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PERFORMANCE ANALYSIS OF PRESSURIZED IRRIGATION SYSTEMS USING SIMULATION MODEL TECHNIQUE

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Abstract

Simulation models are useful tools for enhancing water management on farm level and optimizing water application efficiency. Focusing on water, as water is the key driver of agricultural production and the critical factor of increasing crop production. Evaluating effects of water saving to optimize water application efficiency under limited conditions to enhance sustainability an (surface drip irrigation and solid-set sprinkler) at the Experimental Farm of d profitability of crop production. HydroCalc model was evaluated under two lateral length (30, 50m) and (0, 0.02) slopes under pressurized irrigation systems Agricultural Production and Research Station, National Research Centre (NRC), El Nubaria, Egypt, (latitude 30.87N, longitude 30.17E and altitude 20 m above sea level). The results obtained declared that: The statistical indicators; the regression coefficient ($R^2 > 0.90$) and correlation coefficient confirmed the good performance of HydroCalc in simulating some hydraulic parameters of pressurized irrigation systems. The validation of measured and simulated data clarified it as efficient reliable software to design pressurized irrigation systems to increase the system performance and water application efficiency. The energy savings were (33.18; 27.33%) under slope (0%) and (34.23; 29.54%) under slope (2%) with surface drip irrigation systems when using lateral lengths (30;50m), respectively compared to the solid-set sprinkler irrigation system. It could be concluded to using drip irrigation systems with lateral length 30 m and with slope (2%) downhill for increasing the water application efficiency, decreasing the friction losses along lateral lines and this lead to saving more water head energy.

***Keywords* :** Simulation models, HydroCalc software, drip irrigation, sprinkler irrigation, Water application efficiency.

Introduction

In the year 2000, the world population was 7 billion people and it is expected to increase to 9 billion people in 2050 which means 60% more food needed and more than 19% of agriculture water consumption (including both the rain-fed and the irrigated areas) by 2050. Consequently, the water demand will increase by 55% and the water for the agriculture sector will reduce due to the competition with the other sectors (FAO, 2011).

Therefore, it will be necessary to produce more with less water and land by raising water productivity through the water-saving irrigation application strategies (deficit irrigation scenarios), management practices.

Water-saving techniques refer to a comprehensive exercise, using every possible water-saving measure in the whole farm production, including the full use of natural precipitation, as well as the efficient management of an irrigation water network (Deng *et al*., 2006; Wang *et al*., 2002). Water scarcity affects the agricultural production systems; as a result, water saving technologies and strategies are reaching considerable studies worldwide. The purpose of saving-water irrigation strategies is to use water efficiently in order to lead to a sustainable agriculture. In other words, saving irrigation water practices uses less water while still keeping crop production at an acceptable level (Li, 2006).

Application efficiency is an indication of the percentage of water applied by the irrigation system already available for the crop. Irrigation scheduling implements irrigation in the right place at the right time. To achieve that a good design for the irrigation system is required for making irrigation sustainable, At the environmental and economic levels to improve agricultural productivity, improve farm delivery systems, improve management of degraded soils, improve crop water management and address high energy prices (Howell, 2001; Hoffman *et al*., 2007).

Therefore, it is better to manage water in irrigated agriculture, it is necessary to increase the efficiency of water use, and to promote crop production and soil conservation. Irrigation management should focus on adopting practices that promote water use efficiency so that other sectors can have access to more water for economic use (Molden, 2007).

Optimum design and efficient management and operation of the water applied to crops are required to obtain maximum yield. To increase the sustainability of irrigated agriculture, important aspects that have been considered in many studies in the design of efficient irrigation systems at the farm level (Khan *et al*., 2006; Hsiao *et al*., 2007).

Pressurized irrigation is characterized by their design, sustainability of an irrigation system, high performance of water application on-farm water management practices (Sarwar *et al*., 2001).

Keller and Blienser, (2000) reported that the uniformity of pressurized irrigation is an important design goal. Hassanli *et al*. (2010) specified that irrigation methods have a key role in the efficient use of water but still there is limited information on their application on sugar beet performance in arid countries. Spatial variability maps of soil and crop properties would be appropriate tools to make a precise management strategy. Provide sufficient water and nitrogen distribution when properly designed and operated.

Accurate computation of the amount of pressure loss is very important in the design of surface drip and solid-set sprinkler systems. Failure to properly adjust pressure loss results in inadequate drip irrigation and sprinkler irrigation. Using HydroCalc software give the ability for adjusting pressure loss and being compared between Sprinkler and drip irrigation system (Valipour, 2012).

HydroCalc irrigation planning software is an important calculation tool for conducting some basic hydraulic calculations for pressurized irrigation (surface drip and solid-set sprinkler irrigation systems). The use of HydroCalc allows the designer and end user to evaluate the performance of partial irrigation components in the field, such as drip lines, sprinklers, main and sub-main lines (PVC, PE, etc.), valves and energy calculation (Mansour *et al.,* 2015).

