Misr J. Ag. Eng., 26(4): 1836- 1854 IRRIGATION AND DRAINAGE

DESIGN AND EVALUATION OF TRICKLE IRRIGATION LATERALS WITH SINGLE AND VARING PIPE SIZES

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ABSTRACT

In trickle irrigation system, uniformity of emitter flow rate along lateral depends on lateral length and size, emitter discharge, operating pressure, and manufacturing variation of emitters. The purpose of the study was to evaluate a trickle lateral based on its design criteria to reach minor friction loss and high water uniformity. Three different single trickle laterals as 13, 15, and 17 inner diameters all had 60 m long and 0.5 m spacing was tested under 100, 150, and 200 kPa inlet pressure for 2, 4, and 8 l/h emitter flow rate. A 60 m-lateral with three varying sizes (ϕ17 in 1st, ϕ15 in 2nd, and ϕ13 in 3rd equaled sections) was tested and compared with a 15 mm-single lateral for 8 l/h, both of them were equal in material cost. Friction loss and flow variation were significantly reduced by increasing lateral size and reducing emitter inflow rate. Flow variation as well as uniformity was insignificantly influenced by inlet pressure. Varying sizes-lateral with 150 kPa inlet pressure highly achieved power saving and uniformity compared to single lateral.

Abbreviations: ϕ means lateral diameter in mm.

Keywords: trickle irrigation; friction losses; emitter flow variation; uniformity.

INTRODUCTION

Trickle irrigation system is designed based on regulating inlet pressure at either sub main or lateral. In case of setting pressure regulator at inlet sub main line, 20% pressure variation is distributed as 55% for lateral and 45% for sub main line to achieve the optimum design. In case of setting pressure regulator at each lateral inlet, 20% pressure variation is used to figure out the optimum length of the lateral. The operating pressure that usually ranged from 70 to 250 kPa based on the capacity of the system or the slope of the pipe is the pressure

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at the inlet system design. The pressure head along lateral line is greatly affected by the friction head loss and elevation head. As emitter discharge is related to pressure head along the lateral, the pressure variation changes the water flow from emitters along the line. Therefore, the best design of trickle system is selected due to how uniformly water flow throughout emitters into plant root zone.

Water uniformity can be expressed in trickle irrigation system by uniformity coefficient, distribution uniformity, statistical uniformity coefficient, statistical emission uniformity, field emission uniformity, and emission uniformity which all are a function of coefficient of variation of flow rates. To determine coefficient of variation of water flow rates, an adequate sample size is required in field situation. Coefficient of variation can be theoretical defined based on hydraulic and manufacturing variations in the beginning of system installation. Plugging variation could slightly be considered in the beginning of installation and increased with respect to the operating time and can be managed. Coefficient of variation is considered as a design criterion which can be expressed all uniformity expressions by **Wu and Barragan (2000) and Amer and Gomaa (2003)**. Emission uniformity (EU) which developed by **Keller and Karmeli (1974)** is used to design and evaluate trickle irrigation system. When EU equals 85% as suggested for high value crop, CV of trickle system is less than or equal 6.65% for excellent emitters ($CV_m \leq 5\%$) and hydraulic coefficient of variation ($7.5\% \geq CV_h \geq 4.6\%$) is in between 7.5% and 4.6% considering single emitter is used. CV is ranged from 6.65 to 7.76% for good emitters ($5\% \leq CV_m \leq 7\%$) and $4.6\% \geq CV_h \geq 3.35\%$. It is ranged from 7.76 to 10.08% for marginal emitters ($7\% \leq CV_m \leq 10\%$) and $3.5\% \geq CV_h \geq 1.3\%$. For bad emitters ($CV_m > 10\%$), the design of trickle system for high value crop is undesirable due to CV_h is terminated to be zero. In most cases for system laid on steeply land slope and used to general crops, trickle system always has a low emission uniformity and not acceptable when EU is less than 80%.

Bralts and Edwards (1986) concluded that hydraulic variation of emitter flow rate along the lateral was represented in the flow exponent of emitter but manufacturer's variation of emitter was based on slightly change in the inner diameter of the same type of the emitters represented in the proportionality factor of the emitter. Once, optimum hydraulic and manufacturer's design achieved, it should consider temperature variation, emitter grouping, and emitter plugging. Effect of temperature on emitter flow rate can be considered as small and can be neglected. Change of emitter flow rate due to plugging is respect to time after emitters are installed in the field. Manufacturer's variation as related to the emitter type and grouping by selecting worthy emitters or getting more than one grouped can be reduced. Hydraulic variation can be also controlled by selecting optimum lateral length and type of emitter with minor exponent. Friction loss due to the protrusion of emitter barbs in trickle line flow and manufacturing variation of emitter are pointed in this study.

Bralts and Kesner (1983) developed an equation for determining coefficient of variation of emitter flow based on the location of the tail of normal probability density function. The probability in each tail was one-sixth bell-shape that determination included the upper and the lower values of the distribution. They simplified their equation to be evident. They also added if 18 random measurements of emitter flow rate were made, it would be necessary to sum the three highest and the three lowest values to estimate the coefficient of variation, CV, in turn of determining statistical uniformity coefficient, UC_S = 1-CV.

Trickle irrigation system laterals or sub main are designed for a single pipe size. Energy gradient line for a lateral with a single size was derived and presented by **Wu (1992), Wu and Yue (1993), and Amer and Gomaa (2003**) for designing laterals of trickle irrigation system on level fields or on slopes. Lateral or sub main design may use a series of different pipe sizes. The benefits of a decreasing pipe size or telescopic sub main which decrease cost and pressure variation as in the mainline design. The major disadvantage of decreasing pipe size or telescopic sub main is the installation complication arising from multi-diameter pipes. But, it could simply use varying pipe sizes in laterals due to using low both pressure and diameter.

The objective of this study is to study the performance of water flow throughout emitters along single trickle lateral influenced by lateral size, flow rate, and inlet pressures. A varying sizes lateral is designed to be compared with single lateral based on water uniformity and energy saving.

MATERIALS AND METHODS

Turbo emitter type of 2, 4, and 8 l/h discharge and 5 mm barb outer diameter was selected in this experiment. Flow rates were measured for 36 new emitters from each 2, 4, and 8 l/h under 50, 100, 150, and 200 kPa operating pressure. Characteristic curves of used emitters were logarithmically found for 2, 4, and 8 l/h under the foregoing different pressures. To find out manufacturer's variation for 2, 4, and 8 l/h, 36 new emitters were tested under constant pressure. Pressure was measured using Bourdon-tube gage which was calibrated with pressure transducer and other pressure devices.

