Arab Univ. J. Agric. Sci., Ain Shams Univ., Cairo, Egypt
27(5), 2663-2675, 2019
Website: http://ajs.journals.ekb.eg

ENHANCING THE DISTRIBUTION UNIFORMITY OF WATER FLOW THROUGH DRIP IRRIGATION SYSTEM NETWORK USING CLOSED CIRCUITS

[213]

Aya M.A. Abo-Kora[1*], El-Bagoury[1] K.F.T., Bedair[1] O.M.A. and Sultan[2] W.M.M.

1- Agric. Engineering Dept., Fac. of Agric., Ain Shams Univ., P.O. Box 68 Hadayek Shoubra 11241, Cairo, Egypt
2- Agric. Engineering, Res. Inst., Dokki, Giza, Egypt

*Corresponding author:eng.ayamohamed507@gmail.com

Received 16 May, 2019 Accepted 2 July, 2019

ABSTRACT

This study aimed to enhance distribution uniformity of water flow through drip irrigation system network. The required Laboratory experiments for hydraulic tests and measurements were conducted at National Irrigation Lab of Agricultural Engineering Research Institute ((AENRI), ARC, MOLAR, Egypt. The distribution uniformity is affected by both pressure distribution along pipes and hydraulic characteristics of the drippers. The selected drippers were tested under operating pressures of (50, 75 , 100, 125 and 150 kPa), and the dripper irrigation lateral lengths were (35 ,50 ,75 and 100m). Two designs of drip irrigation were applied; first was closed circuits with two manifolds as a modification of traditional design, and the other design was the traditional with one manifold as a control.

Three types of built in drip lines with flow rate of (4l/h) and two types of on line dripper with flow rate of (2 and 4 l/h) were calibrated. The results indicated that the closed circuits was the best specially when using lateral lengths (75 and 100m), but the values were nearly close in case of using lateral lengths of (35 and 50m).

Maximizing distribution uniformity is possible for traditional design when using self-compensating flow rate where it can reach value of 88.2% with 100m lateral length, the accepted lateral length in case of using built in drip line with 30cm spacing was 75m for closed circuits design where the **DU** % was 94% comparing with 79.2% for traditional design. The closed circuits had a significant positive effect in reducing friction head losses of non-pressure compensating built in drip line ranging from 20 to 41.7 % , where the percentage ranged from 10% to 50% for built in drip line with 50cm spacing – pressure compensating.

Keywords: Drip irrigation, Dripper calibration, Distribution uniformity, Closed circuits, Friction head losses, Lateral lengths.

INTRODUCTION

Distribution uniformity considered apart of successful network, the major part for developing irrigation system was new design considerations such as closed circuits using (two manifolds design) which effect on some hydraulic parameters such as distribution uniformity and coefficient of variation, using closed circuits technique has an effective role in maximizing distribution uniformity especially with long lateral lengths with different operating pressure.

The influence of pressure can be presented as variable in two ways: either, directly as the average of drippers mean flow rates, or as variable percentage of flow rates variation related to the mean flow rate at the recommended operating pressure at 100 kPa, and it has many benefits over conventional drip irrigation (**Singh and Rajput, 2007).**

So that closed circuits are considered one of the modifications of drip irrigation system, and will add advantages to traditional drip irrigation because it can relieve low operating pressures problem at the end of the lateral lines.

(Mansour, H.A. 2012), and it can also reduce some of the problems and constraints, such as non-distribution uniformity along the lateral lines in case of using long lines and low pressure water at the end of lateral irrigation lines in addition to solving the problem of high initial cost for the traditional drip irrigation method and traditional drip system as a control solving.

The objectives of this investigation were

1- Study the effect of the closed flow rate circuits on the problem of pressure reduction at the end stage of lateral lines.

2- Evaluation of some hydraulic parameters such as pressure head, and friction head losses.

3-Study the impact of different drip irrigation circuits and lateral line lengths for both laterals flow rate, uniformity coefficient, and coefficient of variation.

MATERIALS AND METHODS

The laboratory experiments was conducted at National Irrigation Lab at Agricultural Engineering Research Institute (AENRI), Dokki, Giza.

Materials

∗hydraulic test bench

The hydraulic test bench was used to evaluate hydraulic characteristics of dripper as shown in **Fig. (1)**.

