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Effect of changing the cycle ratio on the performance of surge flow under the furrow irrigation system

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ABSTRACT

Aim: The aim of the study was to assess the hydraulic performance for surge flow by measuring the advance time, inflow/outflow rates, application efficiency, distribution uniformity and storage efficiency.

Materials and Methods: Three flow rates (2.7,2 and 1.5 l/s) and three furrow lengths (160,140 and 120 m) were used with three cycle ratios for surge flow (0.33,0.5 and 0.75).

Results: The higher application efficiency (78.47%) was obtained at cycle ratio 0.75 and furrow length 120 m with a 2.7 L/S flow rate. Water losses in this study by surface runoff were more pronounced in cycle ratio 0.33. While the highest distribution uniformity (82.07%) was obtained at cycle ratio 0.75 and furrow length 140 m were 1.5 l/s. The highest storage efficiency obtained at cycle ratio 0.75 and furrow length 160 m with a 2 L/S flow rate.

Conclusion: It was concluded that it is possible to adopt a furrow length of 120 m and cycle ratio of 0.75 with a flow rate of 2.7 l/s in clay soil conditions.

Keywords: Furrow irrigation, Surge flow, Cycle ratio, Advance time and Application efficiency

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Introduction

Surge irrigation is the intermittent application of water to furrows or borders in a series of on off time intervals, which vary from a few minutes to hours. Surging benefits reported on furrows can include faster water advance, increased infiltration uniformity, a reduction in the total volume of water required for an irrigation and less total irrigation time (Sajid et al., 2003).

The main objective of surge flow irrigation is to improve the application efficiency by reducing deep percolation and runoff losses and to obtain a uniform wetting of the root zone, with minor differences in the infiltration depth at the beginning and the end of a furrow. The combined effects of the reduced infiltration during the advance phase plus the more rapid advance with surge flow, lead to a more uniform distribution of water along the furrow. In some soils, the same quantity of water normally required to reach the end of one furrow can be spread out over two furrows with surge flow (Saleh et al., 2006).

There have been two approaches to conducting surge flow experiments. The first approach was to use different instantaneous streams with different cycle ratios to give an equal quantity of water applied to each furrow over a given cycle time. The second approach was to use a constant stream with different cycle times and constant cycle ratios to give a time average stream equal to the continuous flow. The second approach eliminates the effects of using variable instantaneous flow rates on the advance rate. Bishop et al. (1981) conducted field tests to study the effect of cycling furrow inflows on advance rates. They reported that the effects of surge flow irrigation were most apparent during the first irrigation. In the second irrigation the advantages of surge flow were substantially reduced. The difference between the continuous and surge flow treatments was significant and the differences among the surge flow treatments were not. In the second irrigation when infiltration differences were less noticeable in the field or when wheel furrows compaction reduces these differences mechanically, the advance under surge flow was much closer to the advance under continuous flow. Walker et al. (1982)

developed a flowing infiltrometer that measures furrow intake under conditions representative of actual field conditions. The extended Kostiakov equation was used to fit the field measurements. These investigators noticed a significant reduction in the opportunity time exponent and uncertain reduction in the basic intake rate. The number of tests run was too small to determine the specific differences between surged and continuous watering's. The effect of soil type on infiltration in surge flow was dependent on the stability of soil aggregates. When water contacts the soil for the first time in a furrow, the infiltration rate is high. As the water flow continues the infiltration rate at a certain point in the furrow is reduced to a near constant rate. If the water is shut off and allowed to infiltrate, the surface soil particles consolidate and form a seal in the furrow. When the water is reintroduced to the furrow, the intake rate can be reduced due to this sealing resulting in more water movement down the furrow and infiltration into the soil (Yonts et al., 1995).

Abd El-Motaleb (2006) stated that development of perforated pipes to improve surface irrigation performance. The results showed that the highest water application efficiency (87.47 %) and the water distribution uniformity (86.46 %) for furrow have 94 m length, and 0.70 m width with 0.83 l/s.

Jehangir et al (2006) reported that generally, the advance rates of surge and continuous flows were indifferent up to 30 meters from the stream end and the differences became apparent with increase in the distance, therefore, maximum benefits of surged flow can be realized in longer field.

