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Effect of Surge Flow on some Irrigation Indices of Furrow Irrigation System

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ABSTRACT

The objective of this research work is to evaluate the performance of surge and continuous furrow irrigation based on field experiments. The experiment took place on a private farm located in El- Santa district, Gharbeiah Governorate, middle of the Nile Delta, Egypt, cultivated with corn, having a clay-loam textured soil. In this study, two of main design and management variables (unit flow rate, Q_0; and cutoff time, t_{co}) are selected such that the corresponding performance indices (advance time, surface runoff, seasonal irrigation requirements, Q_{req}; application efficiency, E_a; water storage efficiency, E_s; and distribution uniformity (C_U) are measured and discussed. Surge flow with three numbers of surges (i.e. 2, 3 and 4 surges) were compared to continuous flow to opened long furrows of 120 m length without dikes, cultivated with corn (Zea Maize) during growing seasons of 2016 and 2017. Main results cleared out that the water applied during surge treatments advanced faster compared with continuous one. On the average, water saving of 18 to 30% was observed in surge-irrigated furrows under different rates of discharge and on-off cycles. Under surge technique performance indices such as, water needed per each irrigation, seasonal needs of irrigation water, surface run off, application efficiency, storage efficiency and distribution uniformity were enhanced. The surge mode of irrigation is convincingly better compared with continuous irrigation.

Keywords: Furrow irrigation, surge flow, performance indices, application efficiency, water storage efficiency, and distribution uniformity.

INTRODUCTION

Furrow irrigation is the most commonly used irrigation method in the world due to its simplicity of design and low capital investment. Continuous application of water to furrow usually causes excessive deep percolation at the upper part of the furrows, insufficient irrigation at the lower part and considerable runoff, resulting in low application efficiencies and distribution uniformities. Furthermore, excessive flow rates cause erosion for the soil. To improve furrow irrigation performance, several variations of the method have been developed, among them the technique of surge irrigation. Stringham (1988) defined surge irrigation as ‘the intermitted application of irrigation water creating series of on and off moves at constant or variable time spans, this technique became worldwide known after it was extensively applied in USA since the 80’s. Horst *et al*. (2005) reported that, improvement of on-farm irrigation systems and the introduction of low cost water saving irrigation technologies have been identified as key components of reducing agricultural water demand. Ismail (2006) resulted that less runoff loss was observed during the first irrigation than the second for all treatments of surge and continuous flow irrigations. Gillies *et al*. (2007) decided that, it is possible to improve the performance of furrow irrigation system through optimal management practices, such as the selection of correct inflow rates and cut-off times. The most important obstacle against improving furrow irrigation performance is the difficulty in accurately estimating the infiltration function. Saif (2012) resulted that, surge flow had better application efficiency and distribution uniformity comparing with continuous flow, in surge irrigation technique the duration of the rest period was long enough for most of the applied water to infiltrate before the next cycle was started and this had resulted in higher storage efficiency compared to the conventional method. He added that during the second irrigation, surge flow had less pronounced effect. Gudissa and Edossa (2014) evaluated surge (S), cutback (CB) and continuous (C) flow furrow irrigation systems in terms of hydraulic, technical and agronomic performance measures for producing pepper in Loam soil. They recorded that Maximum values of application efficiency, storage efficiency and uniformity coefficient were recorded under surge treatments, whereas the lowest corresponding values were recorded under continuous. Otherwise maximum deep percolation and tail water losses were recorded under cutback and continuous treatments, respectively. Abdel-Moneim *et al*. (2015) showed that, the surge flow resulted in the highest overall efficiencies comparing with continuous flow. Water saving by surge irrigation varied from 23 to 60 % over continuous flow for the first irrigation of a field 149m length. They observed that, surge irrigation at the midpoint of the furrow offered greater opportunity for water intake because it applied water in cycles, a state which resulted in a high amount of water being stored in the root zone, which in turn resulted in high application efficiency. Allam *et al*., (2015) compared surge flow and continuous flow with constant and stepwise increase flow rate. Constant flow rate was 1.56 L/s; stepwise increase flow rate was rise from 0.52 to 1.04 then up to 1.56 L/s. They resulted that, surge flow with constant or variable flow rate conserved irrigation water, decreased advance time to the end of the furrow and increased distribution uniformity comparing with continuous flow. Kifle *et al*.(2017) evaluated the effect of surge flow and alternate irrigation on irrigation performance indicators, the results indicated that higher application efficiency and distribution uniformity were obtained from both surge flow and alternate irrigation as compared to continuous flow. The runoff losses in continuous flow were higher than that of surge and alternate flow at the same flow rate. They recommended that these irrigation methods (surge and alternate) can enhance the poor water management practices in the world with limited water resources. Mattar *et al*. (2017) compared continuous and surge irrigations under different levels of flow rate and tillage depth for assessing their potential in improving irrigation system performance and wheat production. They found that water saving of 8 to 34% in surge-irrigated plots under different levels of flow rate and tillage depth. They found also that, for different parameters like volume of water, distribution uniformity, application efficiency, deep percolation losses and yield of wheat, the surge mode of irrigation is convincingly better compared with conventional/ continuous irrigation even under the border irrigation.