Therefore, the main objective of this study is to validate the HydroCalc model and evaluate the performance of different pressurized irrigation systems (surface drip and soid-set sprinkler irrigation system).

Material and Methods

Hydraulic Irrigation Software Component

HydroCalc irrigation software was designed to help the designer identifying the parameters of an irrigation system. The user will be able to run the program with any appropriate parameters, reviewing output and change the input data in order to conform to the preparation of an appropriate irrigation system.

Some parameters may be selected from the system list whereas the user according to their own needs enters others so they do not conflict with the program's limitations. The software package includes an opening main window, five calculation programs, one language setting window and a database that can be modified and updated by the user.

Hydro Calc. includes several sub-programs as:

1. The Emitters program calculates the accumulated loss emitters pressure, flow rate, and water flow velocity etc. in the specified emitter. Can be changed to suit the required irrigation system standards.
2. The sub-program calculates the cumulative pressure loss and velocity of water flow in the sub-main distributing water pipe (single or telescopic). It changes to suit the required irrigation system standards.
3. The Main Pipe program calculates the cumulative pressure loss and velocity of water flow velocity in the main distributing water pipe (single or telescopic). It changes to suit the required irrigation system standards.
4. The Shape Wizard program helps to transfer the required system parameters (lateral inlet flow rate, the minimum head pressure) from the Emitters program to the sub main program.
5. The Valves program calculates the valve friction loss according to the specified parameters.
6. The Shifts program calculates the number of shifts and irrigation rate and needed according to the given parameters.
7. The Emitters program is the first application, which can be used in the frame of HydroCalc software. There are four basic types of emitters that can be used: online, drip Line, mini-sprinklers and sprinklers.

HydroCalc uses for Emitters subprogram a number of 4 calculation methods as shown in figure (2), each of them in concordance with the loaded data. The first method is Emitter line length that can realize the computation for the entire designated length through it. The second method represented by the pressure range, which will be executed in a way that ensures that the difference in pressure between the emitter's maximum pressure to the minimum pressure transmitter does not exceed the scope of the pressure provided by the user.

Flow Rate Variation represents the third computation method, which can be executed to achieve the requested flow variation and will generate the maximum lateral length under these conditions. The last computation method is Emission Uniformity, which is similar to flow rate variation and will be executed to achieve the maximum lateral length.

Data Input and Calculations

In this study, the input data for lateral and manifold design used to surface drip and onset sprinkler irrigation system design using HydroCalc software are shown in Tables 1 and 2 respectively.

Table 1: Input data for surface drip design:

Manifold		Drip line		Emitters	
Name	**Value**	**Name**	**Value**	**Name**	**Value**
Pipe type	PVC	Tubes type	PE	Emitter type	Built-in
Pipe length	-----	Tubes lengths	30 and 50 m	Emitter flow (Lph)	4.0
Pipe diameter	0.05 m	Inner diameter	0.0142 m	Emitters distance	0.30 m
Pipe roughness (C)	150	Pipe roughness	150	Press head require (m)	10.0 m
Slope	0 m/m	Slope	0 or 0.02 m/m	Calculation method	Flow rate variation
Extra energy losses	0.064	Spacing	1 m		

Table 2: Input data for onset sprinkler design

Manifold		Sprinkler line		Sprinklers	
Name	**Value**	**Name**	**Value**	**Name**	**Value**
Pipe type	PVC	Sprinklers line	-------	Sprinkler type	---------
Pipe length	-----	Tubes lengths	30 and 50 m	Sprinkler flow (lph)	75.0
Pipe diameter	0.05 m	Inner diameter	0.040 m	Sprinkler distance	10 m
Pipe roughness	150	Pipe roughness	150	Press head require (m)	30.0 m
Slope	0 m/m	Slope	0 or 0.02 m/m	Calculation method	Flow rate variation
Extra energy losses	0.064	Spacing	______		

In HydroCalc software flow rate variation and emission, uniformity was calculated as the following equation (Gilary, 2008):

$$FV = 100[(Qmax - Qmin)/Qmax] \ldots\ldots\ldots (1)$$

$$EU = 100(Qmin/Qmax)\left[1 - 1.27CV/n^{1/2}\right] \ldots\ldots\ldots (2)$$

Where FV is flow rate variation (%), Q*max* is the maximum discharge of emitters (L/h), Q*min* is the minimum discharge of emitters (L/h), EU is emission uniformity (%), CV is coefficient of variation of discharge rates, and nis a number of emitters.

Validation of HydroCalc data with measured data:

The emission rate for 10 emitters tested for each Lateral line for lengths (30 and 50 m) at three stages First, middle and end on the line were calculated theoretically using the following procedure: The head loss due to friction and insertion of emitters was calculated and then the pressure head at every emitter was determined. The emission from every emitter calculated using the characteristic equation developed for pressure head vs. discharge for each product.