Materials and Methods

The Experimental was conducted at Faculty of Agricultural Technology and Fish Sciences, Al Neelain University in Khartoum state (15°23′N, 32°54′E; altitude: 384m). A semi-desert /arid climate prevails in this area, with warm winters and hot and dry summers. The average temperature is 29.9 °C and the average annual rainfall is 121 mm. Relative humidity is about 26% in the winter months and decreases to 16% during the summer. An experimental area 3360 m2 (160 x 21 m) was selected. Land preparation was made using a chisel plow, leveling was conducted with a scraper and furrows were made by a ditcher. The experimental area was divided into three plots with three replications (irrigation frequency) of each plot; each plot was 7 m wide and 160 m long. Each plot was used for a specific treatment. The area of each plot was 1120 m2. Each treatment involved five furrows; three middle furrows for monitoring irrigation events and the other two furrows as buffer. In this experiment, three treatments were used (three cycle ratios of the surge flow) with three flows (2.7,2 and 1.5 l/s) for three lengths of furrow (160,140 and 120 m) with 1.4 m spacing for analyzing the potential of reducing tail water and deep percolation losses. The treatment of include three inflow rates of 2.7 l/s (Q1), 2 l/s (Q2) and 1.5 l/s (Q3) and three surge flow cycle ratios of 0.33 (CR1), 0.50 (CR2) and 0.75 (CR3). Used factorial completely randomized design with three factors. The measurements experiential include inflow/outflow rate, advance time; furrow geometry; cut-off time, surface storage and water depth and top width data were collected from the middle adjacent furrows (Walker, and Skogerboe, 1987). Each soil sample was collected randomly from the field and replicated three times at 30 cm incremental depth to 90 cm depth to determine physical properties. The soil mechanical composition was determined by the hydrometric method and the USDA Soil Triangle was used to classify the soil based on the proportions of sand (41.15%), silt (8.07%) and clay (50.78%) as clay. The soil bulk density (g/cm^3) was determined by the methodology suggested by Walker (1989). The data for advance time was determined by stop watch at ten stations on along the furrows and cross section area was determined before and after irrigation run by a profile-meter at three sites located at the start, the center and the end of the field (Walker, 1989).

Hydraulic of surge flow

Net irrigation requirement: The net irrigation requirement is amount of irrigation water required to bring the soil moisture content level in the effective root zone to field capacity excluding precipitation, carry-over soil moisture or ground water contribution or any other gain in soil moisture, which is required to bring the soil moisture in the effective root zone to its filed capacity after 24 hours of irrigation. The following formula was used to determine the net irrigation requirement by Mathew (2004)

$$d_n = \left(\frac{FC - WP}{100}\right) \times A_s \times D \times ASMD \qquad (1)$$

Where; dn = net depth of water to be applied in one irrigation (mm), FC = field capacity by weight, % WP = permanent wilting point by weight, %, As = bulk density of soil, g/cm^3 ,D = effective root zone depth, cm and ASMD = allowable soil moisture depletion %.

$$T_n = \frac{W \times L \times d_n}{600Q} \text{.............................. (2)}$$

in which: W = Furrow spacing, cm L= Length of furrow, m d_n = Depth of irrigation, cm Q = Inflow discharge, l/s.

The duration of on-time for surge cycles was determined by using the following relationships, The Cycle time of a single surge is given by

$$T_c = T_{on} + T_{off} \quad \text{.................................... (3)}$$

in which: T_c = Surge cycle time, min T_{on} = Surge ON time, min T_{off} = Surge OFF time, min

Surge ON time

$$T_{on} = T_n/N \quad \text{........................ (4)}$$

in which: T_n = Net time of irrigation, min and N= Number of surge cycles.

The cycle ratio defined R_c=T_{on}/T_c can be expressed as:

$$R_c = \frac{T_{on}}{T_{on}+T_{off}} \text{.................................... (5)}$$

From Eq (5),T_{off} can be defined as a function of T_{on} and R_c.

$$T_{off} = T_{on}\frac{1-R_c}{R_c} \text{....................... (6)}$$

The gross time irrigation is given by

$$T_g = (n-1)T_c + T_{on} \quad \text{.............................. (7)}$$

Using Eq (7) for Tg can also be written as:

$$T_g = nT_{on} + (n-1)T_{off} = n(T_{on} + T_{off}) - T_{off} = nT_c - T_{off} \text{..................... (8).}$$