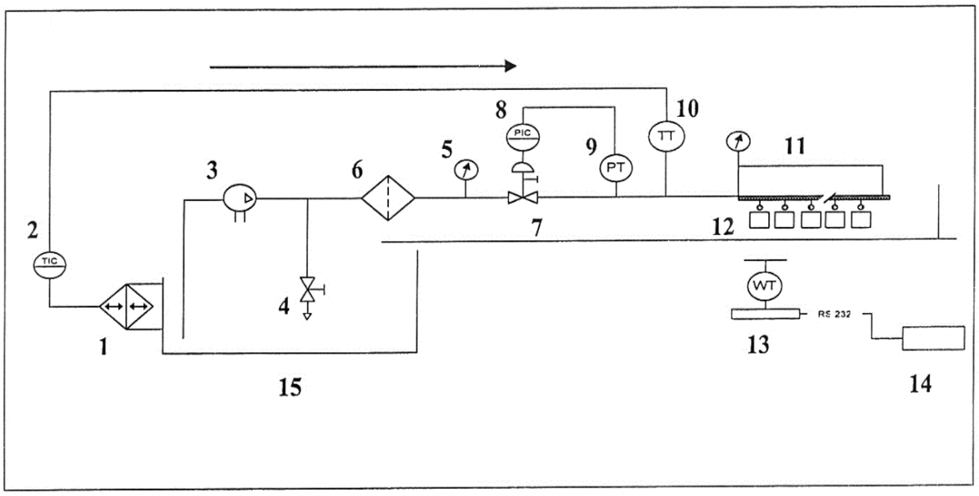

Fig. 1. Hydraulic test bench components

1- Temperature conditioning
2- Temperature regulator;
3- Multi stage pumping unit;
4- Manual discharge valve
5- Direct reading pressure gauge
6- Strainer filter
7- Pressurized air regulating valve
8- Pressure regulator
9- Pressure transmitter
10- Temperature transmitter
11- Lines of pipes including tested drippers (3 m)
12- Water collectors for each dripper in test
13- Weighing scale
14- Personal computer; and
15- Water tank.

⁎ **Manifold lines**: 32 mm nominal diameter Poly Vinyl Chloride (PVC) pipes and-10bar operating pressure were connected to the sub main line through control valves 1`` that delivered water from the source to the Lateral lines.

⁎**Lateral lines:** 16mm nominal diameter low density polyethylene (LDPE) tubes, 1.3 mm thickness and 3m in length. The short length was used to minimize the pressure differences along the section and it was considered a negligible value.

⁎**Drippers**: Five types of built in drip line were collected from the local market.

Fig. (2) and Fig. (3) Show the difference of Internal structure between the pressure compensating and non-pressure compensating dripper.

Two types of drippers were non-pressure compensating long flow-path turbulent flow in line dripper. Distance between drippers was 0.3 and 0.5 m with flow rate (4l/h) and the other type was pressure compensating.

Fig. 2. Section of (non-pressure compensating dripper)

Fig. 3. Section of (pressure compensating dripper)

⁎ **Pressure gauges**

Five pressure gauges were used to determine the pressure of the network

First one was located at the inlet of manifold one (250kPa), the second one located at the end of manifold one (250kPa), the third located at the manifold two end in case of closed circuits with two manifold (250kpa), the fourth located at mid lateral (250kPa), and the fifth pressure gauge located at the lateral end in case of traditional design (100kPa).

Methods of calculation

Flow rate characteristics and variations:

The dripper flow rates are usually characterized by the relationship between flow rates and pressure. The equation for flow rate can be expressed as **(Keller and Karmeli, 1974):**

$$q = kp^x \text{.................................. (1)}$$

Where,

q = the dripper flow rate, (L/h),
p = Operating pressure, (kPa),
k = a dimensionless constant of proportionality that characterizes each dripper, and
x = a dimensionless dripper flow rate exponent that is characterizes by the flow regime.

The value of x characterizes the type of dripper or flow regime according to **Boswell, (1985)** as;

Non-pressure compensating	For laminar flow regime For partially turbulent or unstable flow regime1 For fully turbulent flow regime	x=1 x=0.75 x=0.5
Pressure compensating	For partially pressure compensating For fully pressure compensating	x=0.25 x=0

Jensen (1980) reported an expression for evaluating distribution uniformity of flow through drippers at the lateral line.

The coefficient of manufacture variability measured the variation in flow rate for a given dripper model at a normal operating pressure ranging from 50 to 150 kPa and a water temperature of (20-23)°C, the dripper flow variation was calculated using the following equation:

$$q_{var} = \left({(q_{max} - q_{min})}/{q_{max}} \right) \times 100 \quad \ldots\ldots\ldots (2)$$

Where:

q_{var} = the dripper flow variation, (%);
q_{max} = maximum dripper flow, (l/h),
q_{min} = minimum dripper flow, (l/h).

In general criteria for $q_{var.}$ values are; 10-20 % acceptable; greater than 20%, not acceptable according to **ASAE (1996).**

Dripper manufacture's coefficient of variations (CV)

The manufacture's coefficient of variation "CV" was calculated by measuring the flow rates from a sample of the new drippers according to (**ASAE 1996 Standard**), as follows:

$$CV = \left({S}/{q_a} \right) \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where,

CV = manufacturer's coefficient of dripper variation;
q_a = average flow rate (l/h), and
S = standard deviation of dripper flow rates at a reference pressure head.