The head loss due to friction was calculated using the Darcy-Weisbach equation:

$$h = f\left(\frac{L}{D}\right) * \left(\frac{v^2}{2g}\right) \ldots\ldots\ldots (3)$$

Where h = head loss (m), L = length of pipe (m), D= inner diameter of pipework (m), v= velocity of fluid (m/s) and g= acceleration due to gravity (m/s2).

Friction factor can be expressed as:

$$f = \frac{64}{R_e} \ldots\ldots (for\ R_e \le 2000) \ldots\ldots\ldots (4)$$

$$f = 0.32 * R_e^{-0.25} \ldots\ldots (for\ R_e \ge 2000) \ldots\ldots\ldots (5)$$

Where Re = Reynolds' number, which can be calculated from:

$$R_e = \frac{vD}{\mu} \ldots\ldots\ldots (6)$$

Where v = fluid velocity (m/sec), D = Internal pipe diameter of lateral (m) and ν = kinematic viscosity of water = 1 × 10-6 m²/sec, at 200 C.

Velocity can be calculated from:

$$v = \frac{Q}{A} \ldots\ldots\ldots (7)$$

Where, Q = lateral flow rate (average flow rate per emitter × number of emitters), and A = cross-sectional area of lateral.

The calculated emission rates were then compared with the measured values to see the differences between them.

The calculation and validation of hydraulic analysis of surface drip and onset sprinkler irrigation systems flowchart are presented in figure (3).

The discharge rates and pressures at the drip head were measured under field conditions at three sites along the lateral lines (start, middle and end) for drip and sprinkler irrigation systems with three different lateral lengths (30 and 50 m) and for two different slopes of the drip and sprinkler lines (0 and 2 %). Empirical measurements were used to validate the drip simulation program (HydroCalc simulation program copyright 2009 developed by NETAFIM, USA). The empirical data depended on the laboratory measurements of pressures and discharge, as well as the field uniformity. The Simulated outputs of HydroCalc simulation program (exponent (X), pressure head loss (m), velocity (m/s), and pressure along the lateral line drippers) is shown in Table (3).

Table 3: Simulated exponent (x), Head loss (m) and velocity (m/s) by the HydroCalc simulation program for surface drip and onset sprinkler irrigation system design with different slopes (0 and 2%).

Field slope (%)	Irrigation System							
	Surface drip				Onset sprinkler			
	Drip line length (m)	Exponent (x)	Head loss (m)	Velocity (m/s)	Sprinkler line length (m)	Exponent (x)	Head loss (m)	Velocity (m/s)
0	30	0.72	0.64	1.58	30	0.58	1.43	1.52
	50	0.65	1.48	1.63	50	0.55	2.35	1.64
0.02	30	0.76	0.45	1.51	30	0.63	1.38	1.51
	50	0.68	1.34	1.57	50	0.59	2.26	1.62

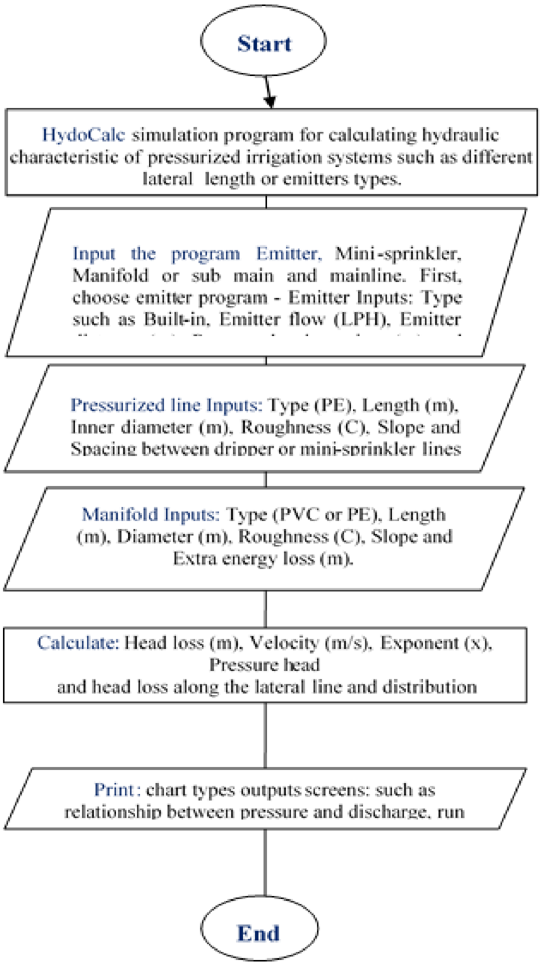

Fig.1: Flow chart components of HydroCalc simulation Program for planning, design, and calculating the hydraulic analysis of drip and sprinkler irrigation systems at different slopes or levels

Results and Discussion

Head pressure analysis along the lateral lines of surface drip and onset sprinkler irrigation designs within operating at a line pressure of 1.0 bar, and with no slope 2%.