Knowing gross irrigation time, the on time and off time is calculated as follows

$$T_g = (n-1)\frac{T_{on}}{R_c} + T_{on} \text{.......................... (9)}$$

$$T_{on} = \frac{R_c T_g}{R_c+(n-1)} \text{................................(10)}$$

$$T_{off} = T_{on}\frac{1-R_c}{R_c} = \frac{R_c T_g}{R_c+n-1}\frac{1-R_c}{R_c} = \frac{T_g}{R_c+n-1} \text{......... (11)}$$

Results and Discussion

Advance time: The mean advance time of during three irrigation successive for different cycle ratios, flow rates and furrow lengths were shown (Fig. 1-9). The mean values for advance time to the end of the furrow for cycle ratio 0.33 were 59.2,67.9 and 76.4 min for flow rate 2.7, 2 and 1.5 l/s, respectively under 120 m furrow length. The mean values for advance time to the end of the furrow for cycle ratio 0.50 were 61.1, 70.9 and 77.9 min for flow rate 2.7, 2 and 1.5 l/s, respectively under 120 m furrow length. The mean values for advance time to the end of the furrow for cycle ratio 0.75 were 63.8, 73.1 and 78.1 min for flow rate 2.7, 2 and 1.5 l/s, respectively under 120 m furrow length. Similarly, the mean values for advance time to the end of the furrow for cycle ratio 0.33 under furrow length 140 m were 77.1, 86.1 and 94.4 min for flow rate 2.7, 2 and 1.5 l/s, respectively. For cycle ratio 0.50 were 76.7, 89.6 and 98.4 min for flow rate 2.7, 2 and 1.5 l/s, respectively. While for cycle ratio 0.75 were 79.9, 90.4 and 100.4 min for flow rate 2.7, 2 and 1.5 l/s, respectively. For furrow length 160 m the mean values for advance time to the end of the furrow for cycle ratio 0.33 were 85.8, 94.5 and 111.8 min for 2.7,2 and 2 l/s flow rate, respectively. For advance time to the end of the furrow for cycle ratio 0.50 were 89, 96.5 and 114.7 min for 2.7,2 and 2 l/s flow rates, respectively. For advance time to the end of the furrow for cycle ratio 0.75 were 90.6, 98.7 and 117.6 min for 2.7,2 and 2 l/s flow rate, respectively. Generally, the cycle ratio 0.33 had a faster advance rate than compared with the cycle ratio 0.50 and 0.75. These findings are in accordance with those obtained by EL-Sayed (2019).

Application efficiency: The results of the statistical analysis of application efficiency are shown in Table.1. It was noted that among the results of the effect of flow rate on application efficiency was the mean values of application efficiency were 60.11, 59.29 and 61.75 % for flow rates of 1.5, 2 and 2.7 l/s respectively. Except for the flow rate of 2 l/s, the results showed an increasing trend with increasing flow rates. The effect of furrow length on application efficiency where the mean values of application efficiency were 63.17, 60.55 and 57.43% for furrow length of 120, 140 and 160m, respectively. The results showed a decreasing trend with increasing furrow length. The effect of the cycle ratio on application efficiency where the mean values of application efficiency were 42.16, 64.95 and 74.05% for a cycle ratio of 0.33, 0.5 and 0.75 respectively. The results showed an increasing trend with an increasing cycle ratio. The effect of the interaction between flow rate and furrow length on application efficiency where the mean highest value of application efficiency was obtained 64.14% at (2.7l/s and 120 m), while the mean lowest value was obtained 56.51% at (2l/s and 160 m). The effect of the interaction between the flow rate and the cycle ratio on application efficiency where the mean highest value of the

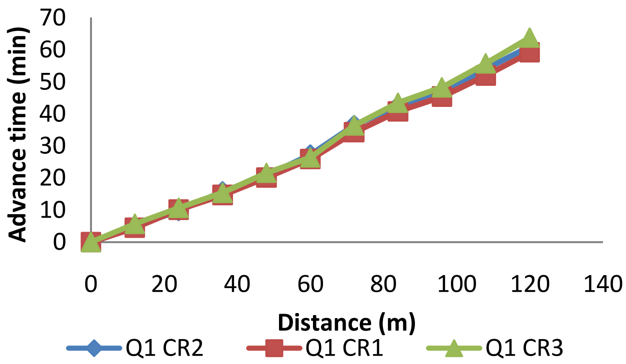

Fig. 1: The mean advance time for cycle ratios (0.33,0.5 and 0.75) for flow rate 2.7 l/s under furrow length 120 m.