Table 1. Show the recommended classification of CV. According to ASAE, standard (1996) based on coefficient of manufacturing variation CV

CV Range (%)	Classification
Below 5	Excellent
5 to 7	Average
7 to 11	Marginal
11 to 15	Poor
Above 15	Unacceptable

Distribution uniformity (DU)

Another measure of dripper uniformity (DU %) was typically used to evaluate manufacturing quality of drippers. The DU is the ratio between the average flow rate in the quarter receiving less water and the average flow rate at the system level. It is used to describe the predicted dripper flow variation along a lateral line and can be assumed as synonymous to that of distribution uniformity (DU). Low quarter DU **(Marriam and Keller, 1978)** as applied to all types of irrigation systems can be expressed as:

$$DU = \left({q_n}/{q_a} \right) \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where,

DU= the distribution uniformity, (%);
q_n = The average of the lowest ¼ of the drippers flow rate, (l/h),
q_a= The average of all dripper flow rate, (l/h).

Table 2. Show the classification of the micro-irrigation uniformity, ranging from excellent to unacceptable, recognized by the standard of **(ASAE, 1996).**

Table 2. Micro-irrigation system uniformity classifications based on dripper flow rate

Classification	Uniformity, DU (%)
Excellent	Above 90%
Good	80%- 90%
Fair	70%- 80%
Poor	60%- 70%
Unacceptable	Below 60%

Friction head losses

The friction head losses for all work were determined, head losses along the laterals were measured by pressure gauges at upstream to evaluate hydraulic heads distribution corresponding, this distribution of pressure gauges in specific location is to ensure the actual values of pressure at different points on the drip irrigation system.

Field Experiments

Traditional drip irrigation design as shown in **Fig. (4)** consisted of one 32mm nominal diameter manifold and three16mm nominal diameter lateral lines with flow rates 4lph, pressure gauges were distributed at different locations in the drip irrigation network to measure the pressure performance along the drip irrigation system to estimate the friction head losses under different operating pressure (50, 75, 100, 125,150) kPa in case of non-pressure compensating drippers and (100, 125, 150, 200) kPa in case of using Pressure compensating drippers, the lateral lengths were (35, 50, 75 and 100m).

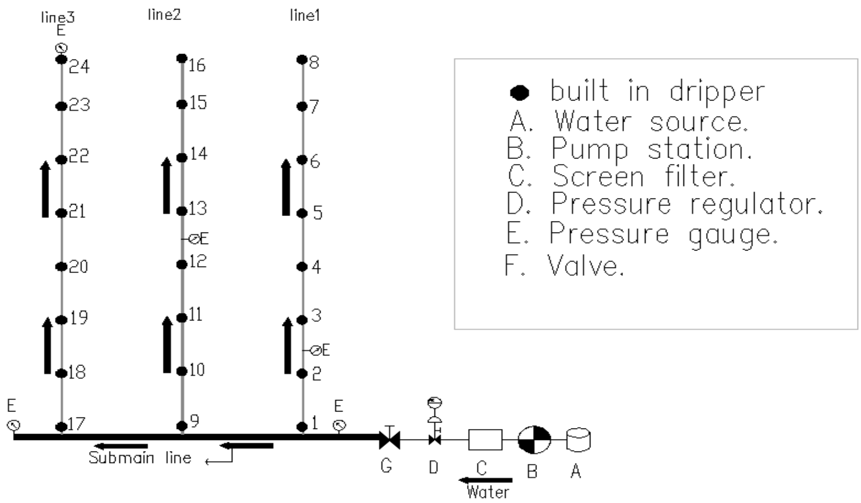

Fig. 4. Layout of traditional drip irrigation design

Closed circuits drip irrigation design as shown in **Fig.(5)**, it had two 32mm manifold branched to three lateral drip lines of 16mm nominal diameter of flow rate (4l/h), lateral ends connected from its two ends with sub main manifold, so that the flow of water was met at the middle of the drip line and thus ensured the equalization of the water at all points of distribution lines and pressure regulation along the network.