Data in Tables (4 and 5) and Figures (2 and 3) shows the head pressures (bar) along the lateral lines of the drip and sprinkler irrigation systems. When lateral line length was 30 m with no slope (2%) in surface drip and onset sprinkler irrigation systems designs were used at the start (distance 1 m), the middle (distance 15 m) and the end (distance 30 m) the head pressures were (0.98, 0.92; 0.97 bar) and (0.97, 0.89; 0.79 bar), respectively.

Clearly, the drip irrigation designs under study could be ranked in the following ascending order drip irrigation > sprinkler irrigation, according to the values of the pressure head. Possibly this was due to increased friction losses for the traditional sprinkler irrigation system. LSD0.01 values under surface drip and onset sprinkler irrigation systems showed there was no significant difference between both start and end values. In contrast, there were significant differences between the middle and both the start and end of head pressure. However, in the drip irrigation system, there were significant differences between all the head pressures whether start, middle or end at lateral line lengths of 30 m. The interaction between methods and treatments, at the start and the end no significant differences between drip and sprinkler irrigation systems while the significant differences between all irrigation methods at the middle values.

Table 4: Operating pressure distribution along lateral line lengths in surface drip irrigation system at slopes 0% and 2%

Slope	Lateral Length = 30m			Lateral Length = 50m		
	Distance(m)	**Simulated**	**Measured**	**Distance(m)**	**Simulated**	**Measured**
0	1	0.96	0.97	1	0.92	0.94
	3	0.94	0.96	5	0.87	0.92
	6	0.93	0.96	10	0.82	0.92
	9	0.92	0.95	15	0.82	0.91
	12	0.92	0.95	20	0.81	0.89
	15	0.91	0.95	25	0.8	0.88
	18	0.91	0.94	30	0.79	0.87
	21	0.89	0.94	35	0.78	0.85
	24	0.88	0.94	40	0.75	0.87
	27	0.88	0.93	45	0.76	0.85
	30	0.88	0.93	50	0.75	0.85
Mean		0.91	0.95		0.81	0.89
2%	1	0.96	0.96	1	0.94	0.94
	3	0.95	0.95	5	0.93	0.94
	6	0.94	0.94	10	0.92	0.93
	9	0.93	0.94	15	0.87	0.92
	12	0.93	0.93	20	0.85	0.92
	15	0.92	0.93	25	0.82	0.92
	18	0.92	0.93	30	0.81	0.91
	21	0.92	0.93	35	0.81	0.91
	24	0.92	0.92	40	0.8	0.9
	27	0.91	0.92	45	0.8	0.9
	30	0.9	0.92	50	0.8	0.9
Mean		0.93	0.93		0.85	0.92
LSD 0.01		0.01	0.02		0.02	0.03

Table 5: Operating pressure distribution along sprinkler line lengths in sprinkler irrigation system at slopes 0 and 2%at slopes 0% and 2%

Slope	Lateral Length =30m			Lateral Length =50m		
	Distance(m)	**Simulated**	**Measured**	**Distance(m)**	**Simulated**	**Measured**
0	1	0.96	0.97	1	0.92	0.94
	3	0.94	0.96	5	0.87	0.92
	6	0.93	0.96	10	0.82	0.92
	9	0.92	0.95	15	0.82	0.91
	12	0.92	0.95	20	0.81	0.89
	15	0.91	0.95	25	0.80	0.88
	18	0.91	0.94	30	0.79	0.87
	21	0.89	0.94	35	0.78	0.85
	24	0.88	0.94	40	0.75	0.87
	27	0.88	0.93	45	0.76	0.85
	30	0.88	0.93	50	0.75	0.85
Mean		0.91	0.95		0.81	0.89
2%	1	0.96	0.96	1	0.94	0.94
	3	0.95	0.95	5	0.93	0.94
	6	0.94	0.94	10	0.92	0.93
	9	0.93	0.94	15	0.87	0.92
	12	0.93	0.93	20	0.85	0.92
	15	0.92	0.93	25	0.82	0.92
	18	0.92	0.93	30	0.81	0.91
	21	0.92	0.93	35	0.81	0.91
	24	0.92	0.92	40	0.80	0.90
	27	0.91	0.92	45	0.80	0.90
	30	0.90	0.92	50	0.80	0.90
Mean		0.93	0.93		0.85	0.92
LSD 0.01		0.02	0.01		0.03	0.02