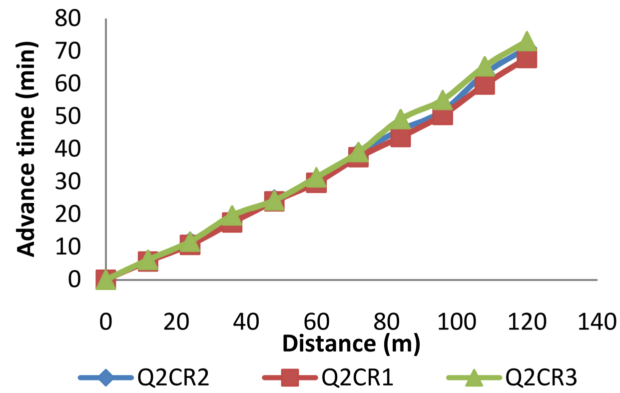

Fig. 2: The mean advance time for cycle ratios (0.33, 0.5 and 0.75) for flow rate 2 l/s under furrow length 120 m

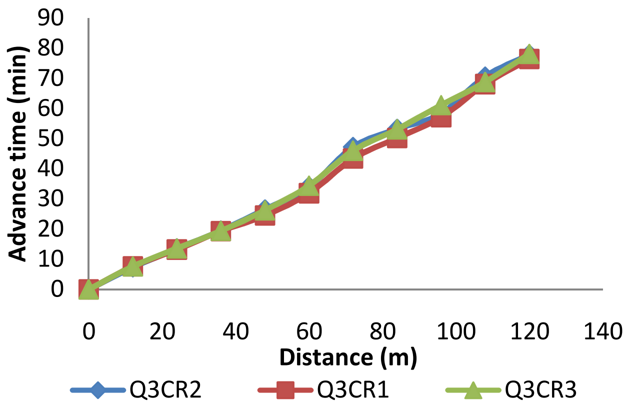

Fig. 3: The mean advance time for cycle ratios (0.33,0.5 and 0.75) for flow rate 1.5 l/s under furrow length 120 m

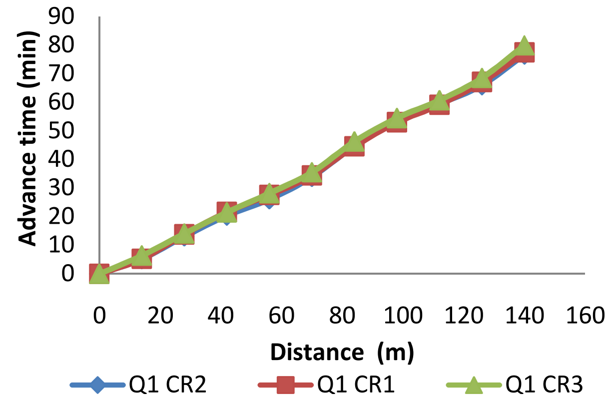

Fig. 4: The mean advance time for cycle ratios (0.33,0.50 and 0.75) for flow rate 2.7 l/s under furrow length 140 m

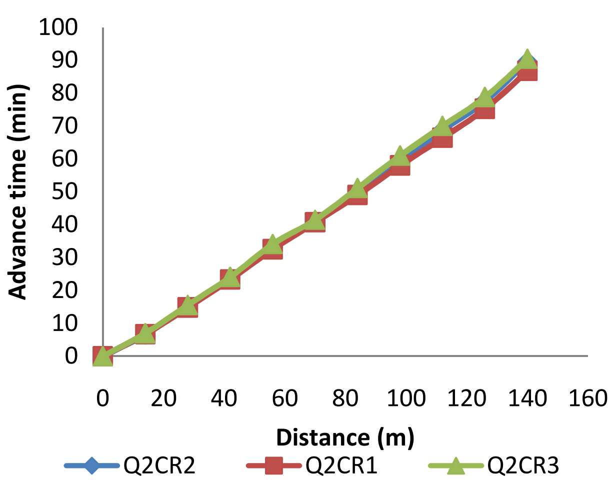

Fig. 5: The mean advance time for cycle ratios(0.33, 0.5 and 0.75) for flow rate 2 l/s under furrow length 140 m