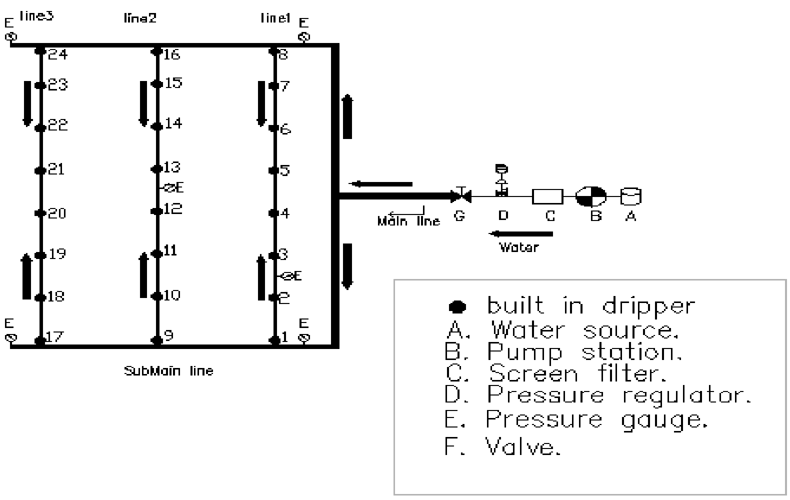

Fig. 5. Layout of closed circuits drip irrigation design with two manifolds

RESULTS AND DISCUSSION

Calibration of used drippers

Data shown in **Fig. (6), Fig. (7)** indicated that once the pressure increases, the dripper flow rates also increase, the laboratory experiments were conducted for two types of drippers (online drip-pers and built in drip line), on line drippers with nominal flow rates about (2-4 l/h), non-pressure compensating, and gives the dripper flow-pressure functions as well as the regression equations.

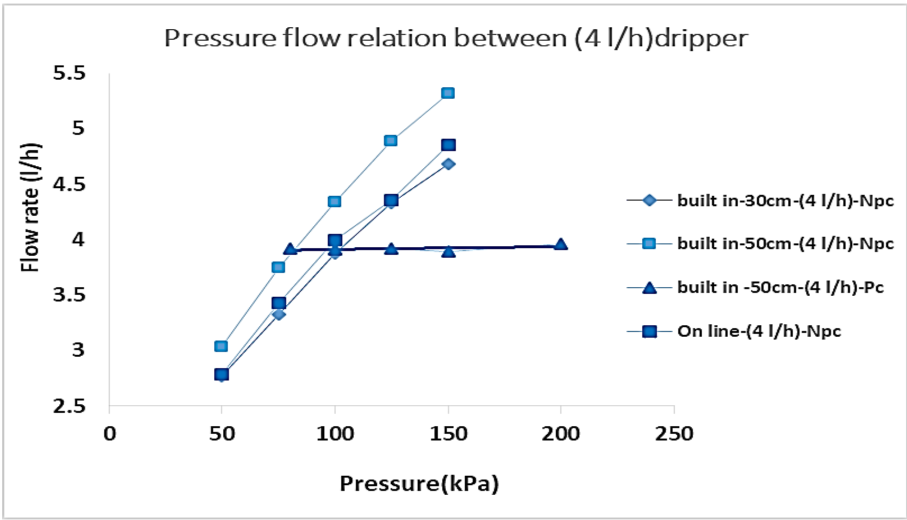

Fig. 6. Performance curves of tested dripper with flow rate (4 l/h)

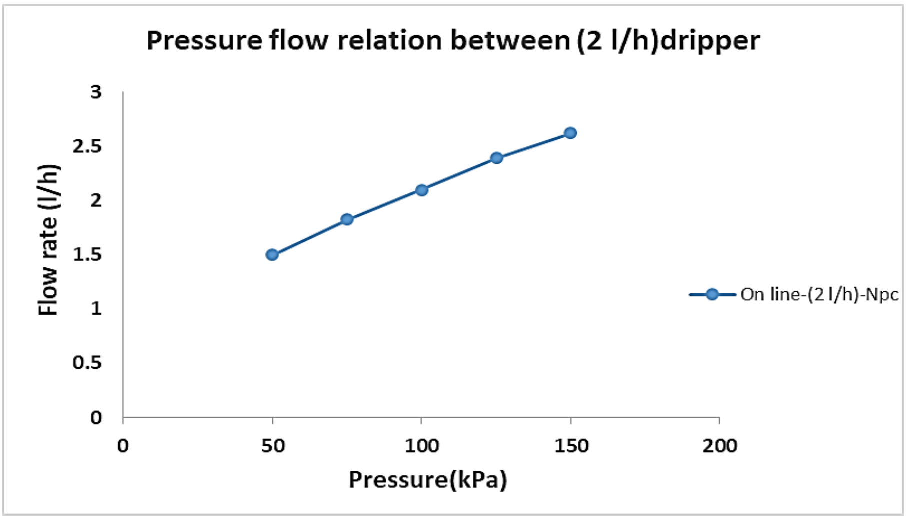

Fig .7. Performance curve of tested dripper with flow rate (2 l/h).

Table 3. Hydraulic characteristics for different dripper under investigation under operating pressure (100 kPa).