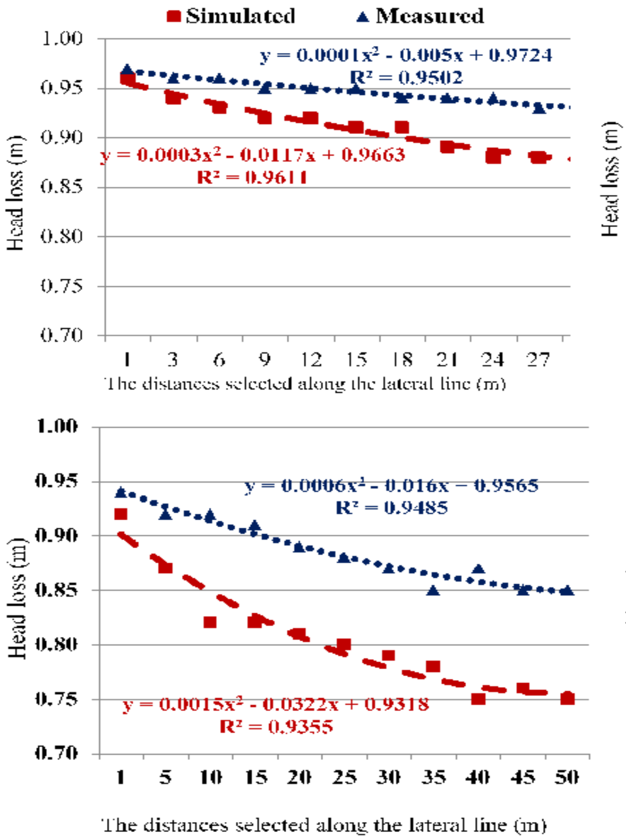

Fig. 2: Simulated and measured head losses with operating at a line pressure of 1.0 bar, 0% slope under the surface drip irrigation design

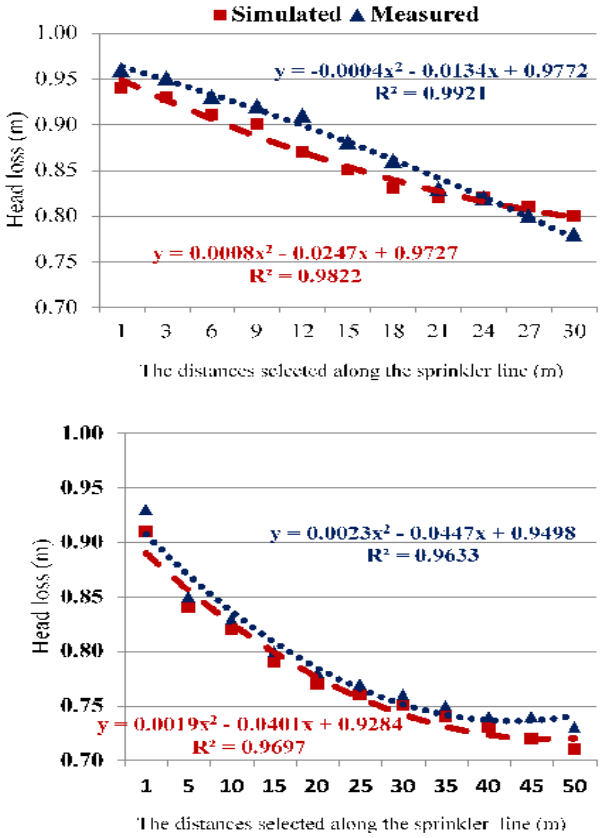

Fig. 3: Simulated and measured head losses with operating at a line pressure of 1.0 bar, 0% slope under the solid-set sprinkler irrigation design

According to LSD0.01 values under surface drip irrigation system, there is no significant difference between both start, end values but there are significant differences between middle and both start and end pressure head values. There are significant differences between all the pressure head values of start, middle and end on the other hand under sprinkler irrigation system. The interaction between methods and treatments: at the start no significant difference between drip and sprinkler irrigation systems method but in the middle there is a significant difference between drip and sprinkler irrigation systems but no significant differences between drip and sprinkler irrigation systems. These data are agreed well with the following references Burt *et al.* (1997), Mizyed *et al.* (1989), Mansour *et al.* (2012), Tayel *et al.* (2016).

Head pressures analysis along the lateral lines of surface drip and onset sprinkler irrigation systems within operating at a line pressure of 1.0 bar, and with sloped down 2%.

Data in Tables (4; 5) and Fig (4; 5) show the head pressures (bar) along the lateral lines of the drip and sprinkler irrigation systems. When lateral line length was 30 m within sloped down (2%) and the drip and sprinkler irrigation systems designs were used at the start(distance 1 m), the middle (distance 15 m) and the end (distance 30 m) the head pressure were (0.98, 0.93; 0.98 bar), (0.96, 0.91; 0.95 bar), and (0.97, 0.91; 0.80 bar), respectively.

Clearly, the irrigation systems under study could be ranked in the following ascending order onset sprinkle irrigation <drip irrigation, according to the values of the pressure head. Possibly this was due to increased friction losses for the sprinkler irrigation systems.