This field study was conducted on a corn (Zea Maize) field during the growing seasons of 2016 and 2017.

The main objective is to assess how far the intermittent irrigation could be followed to improve furrow irrigation performance.

MATERIALS AND METHODS

1 Site description

This study was carried out in a private farm located in El- Santa district, Gharbeiah Governorate, middle of the Nile Delta, Egypt. The field study on surge flow irrigation was conducted on a corn (Zea Maize) field during two growing summer seasons 2016 and 2017. The soil at the experimental site was characterized as a clay-loam, cultivated with traditional crops; the conventional applied irrigation method is flood irrigation. The main soil physical characteristics are indicated in Table (1)

Table 1. Main soil physical characteristics of experimental soil

Depth (cm)	Bulk density (g/cm^3)	Porosity (%)	Field capacity (mm)	Wilting point (mm)	Available soil water (mm)
0-15	1.24	52.3	83.8	42.5	41.3
15- 30	1.47	42.5	65.0	33.0	32.0
30- 60	1.49	44.5	51.7	26. 6	25.1

The net area of the experiment was about 6050m2. Due to lack of gated pipes to deliver the water to the furrows, surge flow was not automated but adapted to the existing conditions; where water is supplied to the furrows using calibrated plastic siphons have internal diameter of 2 inches (≈ 5.0 cm). The water was supplied through lined ditch and the effective hydraulic head was saved constant by an arm - float constructed at the end of the ditch. The furrow spacing is 0.70 m, the furrow length is 120 m, without dikes and the furrow slope is ≈ 0.1%.

2 Treatments

In this study, Surge flow with three number of surges (with cycle ratio of ½); two surges (S2), three surges (S3) and four surges (S4) and two values of flow rates (Q1 = 0.37 L/s and Q2 = 0.74 L/s) were compared to continuous flow (C) to opened long furrows of 120 m length; the experimental field layout and study treatments distribution are shown in Fig.1.

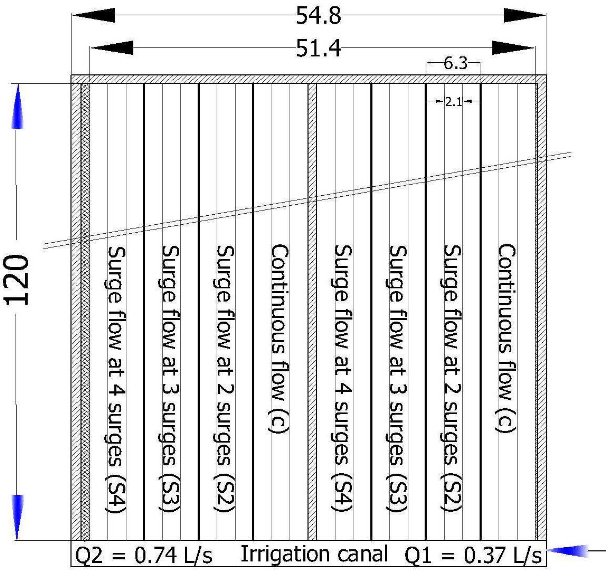


Fig. 1. The experimental field layout and study treatments distribution.

3 Field data measurements:

Advance time

Furrow length was divided into 12 equal stations by 10 m distance between each two Successive stations. Advance time at every station and total irrigation water at end of the furrow were recorded.