Poly Ethylene single laterals of 13, 15, and 17 mm inner diameter all had 1.5 mm thickness, 60 m length, and 0.5 m emitter spacing were alternatively laid on zero-slope soil surface and tested in field situation as shown in Fig. 1(a). Laterals were tested under 100, 150, and 200 kPa inlet pressures for 2, 4, and 8 l/h emitter flow rate. Inlet pressures were regulated by measuring them and adjusting the regulator pressure. Also, a 60 m varying sizes-lateral with 8 l/h emitter flow rate, 60 m length, and 0.5 m emitter spacing, were providing that it started with 17 mm in 1st for 20 m, 15 mm in 2nd for 20 m, and 13 mm in 3rd for 20 m as shown in Fig. 1(b).

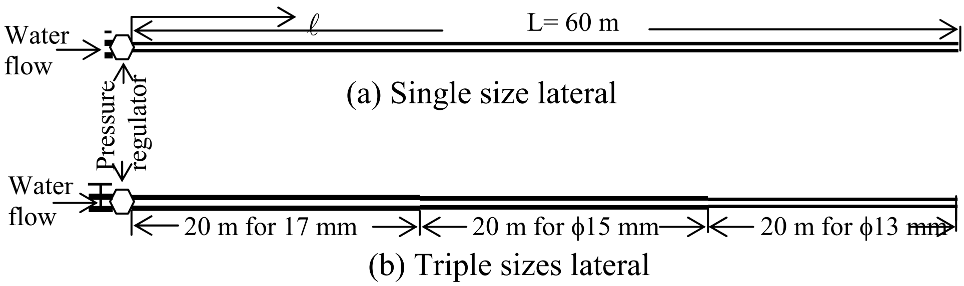

Fig. 1: Experimental layout

Pressure and flow rate were measured each 2 m along lateral for lateral size, inlet pressure, and emitter flow rate set. Pressure was measured using pressure transducer. Flow rate was found by measuring water volume in graduated container in recorded time.

Watters and Keller (1978) used the Darcy-Weisbach equation for smooth pipes with turbulent flow in trickle irrigation systems and combined that with the Blasius equation to predict friction loss of lateral with multiple outlets. The equation was modified by **Amer and Bralts (2005)** by as follows:

$$\Delta H = \frac{K_1}{2.75}\,\frac{\alpha Q^{1.75}}{D^{4.75}}\,L \qquad ---------- \qquad (1)$$

where, ΔH is total friction loss in m, Q is inlet flow rate in m^3/s, L is total length of lateral in m, D is inner diameter in m, α is an equivalent barb coefficient and K_1 is friction factor which depends on water temperature, viscosity and protrusion. K_1 equals 7.94×10^{-4} with no protrusion at 20 ^{o}C. For polyethylene pipe with multiple outlets along the line which flow is non-uniform, an equation is developed based on the change of friction loss due to pipe length considering inconstantly of water flow throughout outlets. The friction loss ΔH_i at any section of lateral was determined according to **Amer and Bralts (2005)** as follows:

$$\Delta H_i = \frac{K_1}{2.75}\,\frac{\alpha Q^{1.75} L}{D^{4.75}}\left(1-\left(1-\frac{\ell}{L}\right)^{2.75}\right) \qquad ------ \qquad (2)$$

where, ΔH_i is friction loss head at a length ℓ measured from inlet end.

Barb coefficient was computed for emitter connections according to **Pitts et al. (1986)** and **Amer and Gomaa (2003)** as follows:

$$\alpha = 1 + \frac{0.01\,d}{S\,D^{1.9}} \qquad ----------- \; (3)$$

where, α is an equivalent barb coefficient, d is outer diameter of emitter barb in m, D is the inner pipe diameter in m, S is emitter spacing in m. Average of friction loss ($\Delta\overline{H}$) in lateral can be expressed by **Amer and Gomaa 2003** as follows:

$$\Delta\overline{H} = \Delta H\left[1-\frac{1}{3.75}\right] \qquad --------- (4)$$

where, ΔH is total friction loss at lateral downstream end.

Pressure head along zero-slope lateral (H_i) was determined as follows:

$$H_i = H - \Delta H_i \qquad ------ \; (5)$$

where H is inlet pressure head and ΔH_i is friction head loss along lateral.

Average pressure head $(\overline{H})$ along zero-slope lateral was determined as follows:

$$\overline{H} = H - \Delta\overline{H} \qquad ------- \; (6)$$

Emitter flow rate along lateral was calculated as follows:

$$q_i = k\,H_i^x \quad ----- (7)$$

where, q_i is emitter flow rate in l/h, H_i is pressure head in m, k and x are emitter flow rate constant and exponent, respectively.

Minimum flow rate (q_{min}) was determined as follows:

$$q_{min} = k\,H_{min}^x \quad --------- (8)$$

where, q_{min} and H_{min} is minimum flow rate and pressure head, respectively.

Average flow rate $(\overline{q})$ was expressed as follows:

$$\overline{q} = k\left(\overline{H}\right)^x -------------- (9)$$

Where, $\overline{q}$ is average flow rate and $\overline{H}$ is average pressure head.

Total coefficient of variation CV_t was calculated according to **Bralts et al., (1981)** as follows:

$$CV_t = \sqrt{CV_m^2 + CV_h^2} \quad ------- (10)$$

Varying sizes of trickle lateral as described in Fig. 2 was used in order to reduce pressure variation. Energy drop along section was determined by using the inlet discharge at the beginning of each section. Inlet discharges Q_1, Q_2, and Q_3 in m^3/s were described as beginning of first, second, and third sections, respectively. L_1, L_2, and L_3 (m) were represented the lateral length from first, second, and third sections to the end of lateral sections, respectively. ℓ_1, ℓ_2, and ℓ_3 (m) were started from the beginning of each section to any point on the section as first, second, and third lengths, respectively. D_1, D_2, and D_3 in m were the first, second, and third section inner pipe diameters, respectively.

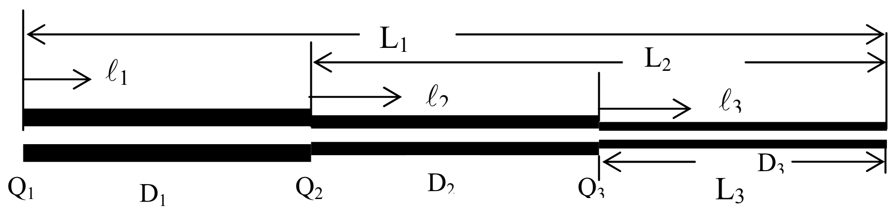

Fig. 2: Three different sizes of three equal lateral sections sketch.