LSD0.01 values under drip irrigation system showed there was no significant difference between both start and end values. In contrast, there were significant differences between the middle and both the start and end of the head pressures. However, in sprinkler irrigation, there were significant differences between all the head pressures of start, middle or end at lateral line lengths of 30m. The interaction between methods and treatments, at the start no significant differences between drip irrigation system and sprinkler irrigation system. In the middle, there are significant differences between the drip irrigation system and sprinkler irrigation system.

When using lateral length 50 m under drip irrigation and sprinkler irrigation system methods, At the start (distance 1 m), the middle (distance 25 m) and the end (distance 50 m) of drippers line pressure head values were (0.95, 0.83; 0.96 bar); (0.90, 0.80; 0.89 bar); and (0.89, 0.79; 0.62 bar), respectively.

According to Lateral length 50m, the values of the pressure head under irrigation methods could be arranged in the following ascending orders sprinkler irrigation<drip irrigation. This may be attributed to the decreased head loss lateral line length by using the drip irrigation system.

LSD0.01 values in shows that under drip irrigation system there is no significant difference between both start and end values of pressure head (bar) but there are significant differences between middle value and both start and end pressure head values. On the other hand, under sprinkler irrigation there are significant differences between all values of start, middle and end. The interaction between irrigation methods: at the start, there are significant differences between the sprinkler irrigation system and drip irrigation system.

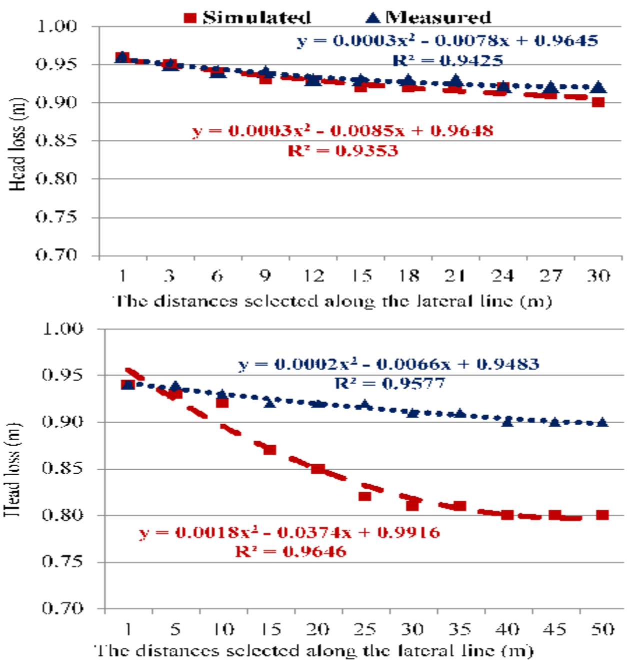

Fig. 4: Simulated and measured head losses with operating at a line pressure of 1.0 bar, 2% slope under the surface drip irrigation design

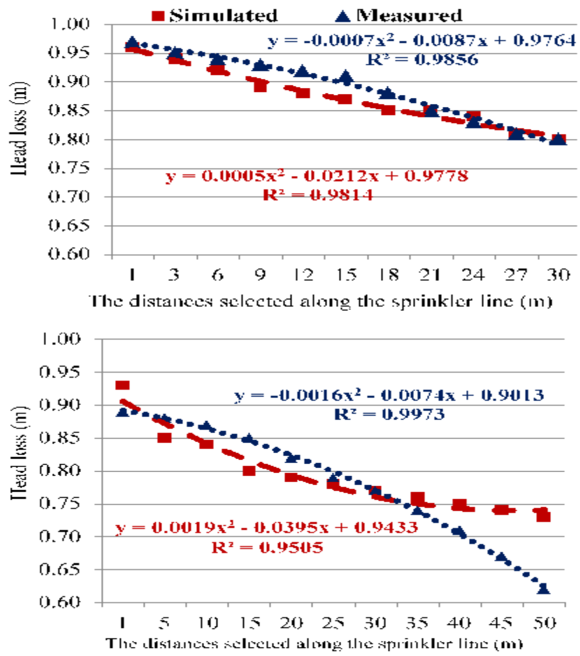

Fig. 5: Simulated and measured head losses with operating at a line pressure of 1.0 bar, 2% slope under the solid-set sprinkler irrigation design

While at both of end and middle there are significant differences between all irrigation methods between drip irrigation and sprinkler irrigation, at the middle and end there are significant differences between all values of irrigation methods when used lateral length 30 m treatment. These data are agreed well with the following references Mizyed *et al*. (1989), Smajstrla *et al*. (1992). Burt *et al*. (1997), Mansour *et al*. (2015) and Tayel *et al*. (2016), Tayel *et al*. (2012), Pibars and Mansour (2015), Tayel *et al*. (2015), Pibars and Mansour (2016), Mansour and Aljughaiman, (2015), Mansour *et al*. (2015 a, b) and Mansour *et al*. (2016 a) and Mansour *et al*. (2016 a, b).

The regression (R^2) and correlation coefficient.

