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DEVELOPMENT AND PERFORMANCE EVALUATION OF PRESSURIZED IRRIGATION SYSTEM

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ABSTRACT: The purpose of the present study is to develop and evaluate a sprinkler irrigation system based on its design criteria to minimize friction loss, pressure head variation, and specific energy and maximize water uniformity distribution. The system was developed from single inlet open lateral (SIOL) to double inlet closed lateral (DICL). Experiments were conducted to study two different parameters (lateral length and irrigation water inlet method to lateral line) affecting the performance of the developed system. The system performance was evaluated in terms of water distribution uniformity, coefficient of uniformity, pressure head variation and specific energy. It was concluded that pressure head variation and specific energy were significantly decreased while water distribution uniformity was improved with DICL compared to SIOL at all lateral lengths. The lateral length of 165m with DICL was recommended to be used as they achieved acceptable distribution uniformity, coefficient of uniformity and pressure head variation values which were 75%, 81% and 18%, respectively.

Key words: Sprinkler irrigation, friction losses, specific energy, distribution uniformity.

INTRODUCTION

Sprinkler irrigation system is considered one of pressurized irrigation systems; it has been used worldwide due to its flexibility and adaptability for various soils, crops and topographical circumstances.

However for an economical system and even water distribution over the total land surface, careful judgment of the design criteria is required. With proper selection of nozzle sizes, riser heights, operating pressure, sprinkler spacing, lateral length and lateral design. Water can be applied uniformly at a rate lower than the infiltration rate of the soil, thereby preventing runoff and the resulting damage to land and crops.

Wu and Gitlin (1982) reported that both the double-inlet and the inflow-outflow systems can be achieve a much better uniformity of water pressure along the lateral line than that of the single inlet system. The pressure difference of a double-inlet or inflow-outflow lateral line system is only about one-third to one-fifth of the pressure difference caused by the single inlet system. **Benami and Offen (1984)** stated that in sprinkler irrigation system planers depends on two arbitrary criteria. The first criterion specifies that a sprinkler recommended in catalog for any given operation conditions should have a minimum acceptable coefficient of uniformity (CU) greater than or equal to 85%. The second criterion specifies that the pressure head variation between all the sprinklers should not exceed a recommended value, generally 20%. **Addink and Bytat (1989) and Keller (1989)** suggested that for practical purposes the allowable pressure loss due to friction can be estimated at 23.4% of the required average pressure. For the same reason, the friction losses in the lateral should be kept to a minimum. Other sources suggest that allowable pressure

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variation should not exceed 20% of the sprinkler operating pressure. **Badr (1992)** found that the distribution uniformity (DU) values under fixed sprinkler irrigation system were increased from 69.0% to 94.60% for square pattern, from 53.0% to 83.90% for rectangular pattern and from 57.0% to 96.70% for triangular pattern. Also, the coefficients of uniformity (CU) values were increased from 80.60% to 96.60% for square pattern, from 70.0% to 90.0% for rectangular pattern, and from 72.60% to 98.0% for triangular pattern. In addition to, the application efficiency of low quarter (AELQ) values were increased from 58.70% to 85.70% for square pattern, from 36.90% to 75.40% for rectangular pattern, and from 43.1% to 92.3% for triangular pattern at operating pressure of 250 kPa. **Mahmoud (2002)** found that the highest distribution uniformity for 80 cm riser height was 83.72% for the combination of 8 mm nozzle diameter, 400 kPa and the rectangular spacing sprinkler pattern, while For the 250 cm riser height the highest distribution uniformity was 83.52% for the combination of 8 mm nozzle diameter, 400 kPa and the rectangular spacing sprinkler pattern. Meanwhile the highest assumed minimum rate of water was 13.72 mm/hr., for the combination of 8 mm nozzle diameter, 400 kPa and 250 cm riser height with the square spacing sprinkler pattern. **Sourell *et al.* (2003)** studied the performance of rotating spray plate sprinklers (RSPS) under experimental conditions (6.1, 7.0, and 7.8 mm nozzle diameters, 1.0 and 1.5 m nozzle height above the ground and working pressures of 100, 150 and 200 kPa). They found that simulated Christiansen uniformity coefficient was 91.80% under the different experimental conditions. **Amer (2006)** found that high degree of water distribution uniformity optimal spacing between spinner sprinklers was found to be as 60% from diameter of throw in square layout and in range from 50 to 70% from diameter of throw in triangular. For impact sprinklers, spacing was recommended to be as 50% from diameter of throw in square layout and in range from 50 to 60% in triangular. Triangular layout achieved higher uniformity than square even for the same served area. **Hegazi *et al.* (2007)** found that optimal spacing between sprinklers was found to be as 40% to 60% from diameter of throw in square layout in range of trajectory angles in between 15º to 30º. **Khader (2009)** stated that the spacing between sprinklers should be higher than or equal to 50% of wetted diameter to avoid water lose and minimize irrigation system cost. Relating to irrigation system design. **Mansour *et al.* (2013)** concluded that the closed circuits are considered one of the modifications of Mini-sprinkler irrigation system. The closed circuits added advantages to Mini-sprinkler irrigation system because it can relieve low operating pressures problem at the end of the lateral lines. In the conventional closed circuits of Mini-sprinkler irrigation system, the farmer has to keep watch on irrigation timetable, which is different for different crops. Using this system, one can save man-power, water to improve production and ultimately profit.