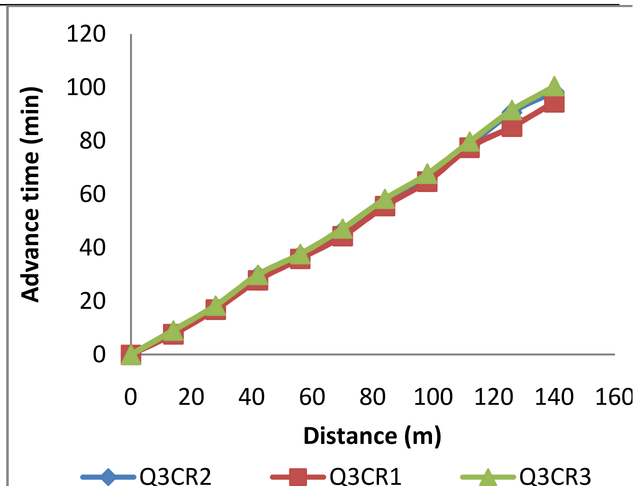

Fig. 6: The mean advance time for cycle ratios (0.33,0.50 and 0.75) for flow rate 1.5 l/s under furrow length 140 m

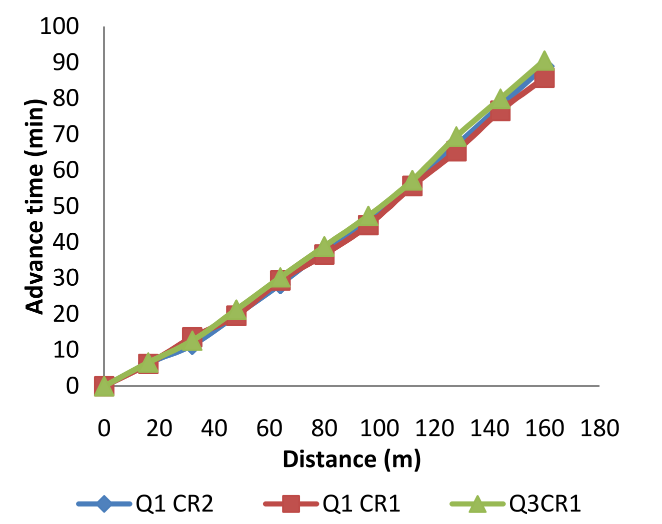

Fig. 7: The mean advance time for cycle ratios (0.33,0.5 and 0.75) for flow rate 2.7 l/s under furrow length 160 m

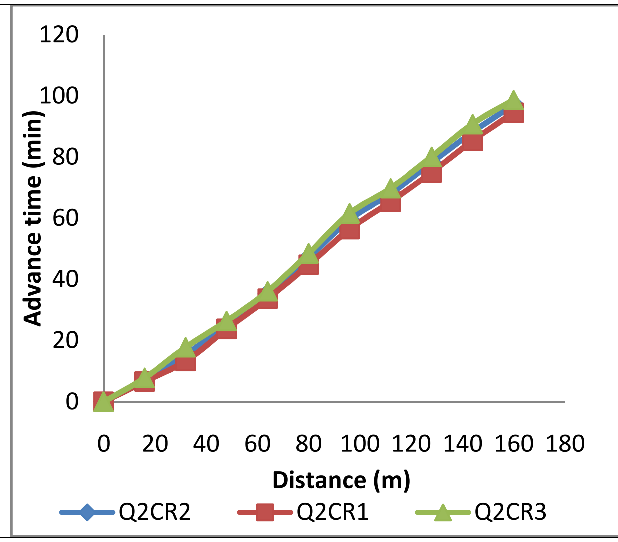

Fig. 8: The mean advance time for cycle ratios (0.33,0.5 and 0.75) for flow rate 2 l/s under furrow length 160 m

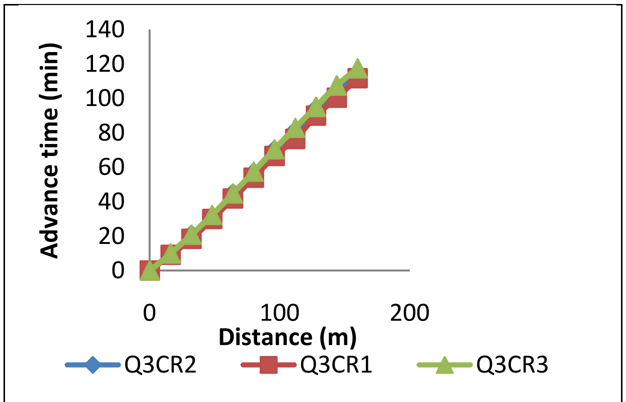

Fig. 9: The mean advance time for cycle ratios (0.33,0.50 and 0.75) for flow rate 1.5 l/s under furrow length 160 m