Applied water

Flow rate for each irrigation event was measured by volumetric method according to James (1988).

Surface Runoff

For each irrigation event, the outflow (Tail water or Surface Runoff) were measured by volumetric method according to James (1988).

Soil water content

Soil water content measurements were performed directly before and two days after irrigation. The methodology applied is referred by Horst *et al*. (2005).

Application efficiency

Water application efficiency (E_a,%) was estimated according to (James 1988).

$$E_a = \frac{Z_{avg}}{D} \times 100 \qquad \text{............... (1)}$$

Where:

Z_{avg} = the average depth of water stored in the root zone and
D = the average depth of applied water.

Storage efficiency

Storage efficiency (E_s,%) was estimated according to (James 1988).

$$E_s = \frac{Z_{avg}}{Z_{req}} \times 100 \qquad \text{............. (2)}$$

Where:

Z_{req} = the average depth required to fill the root zone.

Water application uniformity

Christiansen uniformity coefficient (C_u) was applied to estimate the uniformity distribution according to (James 1988).

$$C_u = 100\left(1.0 - \frac{\sum|x_i - x^-|}{nx^-}\right) \qquad \text{......... (3)}$$

Where:

x_i = volume caught at observation point i,
x^- = average volume amount caught, and
n = number of observations.

Statistical analysis

Experimental design was split plot design "flow rate in main plot and number of surges in sub plot" statistical analysis was carried out by CoStat program for windows.

RESULTS AND DISCUSSION

Effect of surge flow and stream flow rate on:

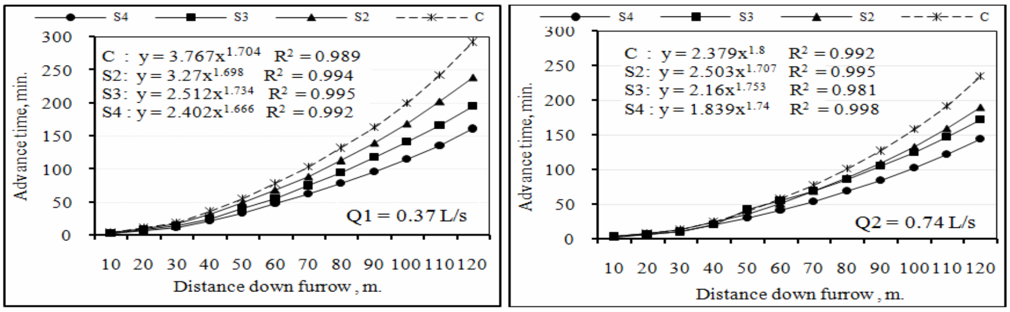
1 Advance time

The advance time was recorded at twelve stations along the furrow for each irrigation along the season. The average of advance time in relation to distance under surge flow at different number of surges and continuous flow for two growing seasons were shown in Fig 2. Data revealed that, for all irrigations surge flow had shorter advance time than continuous flow, under surge flow increasing number of surges from 2 to 4 surges decreased advance time. This may be due to less infiltration rate which happened by surge flow. Increasing flow rate from 0.37 to 0.74 L/s decreased advance time either under continuous or surge flow irrigations.

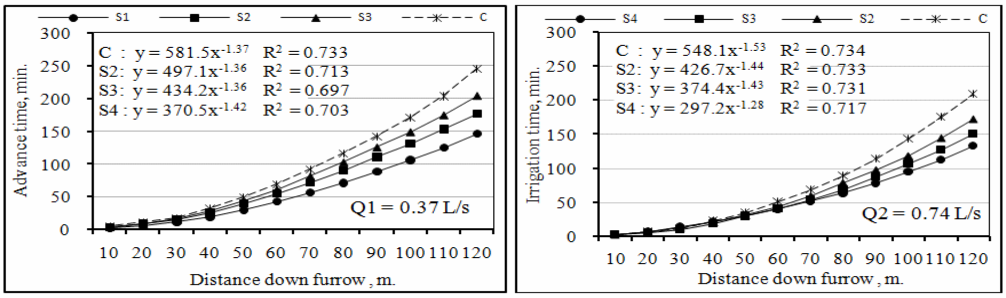
For first irrigation (at planting), the lowest advance time was 161 and 144 min under flow rates 0.37and 0.74 L/s respectively which obtained by S4 while the highest advance time was 292 and 235 min under 0.37and 0.47 L/s flow rates respectively which obtained by C. The results showed that S4 decreased advance time by 17.44, 32.63 and 44.86% compared with S3, S2 and C respectively under flow rate 0.37 L/s and by 16.28, 24.21 and 38.72% under flow rate 0.74 L/s. Increasing flow rate from 0.37 to 0.74 L/s shorted advance time by 10.56 and 19.52% for S4 and C respectively.