The objectives of the present research are to:

- Develop a sprinkler irrigation system as a one of the pressurized systems and estimate the optimum suitable components for reducing friction losses.
- Optimize some design and operating parameters of the developed system to increase the uniformity of water distribution.

MATERIALS AND METHODS

Field experiments were conducted at El-Khattarah Farm, Faculty of Agriculture, Zagazig University, Egypt to develop, evaluate and optimize the parameters of the developed sprinkler irrigation system.

Materials

The purpose of the present study was to develop the conventional sprinkler irrigation system based on its design criteria to a developed system in order to minimize friction loss, pressure head variation, and specific energy and maximize water uniformity distribution.

The conventional sprinkler irrigation system

The conventional sprinkler irrigation system consists of the following main parts:

- An electrical centrifugal pump of 11 kW was connected with a control unit to give recommended flow rate at required pressure.

- Valves and pressure regulators were fitted in the beginning of each lateral to control the discharge and pressure.
- Pressure gauge was used to adjust a 250 kPa sprinkler base pressure.
- An 10 liters water tank was used to define sprinkler discharge.
- The rotating impact sprinklers were set overhead a 0.7 m irristand height and laid on square layout of 11 m apart with 50% overlapping of wetted diameter along and between four polly ethaline (PE) laterals of different lengths with two methods of irrigation water inlet to lateral line.

The developed sprinkler irrigation system

The developed sprinkler irrigation system consists of the same parts as with the conventional system. However, the conventional sprinkler irrigation system was developed from single inlet open lateral (SIOL - The conventional system) to double inlet closed lateral (DICL– The developed system). Fig. 1 shows the main difference between the two systems.

Methods

Experiments were carried out through the year of 2017 to evaluate the performance of the developed sprinkler irrigation system compared to the conventional sprinkler irrigation system.

Experimental conditions

Experiments were conducted to study the performance of the developed sprinkler irrigation system in terms of the following parameters:

* Two methods of irrigation water inlet to lateral line:

- Single inlet open lateral (SIOL) with gradual lateral nominal diameters of 32, 50, and 63 mm to maintain a range of 1-2 m/sec., water speed.
- Double inlet closed lateral (DICL) with one lateral nominal diameter of 32 mm to maintain a range of 1-2 m/sec., water speed.

* Four different lateral lengths of 99, 132, 165 and 176 m to optimize the suitable value of lateral.

A square grid pattern of collectors (121 catch cans) with 1 m spacing was used to estimate distribution uniformity in between four sprinklers and a 1 hr., was the duration of each treatment.

Fig. 2 shows the experimental setup and the layout of sprinkler irrigation experimental design.

Measurements and calculations

The performance of the developed sprinkler irrigation system was evaluated taking into consideration the following indicators:

Distribution uniformity (DU)

The uniformity distribution pattern is a measure of how evenly the sprinkler system applies water over the irrigation area. Determination of the allowed sprinkler lateral length for field utilization requires testing on various lengths until the permitted pressure-drop is reached. Water distribution uniformity in between four sprinklers was recorded at the beginning, middle and end of laterals in DICL and at only the beginning and end of laterals in SIOL.