No	Type of drippers	Flow rate (l/h)	*Manufacture's coefficient of variation (CV %)	*Distribution uniformity (DU %)	*Dripper flow variation (q_{var} %)	Constants of the flow rate equation	
						x	k
1	Built in- 4 l/h-30cm Npc	3.88	5.03 Excellent	92.90 Excellent	12.70 Acceptable	0.484	3.9 fully turbulent
2	Built in- 4 l/h-50cm Npc	4.34	4.292 Excellent	94.48 Excellent	14.48 Acceptable	0.5	4.3 fully turbulent
3	Built in- 50cm-4 l/h-Pc	3.92	4.66 Excellent	93.39 Excellent	17.70 Acceptable	0.0087	3.9 pressure compensating
4	On line-4 l/h- Npc	4.04	5.61 Average	94.69 Excellent	22.87 Unacceptable	0.49	3.9 fully turbulent
5	On line-2 l/h- Npc	2.24	8.41 marginal	90.38 Excellent	28.98 Unacceptable	0.52	3.9 fully turbulent

*According to ASAE (1996).Tables 1&2

As shown in **Table (3)** all correlation coefficients were above (0.9), the built-in drip line were acceptable for all tested parameters CV, DU, and q_{var}.

The CV values were 5.03 %, 4.29%, 4.66% for non-pressure compensating built-in drip line 30cm built-in line 50cm spacing non-pressure compensating, and pressure compensating built-in drip line 50cm spacing respectively.

That is mean high manufacturing quality which is due to high material quality of low density polyethylene (LDPE), DU% values were also accepted because of high values, those were 92.9%, 94.48%, 93.39% for non-pressure compensating built-in drip line 30cm, non-pressure compensating built-in drip line 50cm spacing, and pressure compensating built-in drip line 50cm spacing respectively it is due to using a sample of drippers up to 25 drippers. On other hand the q_{var} values were 12.7%, 14.48%, and 17.7% for, non-pressure compensating built-in drip line 30cm, built-in drip line 50cm spacing non-pressure compensating, and pressure compensating built-in drip line 50cm spacing respectively, this is due to the drippers flow rates equality.

The flow regime were fully turbulent for both of non-pressure compensating built-in drip line 30cm non-pressure compensating, built-in drip line 50cm spacing non-pressure compensating, and fully pressure compensating for built-in drip line 50cm spacing pressure compensating according to its dripper flow exponent (x) values., So that all were acceptable. The (DU) values were founded acceptable with values 94.6% and 90.38% for on line non-pressure compensating dripper 4lph and on line non-pressure compensating dripper 2lph respectively. due to the flow regime values (x) which was fully turbulent., while both of CV% and q_{var} were unacceptable coefficient of variations which were between 5.6 % to 8.4% for on line non-pressure compensating dripper and on line non-pressure compensating dripper 2 l/h respectively, and dripper flow variation were 22.8 and 28.9 for on line non-pressure compensating dripper 4 l/h and on line non-pressure compensating dripper 2 l/h. All values were un acceptable, so were considered out of standard according to **ASAE (1996)**.

Effect of drip irrigation circuits and lateral line length on some hydraulic characteristics

The impact of lateral length and spacing between drippers on dripper flow variation (qvar %) for (4 l/h) drippers and distribution uniformity (DU).

1- Dripper flow variation (qvar %).

As shown in **Table (4)** dripper flow rates varied for different dripper type For all dripper types, the dripper flow rate increased with lateral length in case of closed circuits improves and achieves less flow variation along the lateral line of (35-50-75 and 100m), while in case of closed circuits and with lengths (35-50 and 75m) .

The drippers give acceptable values comparing with traditional design that gives acceptable valued at lengths (35 and 50m) only, while pressure compensating built-in drip line had acceptable value at 75m only.

Table 4. Effect of traditional and closed circuits of drip irrigation systems on dripper flow variation (q_{var} %)

Dripper flow variation q_{var} %					
Type of drippers	Length (m)	Traditional		Closed Circuits	
		q_{var}%	Classification	q_{var}%	Classification
Built in drip line (4 L/h)-50cm NPC(A)	35	13.9	Acceptable	10.5	Acceptable
	50	15.0	Acceptable	13.5	Acceptable
	75	32.2	Unacceptable	18.9	Acceptable
	100	50.1	Unacceptable	25.5	Unacceptable
Built in drip line (4 Lph)-50cm PC(B)	35	11.3	Acceptable	6.8	Acceptable
	50	12.3	Acceptable	11.9	Acceptable
	75	18.9	Acceptable	18.6	Acceptable
	100	32.3	Unacceptable	17.4	Acceptable
Built in drip line (4 L/h)-30cm NPC(C)	35 50 75 100	15.4 15.7 43.5 72.5	Acceptable Accepta-ble Unacceptable Unacceptable	12.4 14.3 14.3 30.8	Acceptable Accepta-ble Acceptable Un-acceptable

NPC non-pressure compensating
PC pressure compensating

Under the condition of using closed circuits and 100 m lines length the q_{var} (%) for pressure compensating built-in drip line 50cm spacing is highly accepted while it is unacceptable by using traditional design for 100 m lateral length.