For second irrigation S4 decreased advance time comparing with C by 40.6 and 36.28% under flow rates 0.37 and 0.74 L/s respectively. Comparing advance time for first and second irrigations, it can be observed that, first irrigation had advance time higher than second irrigation. This may be understood as, in first irrigation, the soil surface was still disturbed, semi rough, high airy dry, had high matric potential and high water holding capacity. This led to less speed of water advance by 11.03, 19.18% under flow rate 0.37 L/s and 8.27, 13.00% under flow rate 0.74 L/s for S4 and C, respectively. Increasing flow rate from 0.37 to 0.74 L/s decreased advance time by 8.85 and 14.04% for S4 and C, respectively.

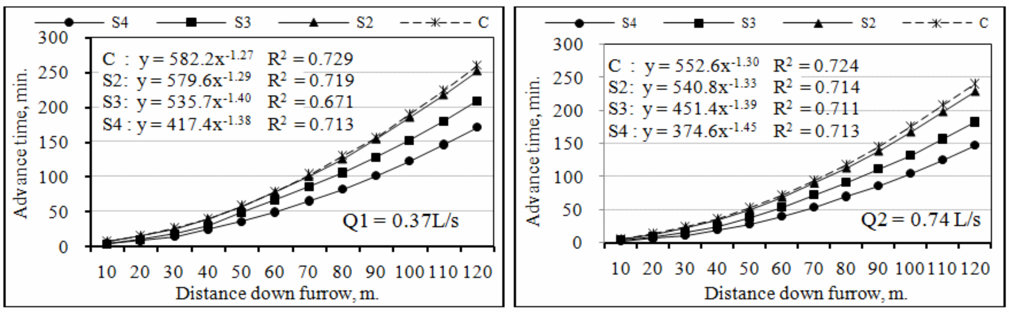
For mean of third and fourth irrigation, advance time for S4 decreased by 34.19 and 38.68% compared with C under two flow rates 0.37and 0.74 L/s respectively. The advance time for mean of third and fourth irrigation increased compared with second irrigation, this may be attributed to weeds growing and root distribution. Increasing flow rate from 0.37 to 0.74 L/s decreased advance time by 14.00 and 7.71% for S4 and C respectively.



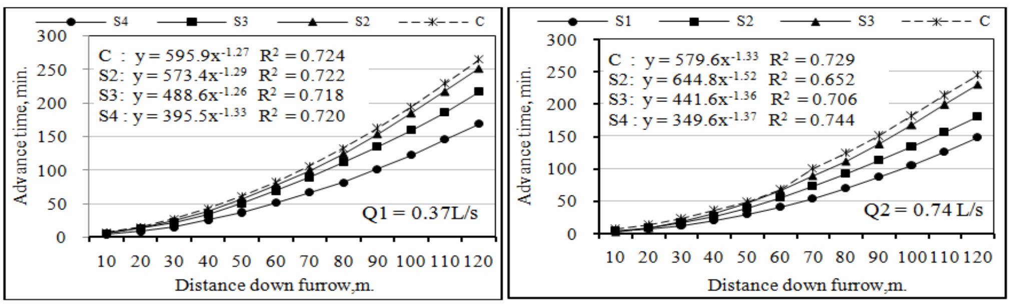
A: First irrigation (at planting)



B: Second irrigation



C: Mean of third and fourth irrigations



D: Mean of fifth and last irrigations

Fig. 2. Effect of surge flow and flow rate on irrigation advance time.