Distribution uniformity (DU) is based on the average rate or depth recorded for the lowest quarter for catch can locations and calculated by the following formula **(Heermann *et al.,* 1990):**

$$DU=100\frac{Z_{lq}}{Z_{av}} \text{..........(1)}$$

Where:

DU - distribution uniformity (%),

Z_{lq} - average catch can depth in the low quarter of the field, mm, and

Z_{av}- average catch can depth in the entire field, mm.

Coefficient of uniformity (CU)

Uniformity tests were conducted by measuring amount of water caught in each can and the coefficient of uniformity was calculated by the following equation **(Christiansen, 1942):**

$$CU=100\left(1-\frac{\Sigma\left|X_i-\bar{X}\right|}{n\,\bar{X}}\right) \text{.......... (2)}$$

Where:

CU - Christiansen's coefficient of uniformity in percent;

X_i - individual collector amount, mm;

$\bar{X}$ - mean of collectors amount, mm; and

n - number of collectors measured.

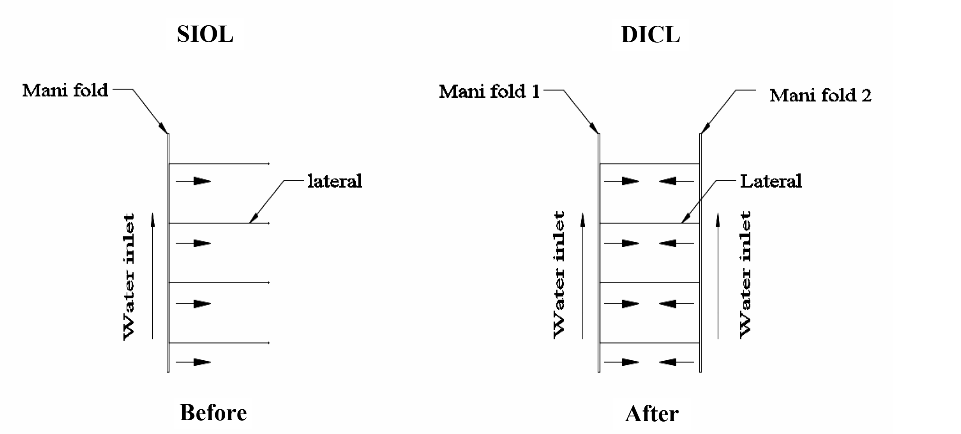

Fig. 1. The sprinkler irrigation system before and after development

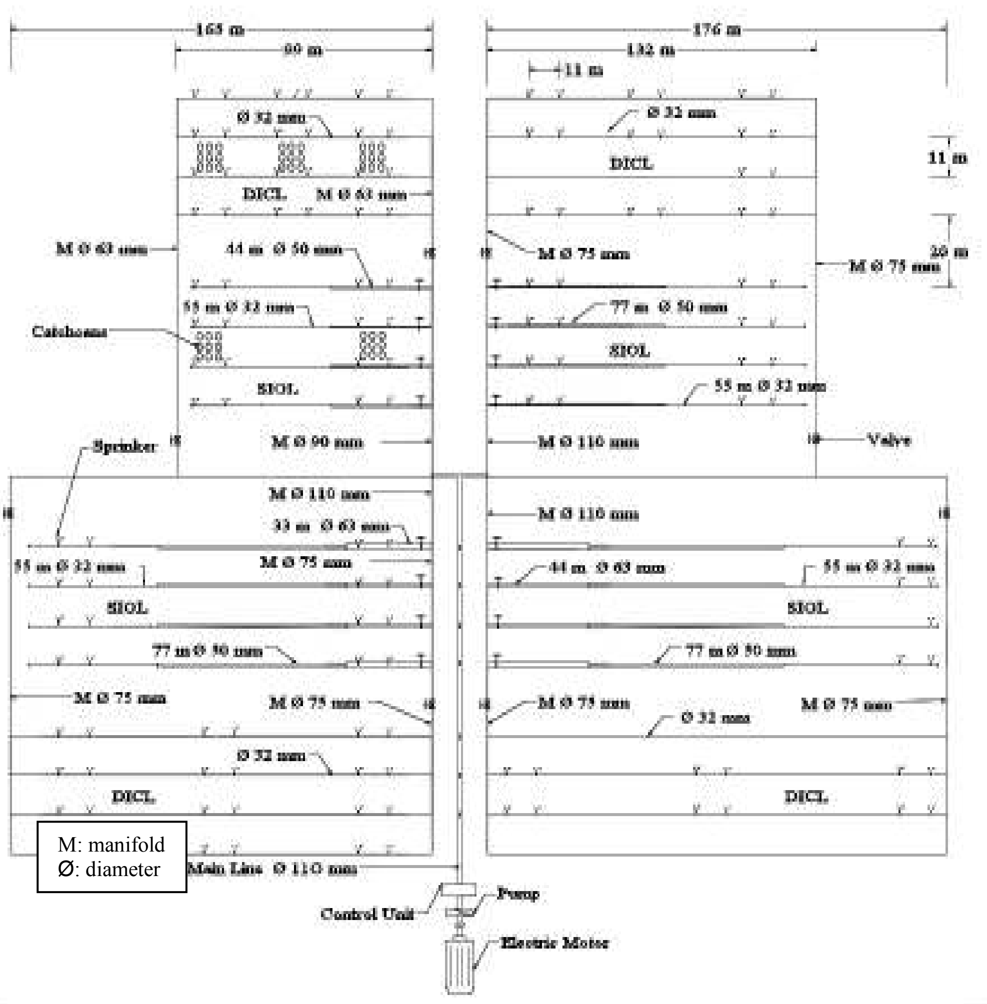

Fig. 2. The experimental setup and the layout of sprinkler irrigation experimental design

Pressure head variation

Wu and Gitlin (1983) Stated that the pressure head variation could be determined by:

$$h_{var} = ((h_{max} - h_{min})/h_{max})\ 100 \quad \dots (3)$$

Where:

h_{var} - pressure head variation (%)

h_{max} - maximum pressure, m, and

h_{min} - minimum pressure, m.

For a practical design, the pressure head variation is usually kept less than 20% **(Benami and Offen, 1984).**

The required power

The required power was estimated using the measurement of line current in Amperes and potential difference in volts. The actual power of the electric motor of the pump (P) was estimated according to the following equation **(Lockwood and Dunstan, 1971):**

$$p = \frac{\sqrt{3}.I.V.\eta.\cos\theta}{1000} \quad \dots\dots.. (4)$$

Where:

P - total consumed power; kW,

I - line current strength in amperes,

V - potential difference (voltage); equal to 380 v,

η - mechanical efficiency; assumed (95 %),

cos θ - power factor (was taken as 85 %),