3- Distribution uniformity (DU %)

Table (5) illustrate the effect of using traditional and closed circuits at different lateral lengths on distribution uniformity (DU%) according to **ASAE standard**, for both of traditional and closed circuits for different lateral lengths (35,50,75 and 100m) for all the selected drippers under operating pressure100kpa:

From the obtained results It is a fact that using closed circuits is more effective than traditional design that is due to better design, higher distribution uniformity values along laterals line, higher system application efficiency, good application for soil feeding power, decreasing the size of some equipment, easy for system flushing and maintenance and easier system installation, these results were in agreement with **Hussein, 2007 and Wu & Gitiln, 1982.**

3- Impact of closed circuits on friction head loss

Figs. 8 & 9 &10 show the effect of using closed circuits and traditional drip irrigation system on friction head losses.

The percentage of reducing friction head losses when using closed circuits is greater for all lengths where it was evident in the length of 100 meters.

The rate of reduction of friction losses was decreased whenever the length of lateral line decreased.

Table 5. Effect of traditional and closed circuits of drip irrigation systems on distribution uniformity (DU)

Distribution uniformity DU%					
		Traditional		Closed Circuits	
Type of drippers	length (m)	DU%	Classification	DU%	Classification
Built in drip line (4 L/h)-50cm NPC(A)	35 50 75 100	95.7 94.5 91.5 75.9	Excellent Excellent Excellent Fair	95.9 95.2 93.0 90.8	Excellent Excellent Excellent Excellent
Built in drip line (4 L/h)-50cm PC(B)	35 50 75 100	95.5 94.4 93.2 88.2	Excellent Excellent Excellent Good	95.7 94.6 93.7 93.8	Excellent Excellent Excellent Excellent
Built in drip line (4 L/h)-30cm NPC(C)	35 50 75 100	93.8 92.5 79.2 56.8	Excellent Excellent Fair Un acceptable	94.4 93.3 92.3 72.8	Excellent Excellent Excellent Fair

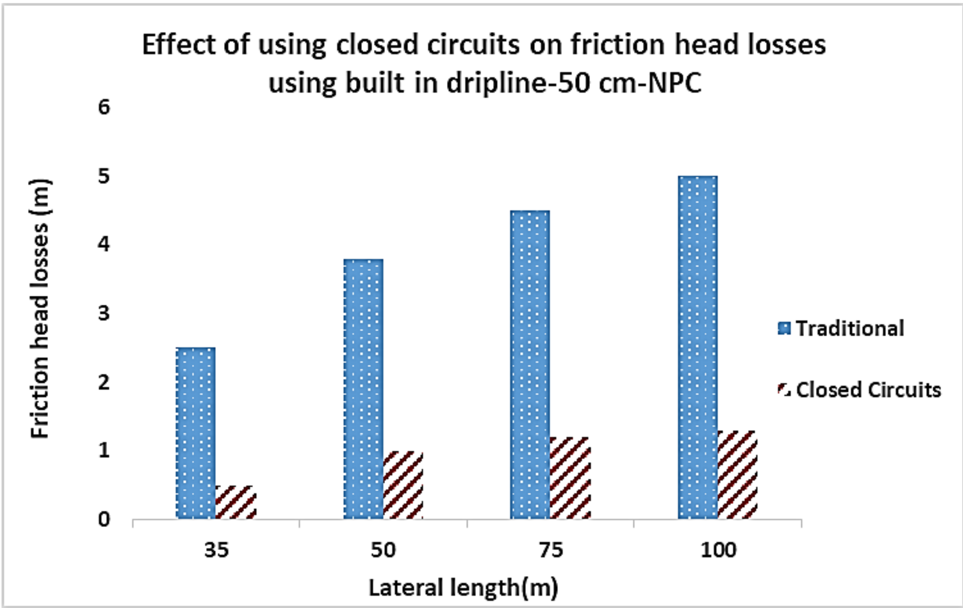

Fig. 8. Friction head loss values for both of closed circuits and traditional in case of using non-pressure compensating (A), built in drip line 50cm spacing

According to **Figure (9)** it is clear that the using of pressure compensating drippers, reduced notice that the friction head losses comparing with of non-pressure compensating drippers used for both closed circuits and traditional systems, that is due to regulating pressure which affect with direct way on variation of flow rates and the variation between them is greater in the case of larger lengths.

The variation of friction head losses between the closed circuits and the traditional system in case of using built in dripper with 30cm spacing increases compared with the previous two types of 50cm spacing between drippers used because of higher numbers of drippers on the line.