For mean of fifth and last irrigation, advance time for S4 decreased by 36.20 and 39.57% compared with C under flow rates 0.37and 0.74 L/s respectively. The results revealed that there is no difference in advance time between the mean of third & fourth and the mean of fifth & last irrigations; increasing flow rate from 0.37 to 0.74 L/s decreased advance time by 12.40 and 7.53% for S4 and C, respectively. The results showed that advance time is highly positive correlated with irrigation order where this correlation was higher for first irrigation compared with next irrigations where correlation coefficient value (R2) for first irrigation ranged from 0.981 to 0.995 while for next irrigation correlation coefficient value (R2) ranged from 0.652 to 0.744.These results may be interpreted as surge application causes a thin surface crust of fine clay and silt which reduces infiltration rate, this may be cause less water vertical penetration and encourage water to advance faster. These results are compromised with that found by Mattar *et al.* (2017).

2 Seasonal applied water

The average of seasonal applied water (m^3/fed.) in relation to flow rate under continuous and surge flow application with different number of surges for two growing seasons are shown in Fig 3. The obtained results indicated that, Flow rate, number of surges and their interaction were found to be statistically significantly affecting the total applied water. Surge flow led to less amount of applied water compared with continuous flow, where advance time decreased. Under surge flow, increasing number of surges from 2 to 4 surges led to less applied water. These results may be interpreted as surge application causes a thin surface crust of fine clay and silt which reduces infiltration rate. Increasing flow rate from 0.37 to 0.74 L/s decreased seasonal applied water under continuous and surge flow irrigations. Surge flow with 2 surges reduced seasonal applied water comparing with continuous flow by 14.7 and 7.5% for flow rates 0.37 and 0.74 L/s respectively. Increasing number of surges from 2 to 3 surges resulted in less seasonal applied water by 6.3 and 4.3% for flow rates 0.37 and 0.74 L/s respectively, Increasing number of surges from 3 to 4 surges reduced seasonal applied water by 1.9 and 5.1% for flow rates 0.37 and 0.74 L/s respectively. S4 treatments saved 21.5 and 16.0% of seasonal applied water for flow rates 0.37 and 0.74 L/s respectively comparing with continuous flow C. The lowest seasonal applied water was 3030 m^3/fed. obtained at S4Q2 treatment, while the highest seasonal applied water was 4300 m^3/fed. obtained at CQ1 treatment.

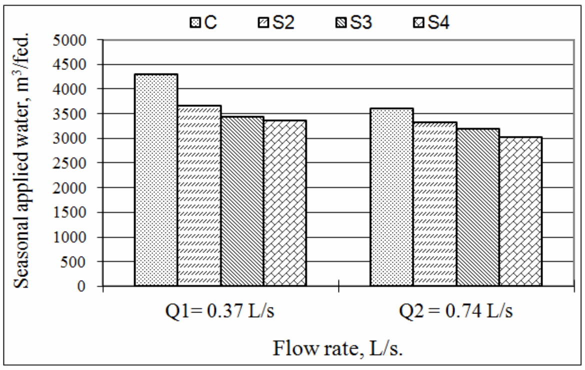


Fig. 3. Effect of surge flow and flow rate on seasonal applied water.

3 Surface Runoff losses

Surface runoff or tail water loss at the exit of middle furrow of each treatment was measured for all irrigations. The average of seasonal surface runoff losses in relation to flow rate at continuous and surge flow irrigation with different number of surges for two growing seasons were shown in Fig 4. The results indicated that, flow rate, number of surges and their interaction were found to be statistically significantly affecting the Surface Runoff losses. Surge flow decreased surface runoff losses comparing with continuous flow. Under surge flow increasing number of surges from 2 to 4 surges decreased surface runoff losses. These results are due to reduce seasonal applied water which happened by surge flow. Increasing flow rate from 0.37 to 0.74 L/s decreased runoff under continuous and surge flow irrigations. S2 treatments reduced surface runoff losses comparing with continuous flow by 21.0 and 18.4% for flow rates 0.37 and 0.74 L/s respectively. Increasing number of surges from 2 to 3 surges reduced surface runoff by 16.7 and 25.4% for flow rates 0.37 and 0.74 L/s respectively, increasing number of surges from 3 to 4 surges reduced surface runoff losses by 29.2 and 30.2% for flow rates 2.7 and 5.4 L/s respectively. S4 treatments reduced surface runoff losses by 53.4 and 57.5% for flow rates 0.37 and 0.74 L/s respectively comparing with C treatments. The lowest run off losses was 621.6 m3/fed. obtained at S4Q2 treatment, while the highest surface runoff losses was 1659 m3/fed. obtained at CQ1 treatment. The conducted results are in agreement with that found by Kifle *et al.*(2017), also the results are in harmony with that of Ismail (2006).