$\sqrt{3}$ - coefficient current three phase.

The specific energy

The specific energy (kW.hr./m^3) was calculated by dividing the consumed power (kW) by the flow rate of the lateral (m^3/hr.).

RESULTS AND DISCUSSION

The discussion will cover the obtained results under the following heads:

Distribution Uniformity (DU)

The trend of distribution uniformity (DU) with different lateral lengths for the two methods of irrigation water inlet to lateral line DICL and SIOL are shown in Fig. 3. In general, for all results the DU values were higher with lateral design of DICL than those with SIOL at all tested lateral lengths. The highest DU value of 78.4% was obtained at lateral length of 99 m with DICL, meanwhile the lowest DU value of 64.5% was obtained at lateral length of 176 m with SIOL.

On the contrary, the results showed that with both DICL and SIOL the DU values decreased with increasing the lateral length, and decreased at the far end of laterals at SIOL more than decreasing at the middle of laterals at DICL design. At lateral length of 99 m with DICL, the DU values were 77.3, 74.2 and 78.4% at the beginning, middle and end of lateral, respectively. While with SIOL, the DU values were 76.8 and 71% at the beginning and end of the lateral respectively. Also at lateral length of 132 m with DICL, the DU values were 78, 74.5 and 77.3% at the beginning, middle and end of lateral, respectively. While with SIOL, the DU values were 76.5 and 69.5% at the beginning and end of the lateral, respectively. As to lateral length of 165m with DICL, the DU values were 76.3, 72 and 75.7% at the beginning, middle and end of lateral, respectively. While with SIOL, the DU values were 74.5 and 66% at the beginning and end of the lateral, respectively. Lastly, with lateral length of 176 m with DICL, the DU values were 75, 70.4 and 76% at the beginning, middle and end of lateral, respectively. While with SIOL, the DU values were 73 and 64.5% at the beginning and end of the lateral, respectively. These results were attributed to the descending in the sprinklers discharge rate resulting from pressure head losses occurred in the middle of DICL and the far end of SIOL.