The friction head loss was determined in the three sections with varying sizes pipe as follows:

$$\Delta H_{i1} = \frac{K_1}{2.75} \frac{\alpha Q_1^{1.75} L_1}{D_1^{4.75}} \left(1 - (1 - \frac{\ell_1}{L_1})^{2.75} \right) ---------- (11)$$

Where, ΔH_{i1} is the friction loss at first section.

$$\Delta H_{i2} = \frac{K_1}{2.75} \frac{\alpha Q_2^{1.75} L_2}{D_2^{4.75}} \left(1 - (1 - \frac{\ell_2}{L_2})^{2.75} \right) + \Delta H_{i1} ------- (12)$$

Where, ΔH_{i2} is the friction loss at second section (m).

$$\Delta H_{i3} = \frac{K_1}{2.75} \frac{\alpha Q_3^{1.75} L_3}{D_3^{4.75}} \left(1 - (1 - \frac{\ell_3}{L_3})^{2.75} \right) + \Delta H_{i2} ------- (13)$$

Where, ΔH_{i3} is the friction loss at the third section (m).

Emission uniformity, EU, is a measure of the uniformity for all emitter emissions along trickle irrigation lateral line. Emission uniformity, EU, was expressed by **Keller and Karmeli (1974**) as follows:

$$EU = \left(1 - 1.27 \frac{CV_m}{\sqrt{n}} \right) \frac{q_{min}}{\bar{q}} ------ (14)$$

Where, CV_m is manufacturing variation, n is emitter grouping,

Keller and Bliesner (1990) modified a formula based on a procedure which given by **Bralts and Edwards (1986).** The procedure was given to determine statistical uniformity coefficient in field situation caused by both hydraulic and manufacturing variations where the variation is uniformly distributed throughout the field. The statistical emission uniformity, EU_S, was modified as follows:

$$EU_S = 1 - 1.27 \sqrt{CV_m^2 + CV_h^2} ------ (15)$$

Where, EU_S is calculated statistical emission uniformity, CV_h is hydraulic variation, CV_m is manufacturing variation.

Uniformity coefficient based on hydraulic and manufacturing variations, UC, was determined according to **Amer and Gomaa (2003)** as follows:

$$UC = 1 - 0.798 \sqrt{CV_m^2 + CV_h^2} -------- (16)$$

Uniformity parameters were found using measured emitter flow rates along lateral using the following equations:

$$UC_f = 1 - 0.798\, CV_f ----- (17)$$

$$EU_{Sf} = 1 - 1.27\, CV_f ----- (18)$$

where, UC_f is field uniformity coefficient, EU_{Sf} is field statistical emission uniformity, and CV_f is field coefficient of variation of measured flow rate.

Hydraulic power loss along lateral was determined as follows:

$$P_{HL} = \Delta H \cdot Q \cdot \gamma \quad ----- (19)$$

where, P_{HL} is hydraulic power loss in watt, ΔH is total friction loss in m, and Q is lateral inlet discharge in m^3/s, and γ water specific weight in N/m^3.

RESULTS AND DESCUSSION

Results from individual testing on grouping emitters clarified that the logarithm equations were converted to power equations fitted ($r^2 > 0.96$) as $q = 0.645\ H^{0.483}$, $q = 1.284\ H^{0.49}$ $q = 2.58\ H^{0.485}$, respectively, where q is emitter discharge in l/h and H is pressure head in m. Manufacturer's variation coefficient CV_m was found as 12, 6.2, and 4.8% for 2, 4, and 8 l/h, respectively. It was evident that the lower the emitter flow rate, the higher the manufacturing variation coefficient. These results were due to manufacturing variation was highly appearing in emitter with tiny emitter path compared with large path one.

In single lateral, Friction losses ΔH_i every 2 m along trickle lateral were measured and compared to the corresponding determined values. Total friction loss, ΔH, was found as 4.1, 6.2, and 8.3 m by applying 100, 150, and 200 kPa inlet pressure, respectively, in ϕ15-lateral (60 m length, 8 l/h emitter flow rate, and 0.5 emitters spacing) as shown in Fig. 3. High correlation was found between measured and determined friction losses. Coefficient of determination, r^2, was found to be more than 0.965 and slope was 0.97. ΔH was lower achieved by applying 100 kPa inlet pressure due to decreasing emitter flow rate by lowing inlet pressure. But pressure variation was almost 40% by applying all three inlet pressures for ϕ15-lateral with 8 l/h emitter spaced 0.5 m. Therefore, it could be concluded that inlet pressures which ranged from 100 to 200 kPa did not affect pressure variation along lateral.

Friction head loss was highly obtained in ϕ13-lateral compared with ϕ15 and ϕ17 laterals with 60 m length, 8 l/h emitter flow rate, and 0.5 emitters spacing at 150 kPa inlet pressures as shown in Fig. 4. Total head loss by friction was 9.92, 6.22, and 3.73 m by using ϕ13, ϕ15, and ϕ17 lateral, respectively. Pressure variation was determined as 64, 40, and 24%, respectively. It seemed that inner diameter of trickle lateral changed from 13 to 17 mm reduce pressure variation along lateral from 64 to 24%. High correlation ($r^2 \geq 0.954$, 1.02 slope value, and no intercept) was found between measured and determined friction losses.