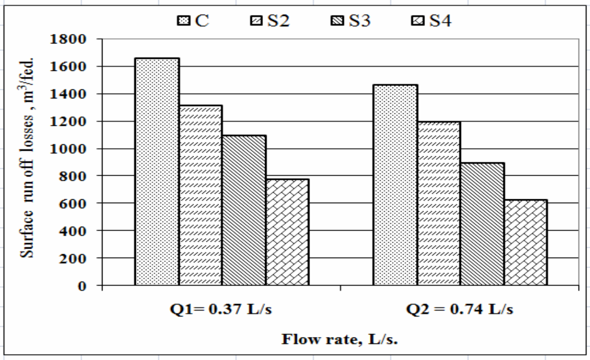


Fig. 4. Effect of surge flow and flow rate on surface runoff losses.

4 Stored water

Furrow length was divided to four quarters (stations), stored water was evaluated for every station. An average of stored water along the furrow in relation to flow rate at continuous and surge flow irrigation with its different number of surges for two growing seasons were shown in Fig 5. The results showed that stored water was affected by flow rate and number of surges, it increased in head furrow and decreased along the furrow in direction of furrow end for all treatments. Increasing flow rate from 0.37 to 0.74 L/s decreased stored water along the furrow for all treatments. Continuous flow recorded highest stored water in head furrow and the lowest in tail furrow comparing with surge flow. Under surge flow, increasing number of surge from 2 to 4 surges decreased stored water in head furrow and increased it in tail furrow, thus the variance in stored water between head and tail furrow decreased. The highest difference in stored water between head and tail water was obtained at CQ1 treatment, while the lowest one was obtained at S4Q2 treatment. These results may be due to soil consolidation and surface sealing which happened by surge flow.

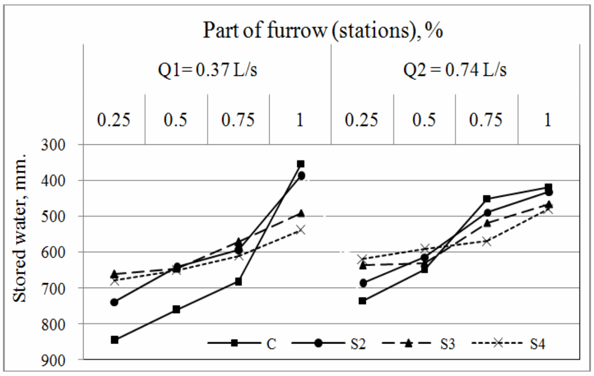


Fig. 5. Effect of surge flow and flow rate on stored water.

5 Application efficiency

An average of application efficiency "Ea %" in relation to flow rates at continuous and surge flow irrigation with its different number of surges for two growing seasons were shown in Fig 6. The results indicated that, flow rate, number of surges and their interaction were found to be statistically significantly affecting the application efficiency. Surge flow increased application efficiency comparing with continuous flow. Under surge flow increasing number of surges from 2 to 4 surges increased application efficiency. These results are due to reduce seasonal applied water by surge flow. Increasing flow rate from 0.37 to 0.74 L/s increased application efficiency under continuous and surge flow irrigations, where seasonal applied water decreased under flow rate 0.74 L/s comparing with flow rate 0.37 L/s. S2 treatments increased application efficiency by 4.73 and 6.33% for flow rates 0.37 and 0.74 L/s respectively comparing C treatments. Increasing number of surges from 2 to 3 surges increased application efficiency by 7.14 and 6.00% for flow rates 0.37 and 0.47 L/s respectively. Increasing number of surges from 3 to 4 surges increased application efficiency by 6.49 and 5.60% for flow rates 0.37 and 0.47 L/s respectively. S4 treatments increased application efficiency by 19.49 and 19.03% for flow rates 0.37 and 0.74 L/s respectively comparing with C treatments. The highest application efficiency was 78.2% obtained at S4Q2 treatment, while the lowest application efficiency was 64.5% obtained at CQ1 treatment. These results are in harmony with that found by Abdel-Moneim *et al*. (2015).