Coefficient of Uniformity (CU)

Coefficient of uniformity (CU) was described as a numerical expression representing the index of water distribution uniformity on the soil surface. The coefficient of uniformity was determined under different combinations of lateral lengths of 99, 132, 165 and 176 m and two methods of irrigation water inlet to lateral line DICL and SIOL. Fig. 4 showed that, the CU values were higher with lateral DICL than those with SIOL at all lateral lengths under study, where the highest value of CU of 87.7% was obtained at lateral length of 99 m with DICL, meanwhile the lowest CU value of 77.6% was obtained at lateral length of 176 m with SIOL.

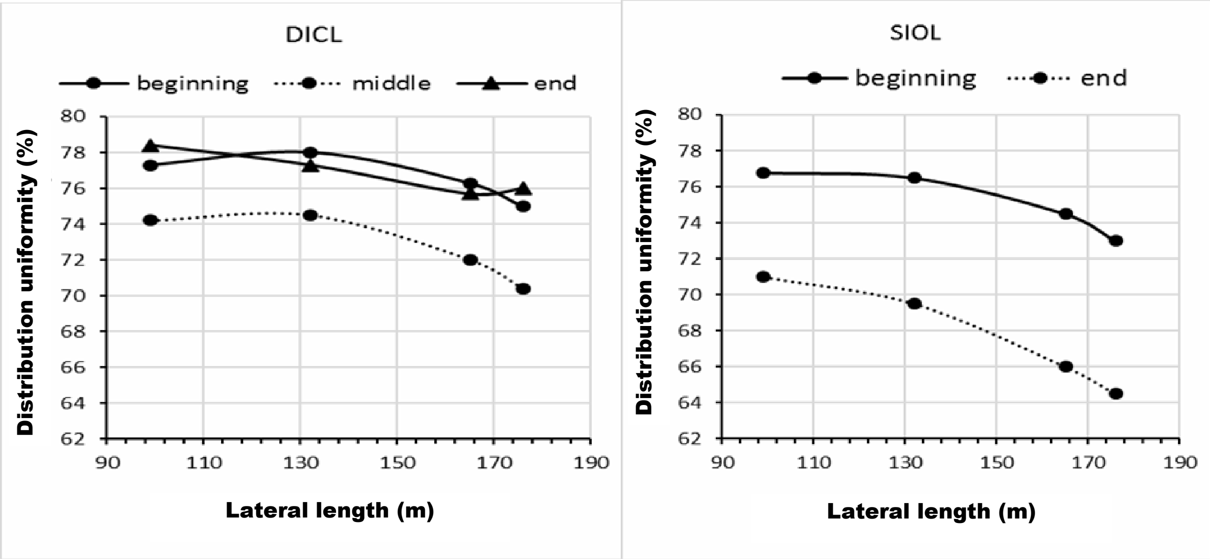

Fig. 3. Effect of lateral length and method of irrigation water inlet to lateral line on distribution uniformity

On the contrary, the results showed that with both DICL and SIOL the CU values decreased with increasing the lateral length, and decreased at the far end of laterals at SIOL more than decreasing at the middle of laterals at DICL. At lateral length of 99 m with DICL, the CU values were 87.7, 85.3 and 86.9% at the beginning, middle and end of lateral, respectively. While with SIOL, the CU values were 86.7 and 82% at the beginning and end of the lateral, respectively. Also at lateral length of 132 m with DICL, the CU values were 86.3, 83.7 and 86.6% at the beginning, middle and end of lateral, respectively. While with SIOL, the CU values were 85.8 and 80.7% at the beginning and end of the lateral, respectively. As to lateral length of 165 m with DICL, the CU values were 85.5, 81.4 and 84.8% at the beginning, middle and end of lateral, respectively. While with SIOL, the CU values were 85 and 78.5% at the beginning and end of the lateral, respectively. Finally, with lateral length of 176 m with DICL, the CU values were 85.1, 79 and 85% at the beginning, middle and end of lateral, respectively. While with SIOL, the CU values were 84.8 and 77.6% at the beginning and end of the lateral, respectively.

Based on obtained results, it is clear that there are parallel trends of CU and DU under all tested lateral lengths and water inlet methods. The highest values of CU and DU were achieved with lateral length of 99 m with DICL. This means that the more improved water distribution uniformity could be achieved under previously mentioned lateral length and inlet method. This result was attributed to the descending in the sprinklers discharge rate resulting from pressure head losses occurred in the middle of DICL and the far end of SIOL.