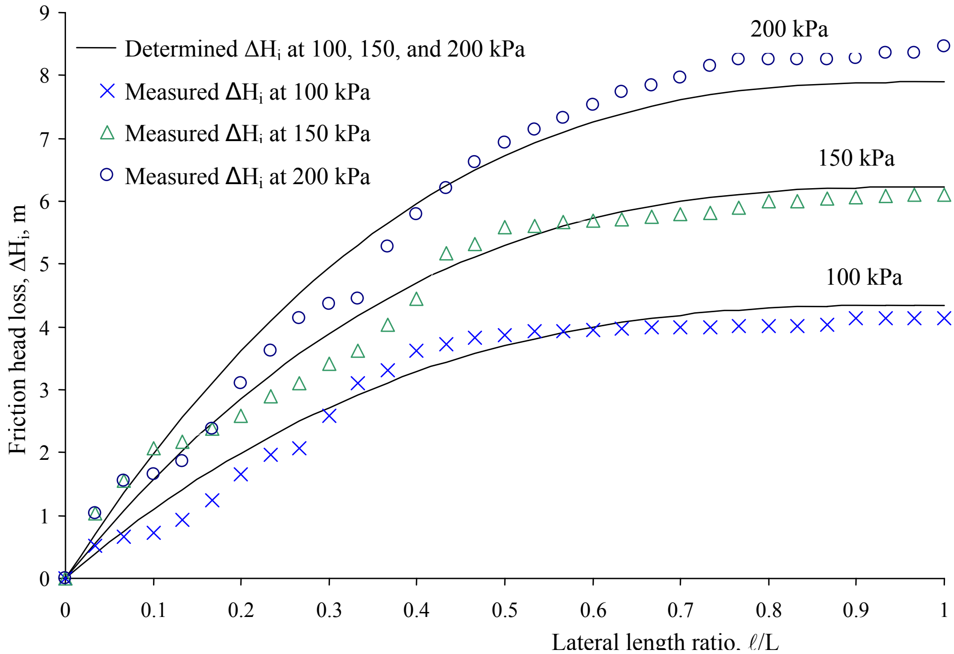

Fig. 3: Friction loss in ϕ15-lateral with 8 l/h emitters discharge spaced at 0.5 m.

By changing emitter flow rate from 2, 4, to 8 l/h along ϕ15-lateral at 150 kPa inlet pressure, friction head loss was increased as shown in Fig. 5. Total friction head loss was recorded as 0.76, 2.40, and 6.22 m by applying 2, 4, 8 l/h emitter flow rate along ϕ15-lateral with 150 kPa inlet pressure, respectively. Pressure variation was determined as 4.9, 15.5, and 40% for 2, 4, and 8 l/h flow rate, respectively. It evident that pressure variation was reduced from 40 to 4.9% by changing flow rate from 8 to 2 l/h along ϕ15-lateral of 60 m long with 150 kPa inlet pressure.

Results of friction loss at 100, 150, and 200 kPa inlet pressure were recorded to 60 m lateral with 8 l/h flow rate and 0.5 emitters spacing of three different sections which were differed in their inner diameters and equaled in their lengths as started with 17 mm for 20 m length that connected to other 20 m length with 15 mm inner diameter, consequently, third section was 13 mm inner diameter and 20 m length as shown in Fig. 6. Total friction head loss at downstream end was obtained as 3.3, 4.3, and 6.2 m at 100, 150, and 200 kPa inlet pressure, respectively. It was seemed that the lateral with high inner diameter had the lower friction losses. High correlation was found between measured and determined friction losses. Coefficient of determination, r^2, was found with no intercept equal to 0.99 and slope was 1.01. Friction head loss at the end of first 20 m of lateral, ϕ17 in 1st section, was 1.68, 2.34, and 3.05 m, at the end of first 40 m of lateral, ϕ15 in 2nd section, was 2.95, 4.05, and 5.29 m, and at the end of 60 m lateral, ϕ13 in 3rd section, was 3.34, 4.3, and 6.2 m by applying 100, 150, and 200 kPa inlet pressure, respectively. Results showed that the high loss of friction head was occurred at the beginning of the first section of lateral; therefore, the large diameter of lateral was used in the first section and so on. In stead of using large diameter the friction loss still had the high friction in the first section due to high pipe discharge in the beginning of lateral.

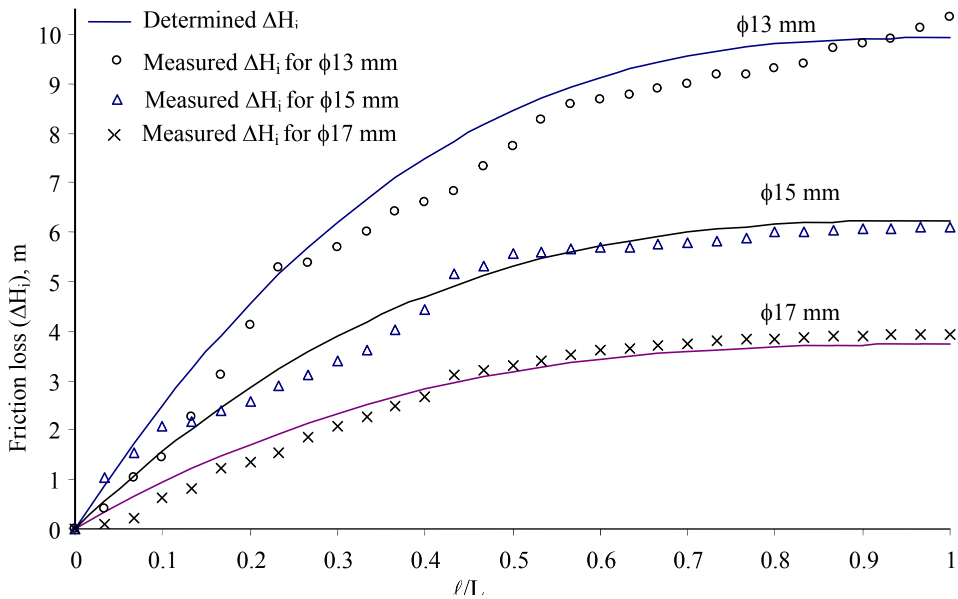

Fig. 4: Friction loss in ϕ13, ϕ 15, and ϕ 17 laterals with 8 l/h spaced at 0.5 m at 150 kPa inlet pressure.

Hydraulic design and emitter manufacturing both affected emitter flow rate along lateral. Generally in new trickle irrigation system, emitter flow rate was uniformly decreased along lateral caused by hydraulic variations. On the other hand, it was varying inconsistently by manufacturing variations. Manufacturing coefficient of variation, CV_m, was measured as 12, 6.2, and 4.8% for 2, 4, and 8 l/h, respectively. The coefficient of variation caused by manufacturing was decreased by increasing emitter discharge because of increasing the cross section area of emitter path. But, hydraulic variation CV_h was varied based on the design criteria of trickle lateral which included the pressure inlet, lateral size, emitter discharge, and spacing among emitters along lateral line. Hereafter, flow variation in trickle and its evaluation were briefly resulted and discussed along both ϕ15-single lateral compared to varying sizes-lateral (ϕ17 for 20 m 1st section, ϕ15 for 2nd section, plus ϕ13 for 3rd section, each section was 20 m long) due to having the same materials cost.