application efficiency was obtained 77.34 % at (2.7l/s and 0.75), while the mean lowest value was obtained 41.32% at (2.7l/s and 0.33). The effect of the interaction between the furrow length and the cycle ratio on application efficiency where the mean highest value of application efficiency was obtained 75.84% at (120m and 0.75), while the mean lowest value was obtained 40.24% at(160m and 0.33).The effect of the interaction between flow rate, length, and cycle ratio on application efficiency the mean highest value of application efficiency was obtained 78.47% at (2.7l/s,120m and 0.75), while the mean lowest value was obtained 39.33% at (2.7l/s, 160m and 0.33). These results are not much different from the results obtained Abd El-Motaleb (2006).

Surface runoff ratio: The results of the statistical analysis of surface runoff ratio were shown (Table 2). It was noted that among the results of the effect of flow rate on surface runoff ratio. The mean values of SRR were 35.84, 39.26 and 37.79% for a flow rate of 1.5, 2 and 2.7 l/s respectively. Except for the flow rate of 2.7 l/s, the results showed an increasing trend with increasing flow rates. The effect of furrow length on surface runoff ratio where the mean values of SRR were 33.58, 37.48 and 41.82 % for furrow length of 120,140 and 160 m respectively. The results showed an increasing trend with increasing furrow length. The reason that the furrow length of 160 m achieved a high surface runoff ratio due to low deep percolation losses. The effect of the cycle ratio on surface runoff ratio was the mean values of SRR were 57.19, 29.93 and 25.76% for cycle ratio of 0.33, 0.5 and 0.75% respectively. the results showed an decreasing trend with increasing cycle ratio. The effect of the interaction between flow rate and furrow length on the surface runoff ratio was the mean highest value of SRR was obtained 42.94% (at 1.5 l/s and 16 m), while the mean lowest value of SRR was obtained 32.54% (at 2.7l/s and 120 m). The effect of the interaction between the flow rate and the cycle ratio on surface runoff ratio was the mean highest value of the SRR was obtained 58.32% (at 2.7l/s and 0.33), while the mean lowest value of the SRR was obtained 22.09% (at 2.7l/s and 0.75). The effect of the interaction between the furrow length and the cycle ratio on surface runoff ratio, the mean highest value of SRR was obtained 59.64% (at 160 m and 0.33),

Table 1. The effect of interaction between furrow length, flow rates and cycle ratio on application efficiency

Length	Q1			Q2			Q3		
m	CR1	CR2	CR3	CR1	CR2	CR3	CR1	CR2	CR3
120	43.73	70.23	78.47	45.47	66.83	73.73	45.50	69.27	75.33
140	40.90	67.93	77.37	41.73	64.47	71.17	41.33	66.37	73.70
160	39.33	61.57	76.20	41.87	58.47	69.90	39.53	59.40	70.60
	Q1*CR1	Q1*CR2	Q1*CR3	Q2*CR1	Q2*CR2	Q2*CR3	Q3*CR1	Q3*CR2	Q3*CR3
Means	41.32	66.58	77.34	43.02	63.26	71.60	42.12	65.01	73.21
	L1*CR1	L1*CR2	L1*CR3	L2*CR1	L2*CR2	L2*CR3	L3*CR1	L3*CR2	L3*CR3
Means	44.90	68.78	75.84	41.32	66.26	74.08	40.24	59.81	72.23
	L1*Q1	L1*Q2	L1*Q3	L2*Q1	L2*Q2	L2*Q3	L3*Q1	L3*Q2	L3*Q3
Means	64.14	62.01	63.37	62.07	59.12	60.47	59.03	56.74	56.51
	Q1	Q2	Q3	L1	L2	L3	CR1	CR2	CR3
Means	61.75	59.29	60.11	63.17	60.55	57.55	42.16	64.95	74.05

Table 2. The effect of interaction between furrow length, flow rates and cycle ratio on Surface runoff ratio.