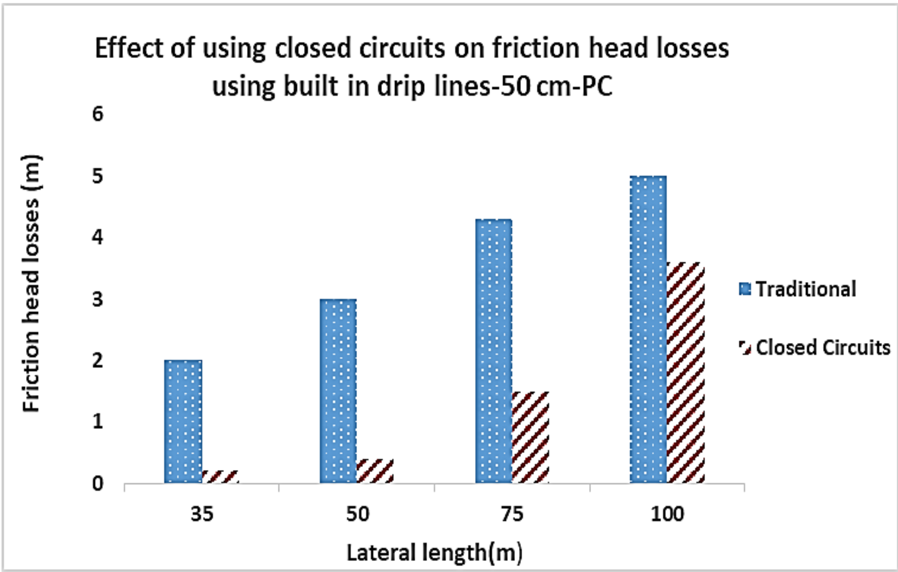

Fig. 9. Friction head loss values for both of closed circuits and traditional in case of using pressure compensating (B), built in drip line -50cm spacing.

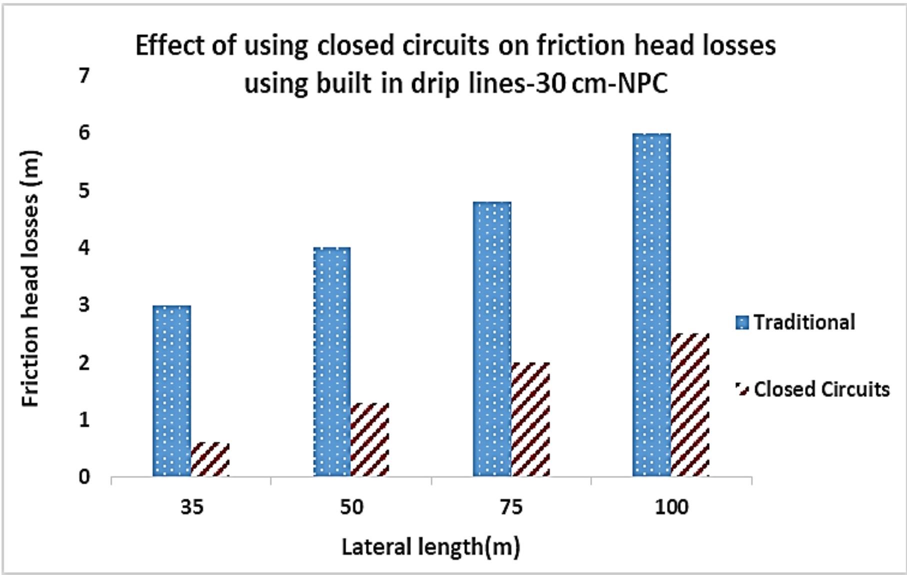

Fig. 10. Friction head loss values for both of closed circuits and traditional in case of using non-pressure compensating(C). Built in drip line -30cm spacing

Therefore, the effect of the closed circuits has more obvious role in case of using 30cm spacing, these results are consistent with **Mansour et al (2010)**, when the lengths of lines 40, 60 and 80 m were used and reached the following with a side length of 40 meters could be organized in the following ascending order according to the predicted head loss values and CM2DIS <CM1DIS> TDIS measurements. The methods in ascending commands can place the following CM1DIS <CM2DIS <TDIS. While with the 80m lateral length the expected pressure loss values can be organized and measured under irrigation methods in the following ascending orders CM2DIS <CM1DIS <TDIS, irrigation systems at 40, 60 and 80 m can be organized according to the lines of friction head losses in the following ascending order:

CM2DIS <CM1DIS <TDIS. Under the slope 0% of the level in the use of CM2DIS, the three designs of the network that described the closed circuits in two method one of them using one manifold and the other design with two manifolds comparing with the traditional design as a control.

*__DIC__; Trickle irrigation circuits, **CM2DIS**: Closed circuits with tow manifolds separated, **CM1DIS**: Closed circuits with one manifold; **TDIS**: Traditional trickle irrigation system.

CONCLUSION

The main results of this search were

1- Using closed circuits had accrued enhancing in distribution uniformity for all used lengths (35-50-75 and 100m) compared with the traditional design.

