is still high.

At the end of this program at this studying is very important to add strength to these researchers and future workers to follow the additions required to develop the future of irrigation bubblers and benefit from the rationalization of water consumption.

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إنشاء برنامج لتصميم نظام ري بالفوارات المنخفضة الضاغط ليكون بديل للري التقليدي بالخطوط

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الهدف من هذا البحث هو إنشاء برنامج بسيط لتصميم نظام ري فوار منخفض الضاغط ليكون بديل مناسب لنظم الري بالخطوط التقليدية بالجاذبية، حيث أجريت التجارب الهيدروليكية والمعملية لمعايرة بعض أقطار الفوارات المختارة وخط الري الفرعي لهذه الفوارات. أظهرت المعايرة المعملية للفوارات عند عدة ضغوط فعالة تبدأ من *1.0* الي *13.0 كيلو باسكال* لخط فرعي بطول *1.2* م وقطر *61.80* مم ولأقطار فوارات *8.8 و13.6* مم، قيم أس تصرف الفوار (x) لمعادلة تصرف الفوار تتراوح ما بين *0.3* و*0.4* على التوالي، حيث صنف السريان لكليهما بالمضطرب جزئياً. وتم حساب قيم معامل اختلاف التصنيع (C_v) حيث كان ما بين (*0.03 إلى 0.08*) و(*0.07* الي *0.15*) للقطرين *8.8 و13.6* مم، على التوالي، حيث صنف على أنه (ما بين ممتاز لثانوي) و(ما بين ثانوي لضعيف) .تم عمل نموذج تصميم رياضي لتصميم نظام الري بالفوارات بناءً على سلسلة من المعادلات الحسابية، وتم إنشاء تطبيق حاسوبي مكتوب ببرنامج *MATLAB* لحل هذه المعادلات والتنبؤ بتصرف الفوارات ومعامل انتظامية إضافة المياه (*CU*). هناك طريقتان لتقدير تصرف الفوارات بواسطة نموذج التصميم: اما باستخدام نتائج معايرة الفوارات المعملية (*E1*) أو باستخدام الحسابات النظرية (*E2*)، وتاليا يتم حساب معامل انتظامية إضافة المياه الذي يقل بزيادة عدد الفوارات حتى يساوي أو يزيد عن *85 %*، وعند هذه النقطة تتوقف الحسابات ويعرض معدل التدفق (Q_T) والضغط (H_T) والطول (L_L) للخط الفرعي عند قيم *CU تتراوح من≤ 85 الى 90 %*، ومن ≤ *90* الى *95 %* ثم≤ *95 %*. كان معامل الارتباط (R^2) بين التصريفات المقاسة والمقدرة (q_b) بواسطة *E1* و*E2* هو (*0.98* و*0.93 %*) للقطر *8.8* مم و (*0.76* و*0.81 %*) للقطر *13.6* مم على التوالي. على الرغم من أنR^2 بين q_b المقاسة والمتوقعة انخفضت بزيادة القطر، إلا أن الارتباط ظل مرتفعًا. ونتيجة لذلك يوصى باستخدام الأقطار أقل من أو تساوي *13.6* مم. ووفقاً لنتائج هذه الدراسة، فإن استخدام هذا النموذج لتصميم نظام بسيط للري الفوار منخفض الضاغط يعد فعال وجدير بالثقة. ويمكن أن يكون هذا النظام للري بديلاً واعداً قابل للتطبيق لنظم الري التقليدية بالخطوط وذو كفاءة عالية في الحفاظ على المياه والطاقة، ويوصى بمزيد من العمل لتيسير استخدامه وانتشاره بين المزارعين.

الكلمات المفتاحية: برنامج تصميم، ري فوار، منخفض الضاغط، تصرف، انتظامية، الارتباط.