Length	Q1			Q2			Q3		
m	CR1	CR2	CR3	CR1	CR2	CR3	CR1	CR2	CR3
120	55.20	20.90	21.53	52.37	27.00	26.27	52.17	22.13	24.67
140	59.10	24.53	22.50	58.27	31.77	28.83	58.67	27.37	26.30
160	60.67	35.87	22.23	57.80	40.93	30.10	60.47	38.90	29.40
	Q1*CR1	Q1*CR2	Q1*CR3	Q2*CR1	Q2*CR2	Q2*CR3	Q3*CR1	Q3*CR2	Q3*CR3
Means	58.32	27.10	22.09	56.14	33.23	28.40	57.10	29.47	26.79
	L1*CR1	L1*CR2	L1*CR3	L2*CR1	L2*CR2	L2*CR3	L3*CR1	L3*CR2	L3*CR3
Means	53.24	23.34	24.16	58.68	27.89	25.88	59.64	38.57	27.24
	L1*Q1	L1*Q2	L1*Q3	L2*Q1	L2*Q2	L2*Q3	L3*Q1	L3*Q2	L3*Q3
Means	32.54	35.21	32.99	35.38	39.62	37.44	39.59	42.94	42.92
	Q1	Q2	Q3	L1	L2	L3	CR1	CR2	CR3
Means	35.84	39.26	37.79	33.58	37.48	41.82	57.19	29.93	25.76

Table 3. The effect of interaction between furrow length, flow rates and cycle ratio on deep percolation ratio.

Length	Q1			Q2			Q3		
m	CR1	CR2	CR3	CR1	CR2	CR3	CR1	CR2	CR3
120	1.07	8.87	0.00	2.17	6.17	0.00	2.33	**8.60**	0.00
140	0.00	7.53	0.13	0.00	3.77	0.00	0.00	6.27	0.00
160	0.00	2.57	1.57	0.33	0.60	0.00	0.00	1.70	0.00
	Q1*CR1	Q1*CR2	Q1*CR3	Q2*CR1	Q2*CR2	Q2*CR3	Q3*CR1	Q3*CR2	Q3*CR3
Means	0.36	6.32	0.57	0.83	3.51	0.00	0.78	5.52	0.00
	L1*CR1	L1*CR2	L1*CR3	L2*CR1	L2*CR2	L2*CR3	L3*CR1	L3*CR2	L3*CR3
Means	1.86	7.88	0.00	0.00	5.86	0.04	0.11	1.62	0.52
	L1*Q1	L1*Q2	L1*Q3	L2*Q1	L2*Q2	L2*Q3	L3*Q1	L3*Q2	L3*Q3
Means	3.31	2.78	3.64	2.56	1.26	2.09	1.38	0.31	0.57
	Q1	Q2	Q3	L1	L2	L3	CR1	CR2	CR3
Means	2.41	1.45	2.10	3.24	1.97	0.75	0.66	5.12	0.19

Table 4. The effect of interaction between furrow length, flow rates and cycle ratio on distribution uniformity.

Length	Q1			Q2			Q3		
m	CR1	CR2	CR3	CR1	CR2	CR3	CR1	CR2	CR3
120	85.97	88.33	86.53	89.47	84.37	85.63	88.90	83.83	89.00
140	91.40	88.93	85.97	89.77	82.67	86.67	88.90	90.30	82.07
160	88.63	87.17	86.80	86.57	86.07	85.53	87.27	89.03	87.27
	Q1*CR1	Q1*CR2	Q1*CR3	Q2*CR1	Q2*CR2	Q2*CR3	Q3*CR1	Q3*CR2	Q3*CR3
Means	88.67	88.14	86.43	88.60	84.37	85.94	88.36	87.72	86.11
	L1*CR1	L1*CR2	L1*CR3	L2*CR1	L2*CR2	L2*CR3	L3*CR1	L3*CR2	L3*CR3
Means	88.11	85.51	87.06	90.02	87.30	84.90	87.49	87.42	86.53
	L1*Q1	L1*Q2	L1*Q3	L2*Q1	L2*Q2	L2*Q3	L3*Q1	L3*Q2	L3*Q3
Means	86.94	86.49	87.24	88.77	86.37	87.09	87.53	86.06	87.86
	Q1	Q2	Q3	L1	L2	L3	CR1	CR2	CR3
Means	87.75	86.30	87.40	86.89	87.41	87.15	88.54	86.74	86.16

while the mean lowest value of SRR was obtained 23.34% (at 120 m and 0.75).

The effect of the interaction between furrow length, flow rate, and cycle ratio on surface runoff ratio whereas the mean highest value for SRR was obtained 60.67% (at 120 m,2.7 l/s and 0.33), while the mean lowest value for SRR was obtained 20.90% (at 120m,2.7 l/s 0.5).