The regression (R^2) and correlation Corrected coefficients Tables (6) and Figures (6 and 7) were obtained to compare the significance of the Simulated and measured head loss along the lateral lines of the two surface drip irrigation and two onset sprinkler irrigation designs.

Table 6: The regression (R^2) and correlation coefficient of drip and sprinkler irrigation systems

Irrigation system	Slope (%)	Length (m)	R^2		Corr. coefficient	
			Measured	Simulated	Measured	Simulated
Surface drip	2	30	0.98	0.96	0.96	0.94
		50	0.95	0.96	0.93	0.94
	0	30	0.95	0.96	0.93	0.96
		50	0.94	0.93	0.92	0.94
Solid-Set sprinkler	2	30	0.95	0.96	0.95	0.88
		50	0.94	0.95	0.84	0.86
	0	30	0.95	0.96	0.85	0.86
		50	0.96	0.96	0.83	0.85

Generally, the values of regression and correlation analysis were (> 0.90) when 0% field slope, 30, and 50 lengths for both irrigation designs. The relationships among the Simulated and measured head losses, as well as regressions and correlations under surface drip irrigation systems, compared with onset sprinkler with no slope 0%. Clearly, the irrigation methods under study that used a lateral line length of 30 m could be ranked in the ascending order by both the Simulated and measured head losses drip < sprinkler. While by using Lateral length 50 m the values of the Simulated and measured head losses under irrigation methods could be ranked in the following ascending orders; drip irrigation < sprinkler irrigation. This may be attributed to the different numbers of dripper or how many drippers were built-in with every lateral line length.

Energy saved comparisons among surface drip and onset sprinkler irrigation systems

It is worth mention that the data in Table (7) and figure (8) indicated that the highest energy savings were when using no slope (0%) with surface drip irrigation system. Savings were (33.18, 27.33%). compared to sprinkler irrigation. While the energy saving values with slope 2% were under drip irrigation (34.23, 29.54%), when using lateral lengths (30, 50,m), respectively relative to a traditional surface drip system and onset sprinkler as a control. These data are agreed well with earlier reports by McIndoe *et al*. (2000), McIndoe (2001) and McChesney *et al*. (2004), Tayel *et al*. (2012), Pibars and Mansour (2015), Tayel *et al*. (2015), Pibars and Mansour (2016), Mansour and Aljughaiman, (2015), Mansour *et al*. (2015 a, b), and Mansour *et al*. (2016 a) and Mansour *et al*. (2016 a, b).

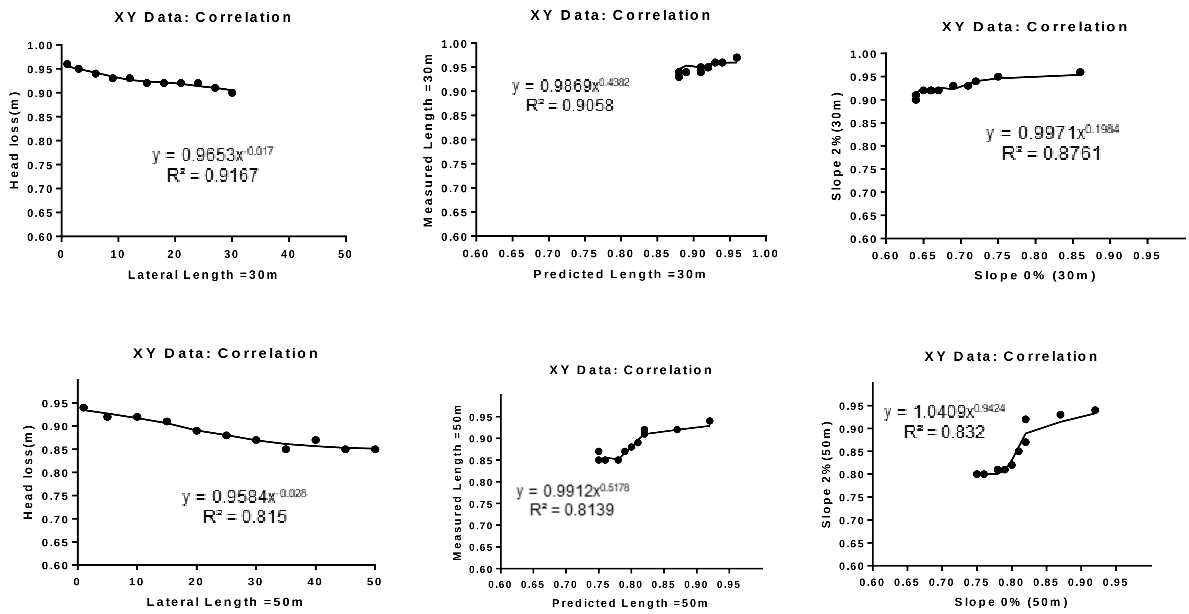

Fig. 6: Correlation coefficient of surface drip irrigation system for different dripper lines lengths