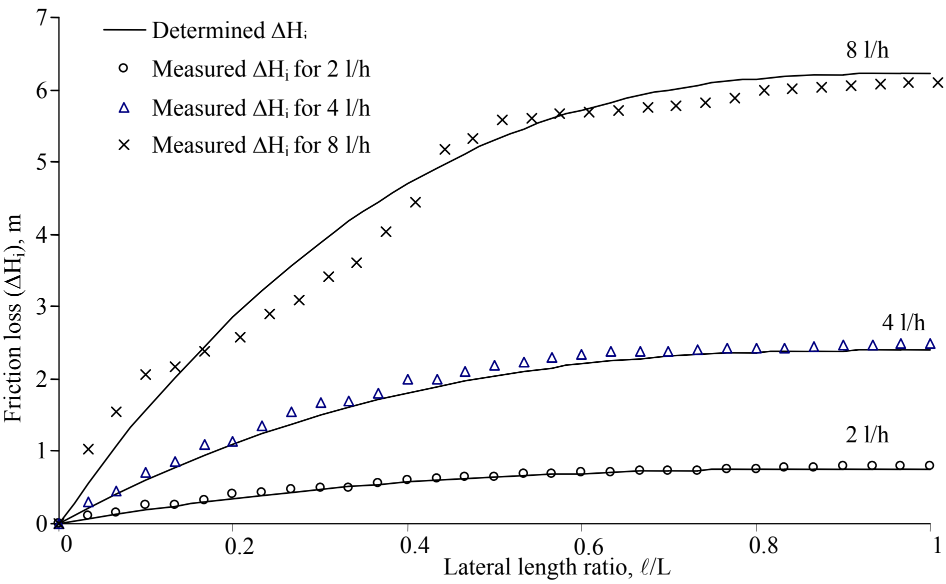

Fig. 5: Friction loss for 2, 4, and 8 l/h emitter flow rate spaced 0.5 m along ϕ15- lateral had 150 kPa inlet pressure

Emitter flow rate was varied by both manufacturing and hydraulic variations as measured each 2 m along ϕ15-single lateral as shown in Fig. 7. Manufacturer's coefficient of variation CV_m was achieved as 4.8% for emitter with 8 l/h nominal flow rate under the three static pressures. The flow rate of emitter (8 l/h nominal discharge) was hydraulically determined and smoothly decreased from 7.9 to 6.1 l/h, from 9.7 to 7.6 l/h, and from 11.2 to 8.9 l/h at 100, 150 and 200 kPa inlet pressure, respectively. The resulted showed that the decrease of emitter flow rate along lateral was slowly by 100 kPa inlet pressure compared with 150 kPa, in turn, it was slower by 150 kPa than by 200 kPa. Hydraulic coefficient of variation CV_h was achieved as 8.7, 8.1 and 7.6% for 100, 150 and 200 kPa inlet pressure, respectively. Hence, total coefficient of variation determined as 9.9, 9.4 and 9.0% under 100, 150 and 200 kPa inlet pressure, respectively. It was seemed that measured data flow rate scattered around calculated emitter flow rate line caused only by hydraulic variation. Field coefficient of variation was equal to 10.1, 9.7 and 9.3% respectively. Field coefficient of variation CV_f was highly correlated to determined total coefficient of variation CV_t.

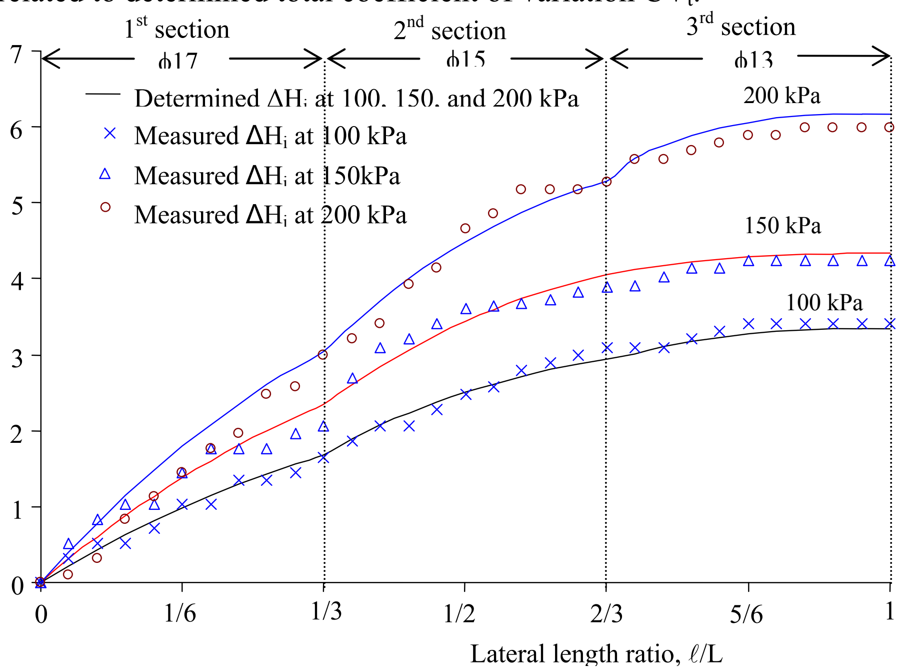

Fig. 6: Friction loss in varying size-lateral with 8 l/h emitters discharge spaced as 0.5 m.

Along three sections of varying sizes-lateral, emitter flow rate was varied by both manufacturing and hydraulic variations and scattered around calculated emitter flow rate line caused only by hydraulic variation as shown in Fig. 8. Manufacturer's coefficient of variation CV_m was about 4.8% for 8 l/h nominal flow rate of emitter at three operating pressures. Emitter flow rate was hydraulically determined and smoothly decreased from 7.9 to 7.4 l/h, and from 9.7 to 8.9 l/h, and from 11.2 to 10.3 l/h under 100, 150 and 200 kPa inlet pressure, respectively. Resulted showed that the decrease of emitter flow rate along lateral was slowly by 100 kPa inlet pressure compared with 150 kPa. In turn, it was slower by 150 kPa than by 200 kPa inlet pressure. Hydraulic coefficient of variation CV_h was achieved as 6.2, 5.3 and 5.7% under 100, 150 and 200 kPa inlet pressure, respectively. But, total coefficient of variation CV_t which was included the hydraulic and manufacturing variations determined as 7.8, 7.2, and 7.4%, respectively. Field coefficient of variation was equal to 7.9, 7.6, and 7.7% respectively. Field coefficient of variation CV_f was highly correlated to determined total coefficient of variation CV_t.