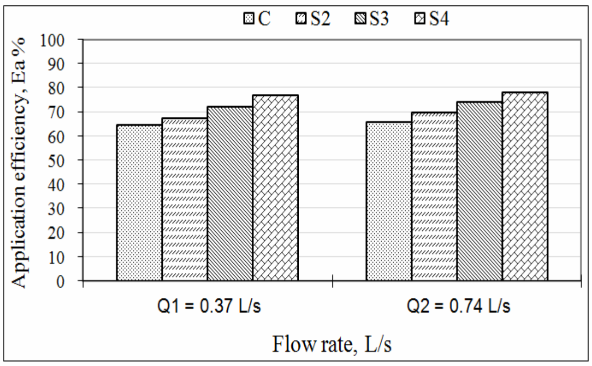


Fig. 6. Effect of surge flow and flow rate on application efficiency.

6 Storage efficiency

An average of storage efficiency, "Es %" in relation to stream flow rate at continuous and surge flow irrigation with its different number of surges for two growing seasons were shown in Fig 7. The results indicated that, flow rate, number of surges and their interaction were found to be statistically significantly affecting the storage efficiency. Surge flow increased storage efficiency comparing with continuous flow. Under surge flow increasing number of surges from 2 to 4 surges increased storage efficiency, where stored water increased. Increasing flow rate from 0.37 to 0.74 L/s increased storage efficiency under continuous and surge flow irrigations. S2 treatments increased storage efficiency by 8.43 and 9.70% for flow rates 0.37 and 5.4 L/s respectively comparing with C treatments. Increasing number of surges from 2 to 3 surges increased storage efficiency by 7.04 and 6.25% for flow rates 0.37 and 0.74 L/s respectively, Increasing number of surges from 3 to 4 surges increased storage efficiency by 6.08 and 4.02% for flow rates 2.7 and 5.4 L/s respectively. S4 treatments increased storage efficiency by 23.12 and 21.22% for flow rates 2.7 and 5.4 L/s respectively comparing with C treatments. The highest storage efficiency was 77.7% obtained at S4Q2 treatment, while the lowest storage efficiency was 62.9% obtained at CQ1 treatment. These results are agreed with results of Saif (2012).

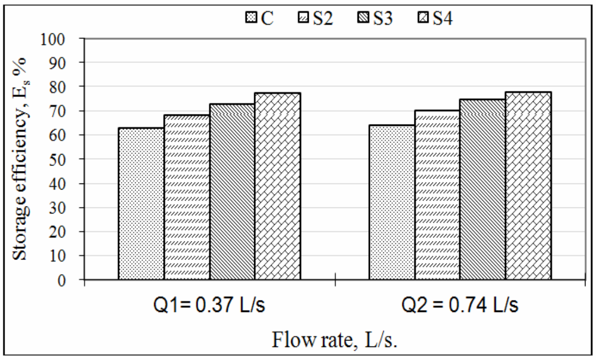


Fig. 7. Effect of surge flow and stream flow rate on storage efficiency.

7 Application uniformity

Application uniformity was expressed by Christiansen uniformity coefficient "Cu". An average of Cu in relation to flow rate at continuous and surge flow irrigation with its different number of surges for two growing seasons were shown in Fig 8. The results showed that, flow rate, number of surges and their interaction were found to be statistically significantly affecting the application uniformity. Surge flow increased application uniformity comparing with continuous flow, under surge flow increasing number of surges from 2 to 4 surges increased application uniformity. Increasing flow rate from 0.37 to 0.74 L/s increased application uniformity for C and S2 treatments and decreased for S3 and S4 treatments. S2 increased application uniformity by 7.69 and 7.21% for flow rates 0.37 and 0.74 L/s respectively comparing with C. Under surge flow increasing number of surges from 2 to 3 surges increased application uniformity by 8.36 and 5.50% for flow rates 0.37 and 0.74 L/s respectively, increasing number of surges from 3 to 4 surges increased application uniformity by 3.39 and 5.74% for flow rates 0.37 and 0.74 L/s respectively. Increasing flow rate from

0.37 to 0.74 L/s increased application uniformity by 0.56 and 0.11% for C and S2 respectively and decreased by 2.53 and 0.31% for S3 and S4 respectively. The highest value of application uniformity were 92.74 which obtained by S4Q1 treatment, while the lowest value were 76.87 which obtained by CQ1 treatment. From the results it could be concluded that increasing number of surges enhanced application uniformity where the difference in stored water along irrigation furrow decreased.