The pressure head variation

The results in Fig. 5 indicate that generally by increasing the lateral length, tended to increase the pressure head variation h_{var} with both DICL and SIOL. Where the highest value of h_{var} of 26% was achieved at lateral length of 176 m with SIOL, while the lowest value of 8% was obtained at lateral length of 99 m with DICL. It can be seen that increasing the lateral length from 99 to 176 m with DICL and SIOL, increased the h_{var} value from 8 to 22% and from 13.5 to 26%, respectively. Meanwhile the h_{var} value of 18% at lateral length of 165 with DICL was accepted. This result is in agreement with the results stated by **Benami and Offen (1984).**

The Required Power and Specific Energy

The effects of lateral lengths and water inlet methods on values of required power and specific energy are shown in Fig. 6. The obtained results show a remarkable rise in required power with a consequent sharp drop in specific energy as the lateral length increased.

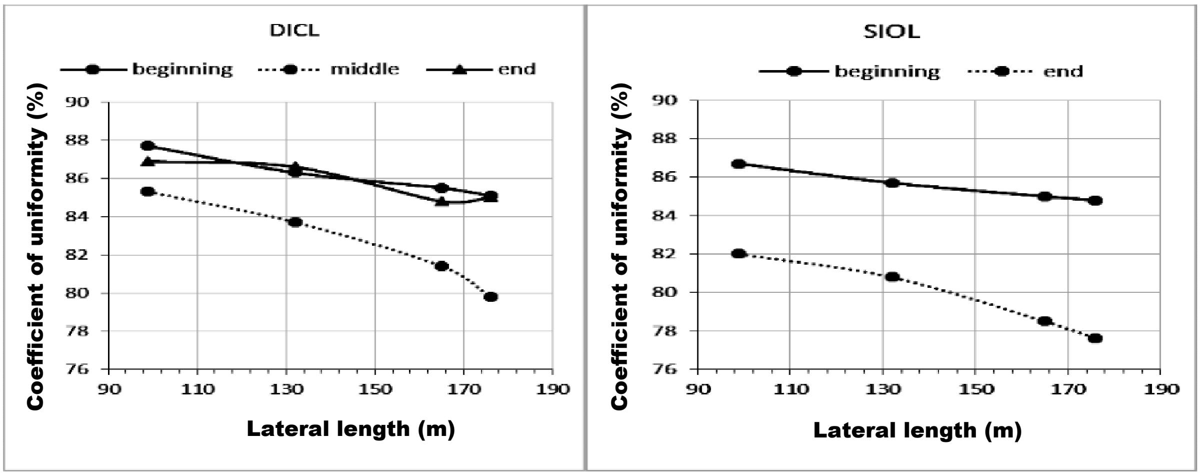

Fig. 4. Effect of lateral length and method of irrigation water inlet to lateral line on coefficient of uniformity

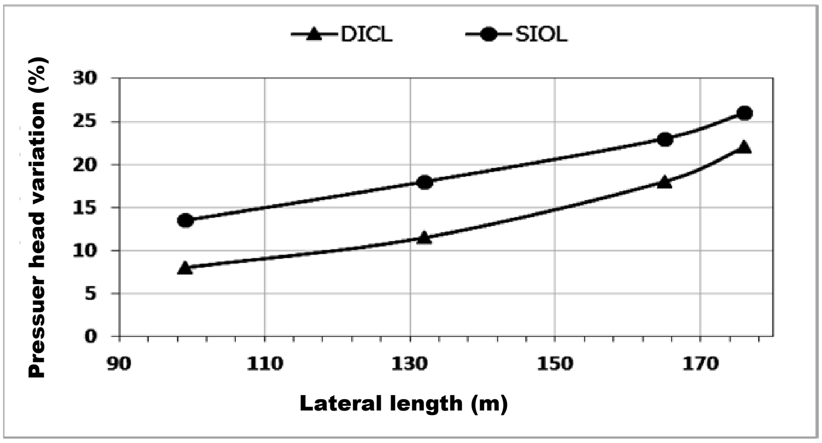

Fig. 5. Effect of lateral length and method of irrigation water inlet to lateral line on pressure head variation