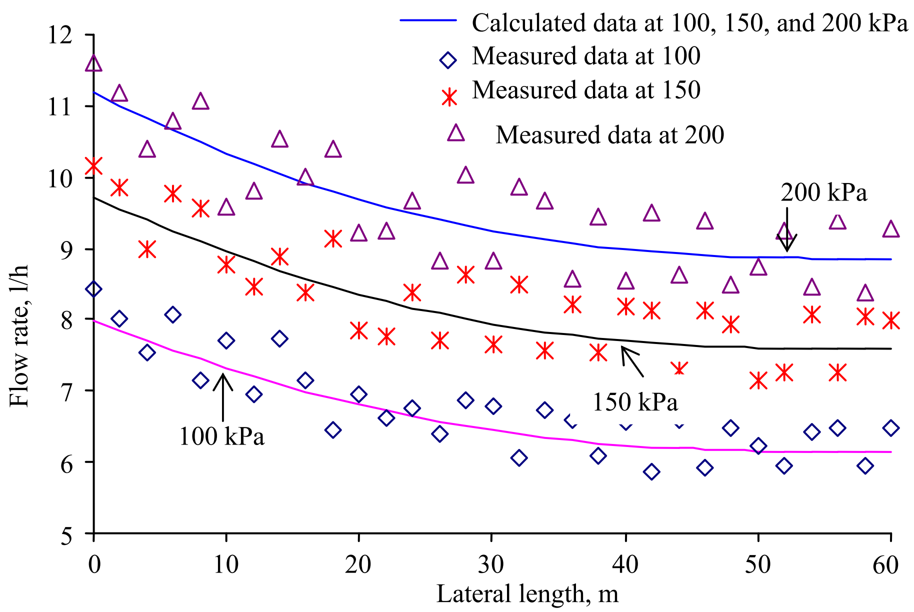

Fig. 7: Emitter flow rate along ϕ15-lateral at three different inlet pressures.

Trickle system design and evaluation parameters for ϕ15-single lateral compared to varying sizes-lateral both 60 m long and 8 l/h flow rate of emitter which spaced 0.5 m at 150 kPa inlet pressure are shown in Table 1. It was observed that friction loss was increased with increasing inlet pressure of lateral in both single and varying sizes laterals. Consequently, average head and flow rate were increased. Pressure variation along lateral was insignificantly affected by changing inlet pressure for the same lateral size and length with the same emitters spacing. Conversely, it was achieved high value almost 40% for ϕ15-single lateral compared to about 30% for varying sizes-lateral.

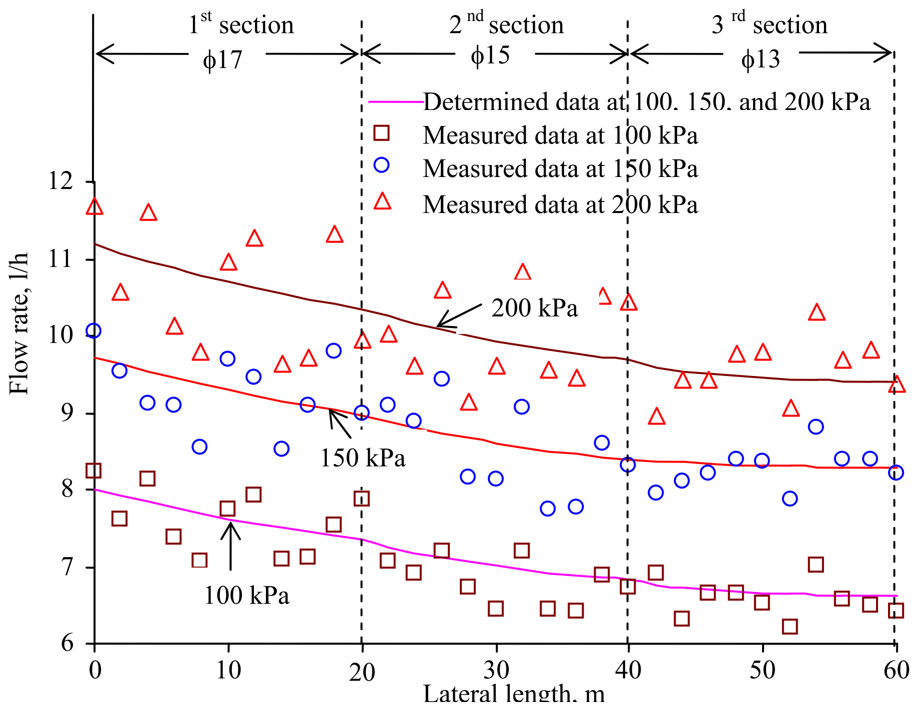

Fig. 8: Emitter flow rate along varying size-lateral at three different inlet pressures

Field coefficient of variation CV_f was found as 9.9, 9.4, and 8.9% at 100, 150, and 200 kPa, respectively. Emission uniformity EU was achieved almost 86.5% for single lateral and about 89.5% for varying sizes-lateral at any inlet pressure. Statistical emission uniformity EU_S was achieved almost 88% for single lateral and about 90.5% for varying sizes-lateral. Uniformity coefficient was determined as 92.4% for single lateral and 94% for varying size lateral. All evaluation parameters such as pressure or flow variations, coefficient of variations, and uniformity were insignificantly changed by inlet pressures. In field situation, EU_{Sf} was about 88% for single lateral and 90.5 % for varying size-lateral. While field uniformity coefficient UC_f was almost 92.5% for single lateral and 94% for varying sizes lateral. These results showed that no significant difference was found among determined and field evaluation parameters due to the newest of trickle system which appeared to no emitters plugging. Hydraulic power loss was increased with increasing inlet pressure of lateral either in single or varying sizes laterals. Power saving percentage occurred by varying sizes-lateral compared to single lateral was 19.8, 26.4, and 18.2% by applying 100, 150, and 200 kPa inlet pressure, respectively. Varying sizes-lateral with 150 kPa inlet pressure highly achieved power saving and uniformity compared to single lateral.

Table 1: Design and evaluation parameters for ϕ15-single lateral and varying sizes-lateral with 8 l/h discharge with 4.8% manufacturing CV.