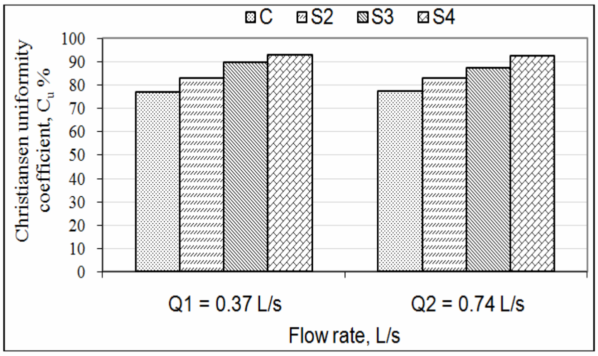


Fig. 8. Effect of surge flow and flow rate on water application uniformity.

CONCLUSION

Generally, surge flow advanced faster than the respective continuous flow. From the respective surge flow treatments, surge flow treatment performed better in reaching the tail end of the furrow with advance time less compared with the respective continuous flow. Surge and continuous flow treatments with similar flow rate went parallel in the first quarter of the furrow length; however, later on the surge treatments reach early to the tail end of the furrows. Flow rate, number of surges and their interaction were found to be statistically significantly affecting the application efficiency, storage efficiency, tail water runoff loss. The interaction effects of flow rate and cycle ratio were statistically significant in affecting seasonal irrigation requirements; application efficiency, Ea; water storage efficiency, Es; and water application uniformity, Cu. Surge flow irrigation was found to perform better than continuous flow irrigation in terms of water saving. It can be applied by farmers in areas where irrigation water is limiting.

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تأثير السريان النبضي على بعض مؤشرات الري لنظام الري بالخطوط

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أجريت دراسة حقلية بناحية مركز السنطة – محافظة الغربية – وسط الدلتا – مصر خلال موسمي صيف 2016 و 2017م لتقييم مدى إمكانية استخدام أسلوب الري النبضي لتحسين بعض مؤشرات الري لنظام الري بالخطوط حيث تم اجراء التجربة على خطوط مفتوحة بطول 120م منزرعة بمحصول الذرة بدون بتون.وقد أختير عاملان من عوامل تصميم الري النبضي وهما معدل السريان حيث طبق معدلان للسريان هما 0.37 ل/ث ، 0.74 ل/ث وعدد النبضات اللازمة لإتمام عملية الرى حيث أضيفت مياه الرى باتباع أربعة أساليب هى الإضافة المستمرة دون توقف حتى تمام الإضافة ،الإضافة من خلال نبضتين ، ثلاث نبضات ، أربع نبضات وقورنت بعض مؤشرات الرى تحت الأسلوبين (المستمر والمتقطع) ، حيث تم تقييم تأثير عوامل الدراسة على بعض مؤشرات الري وهي زمن التقدم ، كمية ماء الري المضافة ، الجريان السطحى ، الماء المخزن في منطقة الجذور ، كفاءة إضافة المياة ، كفاءة تخزين المياه ، انتظامية التوزيع على طول الخط. أشارت أهم النتائج المتحصل عليها الى ان معدل تقدم الماء داخل الخطوط كان اسرع عند اتباع أسلوب السريان النبضي مقارنا بالسريان المستمر . حدث توفير في كمية مياء الري المضافة بفعل السريان النبضي بنسبة تراوحت ما بين 18 و 30% مقارنة بالسريان المستمر لمعدلات السريان المختلفة. أظهرالسريان النبضى تحسنا ملحوظاً في مؤشرات الآداء المختلفة مثل كمية الماء اللازم لكل رية ، كمية ماء الري الكلية المضافة خلال الموسم ، الجريان السطحي ، كفاءة إضافة المياة ، كفاءة تخزين المياه ، انتظامية التوزيع ، بالتالي فإن السريان النبضي يعتبر تقنية أفضل للري مقارنة بالسريان المستمر.