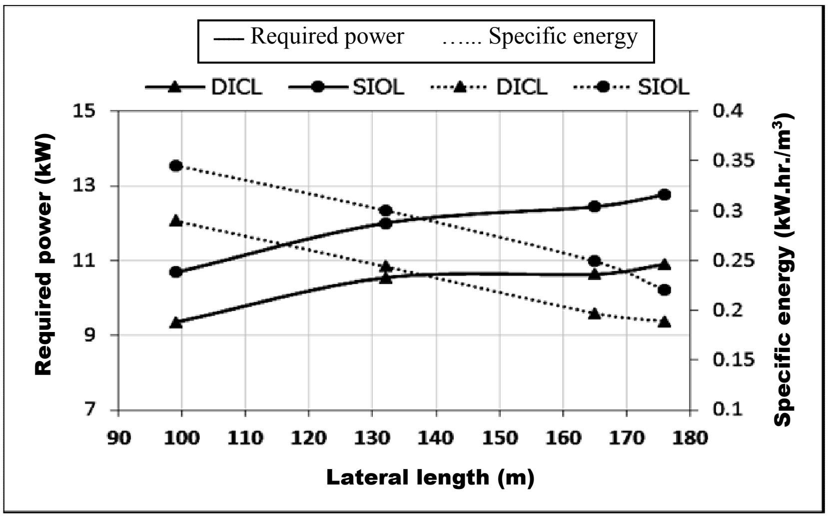

Fig. 6. Effect of lateral length and method of irrigation water inlet to lateral line on required power and specific energy

Results showed that increasing lateral length from 99 to 176 m with DICL and SIOL, increased required power values form 9.35 to 10.9 kW and from 10.68 to 12.76 kW, respectively. While increasing lateral length from 99 to 176 m with DICL and SIOL, leads to decrease specific energy values from 0.29 to 0.189 kW.hr./m^3 and from 0.345 to 0.22 kW.hr./ m^3, respectively.

From this point of view, it was noticed that the highest required power value of 12.89 kW was obtained at lateral length of 176 m and SIOL. Meanwhile the lowest required power value of 9.35 kW was obtained at lateral length of 99 m with DICL.

At the same time, the highest value of specific energy of 0.345 kW.hr./m^3 was noticed at lateral length of 99 m with SIOL. Meanwhile the lowest value of specific energy of 0.185 kW.hr./m^3 was noticed at lateral length of 176 m and DICL. The major reason for increasing required power by increasing lateral length is due to increase electricity consumption as a result of increasing discharge rate. However, major reason for decreasing specific energy is due to increase discharge rate, m^3/hr.

Conclusion

A sprinkler irrigation system was developed and evaluated based on its design criteria to minimize friction loss, pressure head variation, and specific energy and maximize water uniformity distribution.

The experimental results reveal that the distribution uniformity and coefficient of uniformity were higher with inlet method DICL than SIOL with all tested lateral lengths.

The pressure head variation, required power and specific energy were lower with DICL than SIOL with all lateral lengths.

The recommended lateral length was 165 m combined with DICL. This combination achieved acceptable pressure head variation of 18% which not exceeded permitted limit of 20% of required pressure along the lateral and acceptable DU and CU of 72% and 81.4%, respectively.

REFERENCES

Addink, H. and Bytat (1989). Design and operation of farm irrigation systems, ASAE, USA, 31 (3): 821-829.

Amer, K.H. (2006). Water distribution uniformity as affected by sprinkler performance. Misr J. Agric. Eng., 23 (1): 82 - 95.

Badr, A.E. (1992). Water distribution from different sprinkler arrangements and its effect on yield (under fixed sprinkler irrigation system). Misr J. Agric. Eng., 9 (3): 398 - 419.

Benami, L. and A. Offen (1984). Irrigation Engineering. Publications by IESP. Haifa, Occupied Platestine, ISBN, 695 (22) : 92-99.

Christiansen, J.E. (1942). Irrigation by sprinkling. Univ. of Calif. Agric. Exp. Sta. Bul., 670 : 124.

Heermann, D.F., W.W. Wallender and G.M. Bos (1990). Irrigation efficiency and uniformity. (CF Hoffman, GJ, Howell, TA, Solomon, KH (Eds.), Management of Farm Irrigation Systems. ASAE, St. Joseph, MI. 125 - 149).