Design & evaluation Parameters*	Single ϕ15-lateral at kPa inlet pressure			Varying sizes-lateral at kPa inlet pressure		
	100	150	200	100	150	200
Friction loss, ΔH (m)	4.3	6.2	7.9	3.3	4.3	6.2
Average pressure head (m)	7.1	10.9	14.9	7.9	12.3	16.1
Average flow rate (l/h)	6.7	8.2	9.5	7.0	8.7	9.9
Minimum flow rate, (l/h)	6.1	7.6	8.9	6.6	8.3	9.4
Pressure variation (%)	41.6	40.0	38.2	31.9	27.8	30.0
Hydraulic CV (%)	8.7	8.1	7.6	6.2	5.3	5.7
Total CV (%)	9.9	9.4	9.0	7.8	7.2	7.4
Emission uniformity (%)	86.2	86.7	87.2	88.6	89.5	89.1
Statistical EU (%)	87.4	88.0	88.6	90.0	90.9	90.6
UC (%)	92.1	92.5	92.8	93.7	94.3	94.1
Field CV (%)	10.1	9.7	9.3	7.9	7.6	7.7
Field statistical EU (%)	87.2	87.7	88.2	90.0	90.3	90.2
Field UC (%)	92.0	92.3	92.7	93.8	94.0	93.9
Hydraulic power loss (watt)	9.5	16.8	24.8	7.62	12.3	20.2
Power saving (%)	0.0	0.0	0.0	19.8	26.4	18.2

*CV is coefficient of variation, EU is emission uniformity, and UC is uniformity coefficient.

CONCLUSION

Optimum design of trickle irrigation lateral could be done by managing lateral length and size, emitter discharge, and inlet pressure, emitters spacing with selecting high quality of emitters. Optimum lateral dimension should be constrained by either flow variation or emission uniformity of trickle unit. For that purpose, a field experiment was conducted to test 17, 15, and 13 mm inner diameter single laterals companying with 2, 4, and 8 l/h emitter flow rate and 100, 150, 200 kPa inlet pressure. Laterals were 60 m long and were laid on zero slope. Emitter was spaced 0.5 m. A 60 m- varying sizes lateral consisted of three equal sections sized as ϕ17 in 1st, ϕ15 in 2nd, and ϕ13 in 3rd sections was tested and compared with ϕ15-single lateral for 8 l/h, and 0.5 m emitter spacing under 100, 150, 200 kPa inlet pressure.

Manufacturer's variation coefficient CV_m was found as 12, 6.2, and 4.8% for 2, 4, and 8 l/h, respectively. CV_m was decreased by increasing emitter flow because of increasing the cross section area of emitter path. But, hydraulic coefficient of variation CV_h was varied based on the design criteria of trickle lateral which included the pressure inlet, lateral size, emitter discharge, and spacing among emitters along lateral line.

Friction loss of trickle lateral ΔH was significant increased by increasing lateral size and emitter flow rate and decreasing inlet pressure. ΔH was valued as 0.76, 2.40, and 6.22 m by applying 2, 4, and 8 l/h emitter flow rate along ϕ15-lateral with 150 kPa inlet pressure. ΔH was 9.92, 6.22, and 3.73 m by using ϕ13, ϕ15, and ϕ17 lateral with 8 l/h emitter flow rate at 150 kPa inlet pressure, respectively. Using ϕ15 lateral with 8 l/h emitter flow rate, ΔH was achieved 4.3, 6.2, and 7.9 m at 100, 150, and 200 kPa inlet pressure, respectively. While for varying sizes-lateral, ΔH was reduced to 3.3, 4.3, and 6.2 m, respectively. Insignificant difference between measured ΔH and determined ΔH was found.

By comparing ϕ15-single lateral with varying sizes-lateral both 60 m long and 8 l/h flow rate at 150 inlet pressure, evaluation parameters were achieved almost 87.7 and 89.5% emission uniformity EU, 88% and 90.9% statistical emission uniformity EU_S, 92.5 and 94.3% uniformity coefficient UC, 87.7 and 90.3% field statistical uniformity EU_{Sf}, 92.3 and 94.0 % field uniformity coefficient UC_f for single lateral and varying sizes lateral, respectively. These results showed that no significant difference was found among determined and field evaluation parameters due to the newest of trickle system which appeared no emitters plugging. Hydraulic power loss was increased with increasing inlet pressure of lateral either in single or varying sizes laterals. Power saving percentage occurred by varying sizes-lateral compared to single lateral was 19.8, 26.4, and 18.2% by applying 100, 150, and 200 kPa inlet pressure, respectively.

The results could conclude that pressure and flow variations as well as all uniformity parameters were insignificantly influenced by inlet pressure; nevertheless, they were significantly affected by lateral size and emitter flow rate. Low flow variation as well as high uniformity was obtained by reducing emitter flow rate, increasing lateral size, and applying varying sizes-lateral at 150 kPa inlet pressure, power saving and uniformity were highly achieved instead of single lateral.

REFERENCES

Amer, K. H. and A. H. Gomaa (2003). "Uniformity determination in trickle irrigation lateral design". Misr J. Ag. Eng., 20(2): 405-434.

Amer, K. H. and V. Bralts (2005). "Optimal design of trickle irrigation submain unit dimensions". Misr J. Ag. Eng., 22(3): 820-839.

Bralts, V.F., I.P. Wu and H.M. Gitlin (1981). Manufacturing variation and drip irrigation uniformity. Trans. of the ASAE 24(1): 113-119.

Bralts, V.F. and C.D. Kesner (1983). Trickle irrigation field uniformity estimation. . Trans. of the ASAE, 26(5): 1369-1374.

Bralts, V.F. and D.M. Edwards (1986). "Field evaluation of trickle irrigation submain units". Trans. of the ASAE, 29(6): 1659-1664.

Keller, J., and D. Karmeli (1974). Trickle irrigation design parameters. Trans. of the ASAE 17(4): 678-684.

Keller, J., and R.N. Bliesner (1990). Sprinkler and trickle irrigation. Van Nostrand, Reinhold, NY: 600p.

Pitts, D. J.; A. Ferguson and R. E. Wright (1986). "Trickle irrigation lateral design by computer analysis". Trans. Of ASAE, 29(5): 1320-1324.

Watters, G.Z. and J. Keller (1978). "Trickle irrigation tubing hydraulics". ASAE Paper 78-2015.

Wu, I.P. (1992). Energy gradient line approach for direct hydraulic calculation in drip irrigation system. Irrig. Sci. 13: 21-29.

Wu I.P. and R. Yue (1993). Drip lateral design using energy gradient line approach. Trans. of the ASAE 36(2): 389-394.

Wu I.P. and J. Barragan (2000). Design criteria for microirrigation systems. Trans. of the ASAE. 43(5): 1145-1154.