2- The distribution uniformity were high valued and reached to 88.2% for traditional design when using pressure compensating dripper 0.5 m spacing.

3- Not recommended to use built in dripper 0.3cm spacing for lateral lengths 75mor 100m when using traditional design, the accepted values appeared when using closed circuits (two manifold) for lateral length 75m.

4-In case of using closed circuits the pressure is nearly constant along the lateral compared with traditional design (one manifold).

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مجلد(27)، عدد(5)، 2663-2675، 2019
Website: http://ajs.journals.ekb.eg

تحسين كفاءه التوزيع لنظام الرى بالتنقيط بإستخدام دوائر الرى المغلقة

[213]

آية محمد على أبوقورة[1*] – خالد فران طاهر الباجورى[1] – أسامة محمد أحمد بدير[1] – وائل محمود مختار سلطان[2]

1- قسم الهندسة الزراعية – كلية الزراعة – جامعة عين شمس – ص.ب 68 – حدائق شبرا 11241 – القاهرة – مصر
2- معهد بحوث الهندسة الزراعية – مركز البحوث الزراعية – الدقى – الجيزة – مصر
*Corresponding author:eng.ayamohamed507@gmail.com

Received 16 May, 2019 Accepted 2 July, 2019

الموجـــــــز

يهدف البحث إلى تحسين إنتظامية توزيع المياه خلال شبكة الرى بالتنقيط.

وقد أجريت التجارب المعملية في المعمل القومي لإختبار مكونات شبكات الري الحقلي بمعهد بحوث الهندسة الزراعية (AEnRI) الدقى- الجيزة، تحت ضغوط مختلفة (50, 75, 100, 125، 150 كيلو باسكال) وتم قياس تصرف النقاطات واختلاف معامل التصنيع لها و انتظامية توزيعها.

تم إستخدام أحد تصميمات دوائر الرى المغلقة بإستخدام خطين توزيع منفصلين لتغذية الخطوط الفرعية من كلا الجانبين وإستخدام النظام التقليدي أحدادي التغذية من جانب واحد متصل لتغذية الخطوط الفرعية وذلك للمقارنة.

تكونت الشبكة من ثلاث خطوط معاملات بأطوال فرعية (35-50-75-100 متر) وإستخدام ثلاثة أنواع من الخراطيم ذاتية التنقيط الموجودة بالسوق المحلى النوع الأول خراطيم ذات مسافات بين النقاطات 50 سم بتصرف 4 لتر/ساعة-غير منظم للضغط والنوع الثانى يحمل نفس التصرف تقريبا والمسافات البينية للنقاطات ولكنه من النوع المنظم للضغط ،والنوع الثالث من الخراطيم ذاتيه التنقيط ذو مسافات بينيه 30سم وتصرف 4 لتر/ساعة وغير منظم للضغط.

تمت دراسة تأثير إستخدام دوائر الرى المغلقة على بعض الخصائص الهيدروليكية مثل تصرف النقاط - معامل الإختلاف لتصرفات النقاطات - تصرفات الخطوط الفرعية - تدرج سلوك الضغط خلال شبكة الرى - معامل الإنتظامية - توزيع الضغط فى الخط الفرعى - فاقد الإحتكاك.

وكانت أفضل النتائج لإنتظامية التوزيع وانتظام توزيع الضغط على طول الشبكة كان عند إستخدام الدوائر المغلقة والمسافة بين النقاطات (0.5 متر) عند جميع الأطوال المستخدمة حتى 100 متر تم تحسين انتظامية التوزيع للمياة والضغوط خلال الشبكة مقارنه بالنظام التقليدى الذى يتم إستبعاده فى حالة زياده الأطوال عن 75متر حيث وصلت نسبه إنتظاميه التوزيع فى النظام التقليدى إلى 75.9%. ولا ينصح بإستخدام الدوائر المغلقة فى حاله إستخدام خراطيم النقاطات الغير منظمة للضغط ذات مساقات بينيه للنقاطات (0.3 متر) عند زيادة الأطول حتى 100 متر حيث كانت اللإنتظامية عند 100 متر (79.8%) بينما لا يمكن قبول ذات النقاطات بإستخدام النظام التقليدى فى كلا الطولين (75-100متر) لنفس الحالة أما فى حاله إستخدام خراطيم منظمة للضغط تم تحسن

تحكيم: أ.د عبد الغني محمد الجندي
أ.د محمد عبد الوهاب قاسم

الإنتظامية عند طول 100متر لتصل ل 88.2% فى حالة النظام التقليدى مقارنه بالنوع السابق فهى تعد مقبوله وفقا للجمعية الأمريكية للهندسة الزراعية (1996).

الكلمات الدالة: الرى بالتنقيط، معايرة النقاطات، إنتظامية التوزيع، الدوائر المغلقة، فواقد الإحتكاك، أطوال الخطوط الفرعية