Hegazi, M., K.H. Amer and H. Moghazy (2007). Sprinkler irrigation systems layout based on water distribution pattern. Misr J. Agric. Eng., 24 (2): 360 - 377.

Keller, J. (1989). Sprinkler and Trickle Irrigation. Utah State University. Utah

Khader, A.F. (2009). Performance evaluation of some new sprinkler types. M. Sc. Thesis, Agric. Eng. Dept., Fac. Agric., Suez Canal Univ., Egypt.

Lockwood, F.B. and R. Dunstan (1971). Electrical engineering principles. Meinemann Educational Books. Ltd. London.

Mahmoud, H.M. (2002). Evaluation of the sprinkler irrigation systems under different operating conditions. M. Sc. Thesis, Agric. Eng. Dept., Fac. Agric., Alex. Univ., Egypt.

Mansour, H.A., H.M. Mehanna, M.E. El-Hagarey and A.S. Hassan (2013). Using Automation Controller System and Simulation Program for Testing Closed Circuits of Mini-Sprinkler

Irrigation System. Open J. Modelling and Simulation, 1: 14-23.

Sourell, H., J.M. Faci, E. Playan and M. Asce (2003). Performance of rotating spray plate sprinklers in indoor experiments. J. Irrigation and Drainage Eng., 129 (5): 376 - 380.

Wu, I.P. and H.M. Gitlin (1982). Drip irrigation lateral line network design. Trans. ASAE, 25 (3): 675-685.

Wu, I.P. and H.M. Gitlin (1983). Sprinkler irrigation for uniformity on slopes. Trans. of the ASAE, 26: 1698 - 1703.

تطــــوير و تقييـــــــم أداء نظـــــــــام ري ضغـطــي

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أجريت هذه الدراسة بهدف تطوير وتقييم نظام للري بالرش كنظام للري الضغطي عن طريق اختبار أربعة أطوال مختلفة للخطوط الجانبية (خطوط الرشاشات) وهي ٩٩، ١٣٢، ١٦٥، ١٧٦م مع طريقتين مختلفين لدخول مياه الري للخطوط الجانبية، الأولي هي الطريقة المغلقة ذات التغذية المزدوجة أي أنه يتم تغذية الخط الجانبي الواحد من إتجاهين عن طريق مشعبين متصلين بالخط الجانبي من بدايته ونهايته، ويكون ذو قطر خارجي واحد ٣٢مم، أما الثانيه فهي الطريقة المفتوحه ذات التغذية الفردية كما في التخطيط العادي حيث يتصل الخط الجانبي من بدايته فقط بالمشعب ويكون ذو قطر خارجي متدرج من ٦٣ إلى ٥٠ إلى ٣٢مم للمحافظة علي سرعة المياه بحيث لا تتعدي ٢م/ث، وتم تقييم هذه المعاملات تحت الدراسة عن طريق مؤشرات إنتظامية توزيع المياه والإختلاف في الضغط وإحتياجات القدرة والطاقة، وكانت النتائج المتحصل عليها كالتالي: بوجه عام لوحظ ارتفاع قيم انتظامية التوزيع ومعامل الإنتظامية مع الطريقة المغلقة ذات التغذية المزدوجة مقارنة بالطريقة المفتوحة ذات التغذية الفردية وذلك مع جميع أطوال الخط الجانبي تحت الدراسة، نسبة الاختلاف في ضغط التشغيل علي طول الخط الجانبي واحتياجات القدرة والطاقة كانت أقل مع الطريقة المغلقة ذات التغذية المزدوجة عنها مع التخطيط العادي عند جميع الأطوال للخط الجانبي تحت الدراسة، أقصى طول مسموح به للخط الجانبي كان ١٦٥م بنسبة انخفاض ضغط ١٨% مع الطريقة المغلقة ذات التغذية المزدوجة حيث أن أقصي نسبة مسموح بها ٢٠% علي طول الخط الجانبي، كما انه عند ذلك الطول كانت قيم احتياجات القدرة والطاقة ١٠,٦٣ كيلووات و٠,١٨٥ كيلووات.ساعة/م^{٣}، على التوالي، ونسب انتظامية التوزيع ومعامل الإنتظامية كانت بقيم مقبولة وهي ٧٢,٤ و ٨١%، على التوالي عند نقطة أقصي إنخفاض للضغط والمسجلة في منتصف الخط.

المحكمـــــون:

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