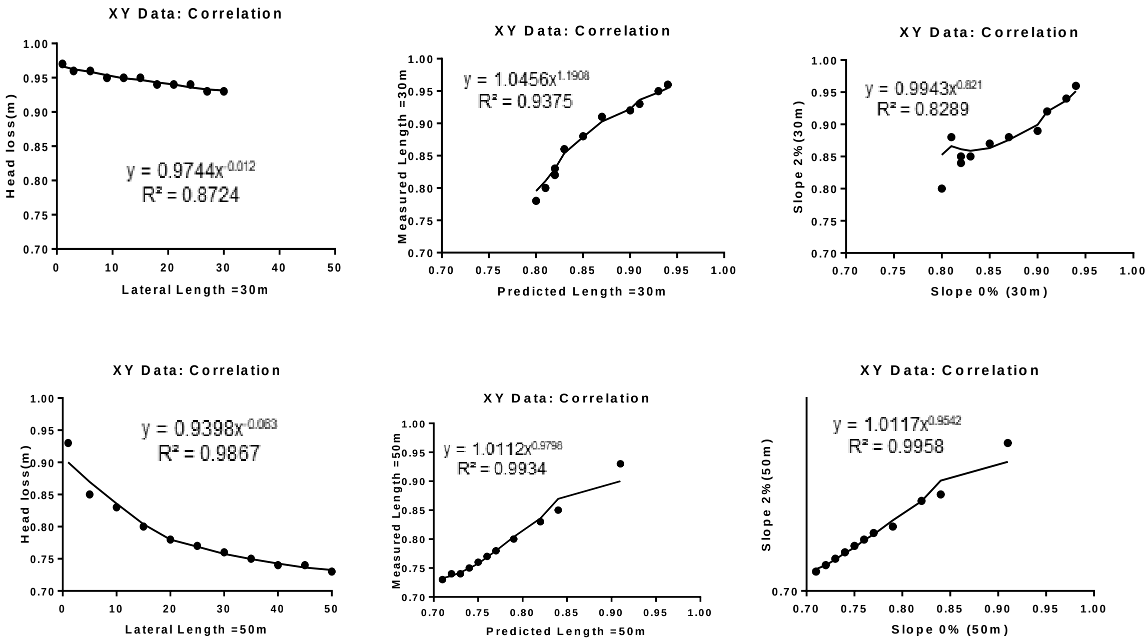

Fig. 7 : Correlation coefficient of onset sprinkler irrigation system for different sprinkler lines lengths

Table 7: Energy saved closed circuit designs

Field slope (%)	Energy saving (%) of irrigation method			
	Surface drip		Onset sprinkler	
	30	50	30	50
0	33.18	27.33	28.52	25.21
2	34.23	29.54	29.45	26.72

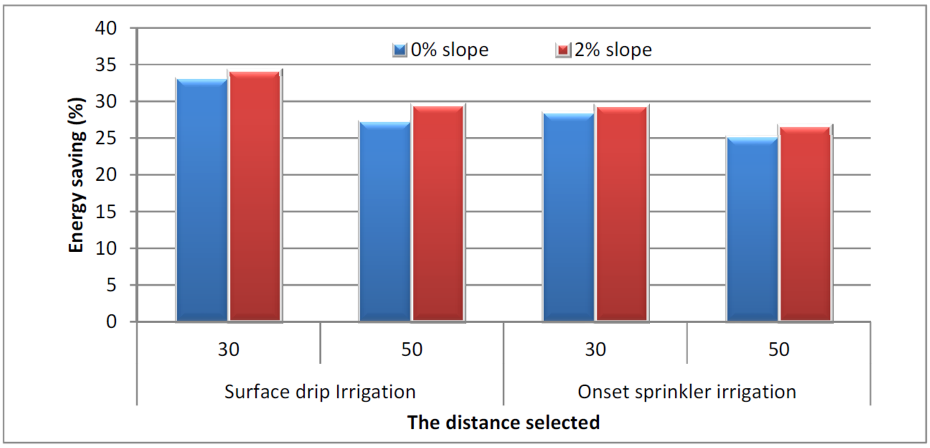

Fig. 8 : Energy saved closed circuit designs

Conclusion

The statistical indicators (the regression (R^2) and correlation coefficient) confirmed the good performance of HydroCalc in simulating some hydraulic parameters pressurized irrigation systems. The validation of measured and obtained data from HydroCalc clarified it as efficient reliable software to design pressurized irrigation systems to increase the system performance and water application efficiency and can depend on the designing irrigation. The energy savings were (33.18; 27.33%) and (34.23; 29.54%) under slope (0 and 2%) with drip irrigation systems when using lateral lengths

(30; 50m), respectively compared to sprinkler irrigation system. It could be concluded to using drip irrigation systems with lateral length 30 m and with slope (2%) downhill for increasing the water application efficiency, decreasing the friction losses along lateral lines and this lead to saving more water head energy.

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