الملخص العربى

تصميم وتقييم خطوط الرى بالتنقيط ذى القطر الواحد أومتدرجة القطر

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عند تصميم نظام الرى بالتنقيط بوضع منظم ضغط عند بداية الخط الفرعى تكون قطعة الرى بالتنقيط هى أساس التصميم آما عند وضع منظم الضغط عند بداية كل خط تنقيط يتحول الخط الفرعى إلى ناقل للمياه وحافظ لطاقتها كونه جزء متفرع من الخط الرئيسى ويكون تصميم شبكة الرى بالتنقيط أساسها خط التنقيط ، ولتوفيق المعايير التصميمة المثلى لخط الرى بالتنقيط مثل اختيار نوع النقاط وتصرفه وقطر وطول الخط وضغط بدايته بحيث تتراوح إنتظامية تدفق النقاطات من ٨٥-٩٠٪ حسب أهمية المحصول . أيضا يمكن تحسين أداء شبكات الرى بالتنقيط بتدريج قطر خطوط الرى عوضاً عن استخدام خطوط ذى قطر موحد.

تم إختبار خطوط تنقيط موضوعة على أرض مستوية بأقطار داخلية هى ١٣ ، ١٥ ، ١٧ مم حيث كان لها نفس السمك وهو ١.٥ مم مع نقاطات تصرفها هو ٢ ، ٤ ، ٨ لتر/س عند ضغوط البداية ١٠٠ ، ١٥٠ ، ٢٠٠ ك باسكال مع ثبات طول الخط وهو ٦٠ متر والمسافة بين النقاطات وهى ٠.٥ متر ، تم إختبار خط تنقيط متدرج القطر حيث إبتدأ بقطر ١٧ مم لطول ٢٠ م ثم قطر ١٥ مم لطول ٢٠ م ثم ١٣ مم لطول ٢٠ م ومقارنته لخط ذو قطر موحد ١٥ مم لطول ٦٠ م لكونهم متساويين فى تكاليف ومواد الإنشاء ، كلا الخطين لهما نقاطات ٨ لتر/س على مسافات ٠.٥ م حيث تم الإختبار عند ضغوط بداية هى ١٠٠ ، ١٥٠ ، ٢٠٠ ك باسكال. تم إختبار النقاطات تصنيعياً وهيدروليكياً قبل بدأ التجربة.

أظهرت النتائج أن معامل الإختلاف التصنيعى حقق ١٢ ، ٦.٢ ، ٤.٨٪ لتصرف النقاطات ٢ ، ٤ ، ٨ لتر/س ، على التوالى ، ويرجع تناقص المعامل نتيجة إلى زيادة ممر النقاط الداخلى حيث تقل ظهور العيوب التصنيعية. أما معامل الاختلاف الهيدروليكى تأثر معنوياً بتغير كلاً من قطر خط التنقيط وتصرف النقاطات وغير معنوياً بضغط بداية الخط . تناقص فاقد الضاغط بالإحتكاك معنوياً من ٦.٢٢ ، ٢.٤ ، إلى ٠.٧٦ متر بتخفيض تصرف النقاطات على طول خط التنقيط لقطر ١٥ مم عند ضغط البداية ١٥٠ ك باسكال من ٢ ، ٤ ، إلى ٨ لتر/س ، على التوالى ، وعند استخدام خط تنقيط موحدالقطر لنقاطات تصرفها ٨ لتر/س وعند ضغط بداية مقداره ١٥٠ ك باسكال قل فاقد الإحتكاك من ٩.٩٢ ، ٦.٢٢ ، إلى ٣.٧٣ م عند زيادة قطر الخط من ١٣ ، ١٥ ، إلى ١٧ مم ، على التوالى ، كما قل الفاقد من ٤.٣ ، ٦.٢ ، ٧.٩ م باستخدام خط تنقيط موحد القطر ١٥ مم إلى ٣.٣ ، ٤.٣ ، ٦.٢ م باستخدام خط تنقيط متدرج القطر (١٧ ثم ١٥ ثم إلى ١٣مم كلاً بطول ٢٠ م) وذلك عند ضغوط بداية هى ١٠٠ ، ١٥٠ ، ٢٠٠ ك باسكال ، على التوالى ، عند استخدام تصرف نقاطات ٨ لتر/س.

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بمقارنة خط تنقيط متدرج القطر (١٧ ثم ١٥ ثم إلى ١٣مم كلاً بطول ٢٠ م) مع خط موحد القطر ١٥ مم حيث حققت مقاييس الإنتظامية قيماً هى ٨٦.٧ ، ٨٩.٥٪ لإنتظامية التدفق ، ٨٨.٠ ، ٩٠.٩٪ لإنتظامية التدفق الإحصائية ، ٩٢.٥ ، ٩٤.٣٪ لمعامل الإنتظامية ، ٨٧.٧ ، ٩٠.٣٪ لإنتظامية التدفق الإحصائية الحقلية ، ٩٢.٣ ، ٩٤.٠٪ لمعامل الإنتظامية الحقلى لكل من خط التنقيط موحد القطر ومتدرج القطر ، على التوالى ، حيث أظهرت النتائج أنه لاتوجد فروق معنوية بين القيم المحسوبة والحقلية لمقاييس الإنتظامية وهذا راجع لكون أن الخطوط والنقاطات حديثة الإنشاء ولايظهر أى إنسداد بداخلها ، كما أوضحت المقارنة أن نسبة الطاقة المتوفرة باستخدام خط الرى متدرج القطر كانت ١٩.٨ ، ٢٦.٤ ، ١٨.٢٪ عند ضغوط البداية ١٠٠ ، ١٥٠ ، ٢٠٠ ك باسكال ، على التوالى ، بالمقارنة بخط ١٥ مم قطر موحد.

أظهرت النتائج أن التغير فى الضغط وتصرف النقاطات وكذلك مقايس الإنتظامية على طول خط التنقيط لم تتغير معنوياً بتغير ضغط البداية بل تغيروا معنوياً بتغير قطر الخط وتصرف النقاطات حيث تم الحصول على أقل تغير فى الضغط أو التصرف وأعلى إنتظامية بزيادة قطر الخط وتقليل تصرف النقاط مع تدريج الخط من قطر أوسع إلى قطر أضيق ، حيث إتضح أن استخدام خط متدرج عند ضغط بداية ١٥٠ ك باسكال حقق توفير أكبر فى الطاقة مع إنتظامية توزيع للمياه أعلى عوضاً عن استخدام خط بقطر موحد.