Deep percolation ratio: The results of the statistical analysis of deep percolation ratio are shown in Table 3. Observed that among the results of the effect of flow rate on deep percolation ratio and the mean values of DPR were 2.41, 1.45 and 2.10% for flow rate of 2.7,2 and 1.5 l/s respectively. Except for the flow rate of 1.5 l/s, the results showed a decreasing trend with decreasing flow rate. The effect of furrow length on deep percolation ratio the mean values of DPR were 3.24, 1.97 and 0.75% for furrow length of 120,140 and 160 m respectively. The results showed an decreasing trend with the increase in the furrow length.

The effect of cycle ratio on deep percolation ratio the mean values of DPR were 0.66, 5.12 and 0.19% for cycle ratio of 0.33, 0.5 and 0.75 respectively. The results showed a decreasing trend with the increase in the cycle ratio.

The effect of the interaction between flow rate and furrow length on the deep percolation ratio was the mean highest value of DPR was obtained 3.64% (at 1.5 l/s and 120m), while the mean lowest value of DPR was obtained 0.31% (at 2l/s and 160 m).

The effect of the interaction between the flow rate and the cycle ratio on deep percolation ratio was the mean highest value of the DPR was obtained 6.32%(at 2.7 l/s and 0.5), while the means lowest value of the DPR was obtained 0.0% (at 2 l/s and 0.75). The effect of the interaction between the furrow length and the cycle ratio on deep percolation ratio the mean highest value of DPR was obtained 7.88% (at 120m and 0.5), while the mean lowest value of DPR was obtained 0.0% (at 120 m and 0.75).

The effect of the interaction between furrow length, flow rate and cycle ratio on deep percolation ratio where the mean highest value for DPR was obtained 8.87% (120 m,2.7 l/s and 0.5), while the mean lowest value for DPR was obtained 0.0%.

Distribution uniformity: The results of the statistical analysis of distribution uniformity were shown (Table 4). It was noted that among the results of the effect of flow rate on distribution uniformity and the mean values of DU were 87.40, 86.30 and 87.75% for flow rate of 1.5,2 and 2.7 l/s respectively. Except for the flow rate of 2.7 l/s, the results showed a decreasing trend with increasing flow rate. The effect of furrow length on distribution uniformity the mean values of DU were 86.89, 87.41 and 87.15 % for furrow length of 120,140 and 160 m respectively. Except for the furrow length of 160 m, the results showed an increasing trend with the increase in the furrow length.

The effect of cycle ratio on distribution uniformity the mean values of DU were 88.54, 86.74 and 86.16 % for cycle ratio of 0.33, 0.5 and 0.75 respectively. The results showed a decreasing trend with the increase in the cycle ratio.

The effect of the interaction between flow rate and furrow length on the distribution uniformity was the mean highest value of DU was obtained 88.77% (at 2.7 l/s and 140m), while the mean lowest value of DU was obtained 86.06% (at 2l/s and 160 m).

The effect of the interaction between the flow rate and the cycle ratio on distribution uniformity was the mean highest value of the DU was obtained 88.67%(at 2.7 l/s and 0.33), while the means lowest value of the DU was obtained 84.37% (at 2 l/s and 0.5). The effect of the interaction between the furrow length and the cycle ratio on distribution uniformity the mean highest value of DU was obtained 90.02% (at 140m and 0.5), while the mean lowest value of DU was obtained 84.90% (at 140 m and 0.75).

The effect of the interaction between furrow length, flow rate and cycle ratio on distribution uniformity where the mean highest value for DU was obtained 91.40% (140 m, 2.7 l/s and 0.33), while the mean lowest value for DU was obtained 82.07% (at 140m,1.5 l/s and 0.75).These results are agreement with the results obtained by Abd El-Motaleb (2006).

Storage efficiency: The results of the statistical analysis of storage efficiency were shown (Table 5). Observed that among the results of the effect of flow rate on storage efficiency and the mean values of ES were 95.47, 94.22 and 94.57% for flow rate of 1.5,2 and 2.7 l/s respectively. Except for the flow rate of 2.7 l/s, the results showed a decreasing trend with increasing flow rate. The effect of furrow length on storage efficiency the

Table **5**. The effect of interaction between furrow length, flow rates and cycle ratio on storage efficiency.

Length	Q1			Q2			Q3		
m	CR1	CR2	CR3	CR1	CR2	CR3	CR1	CR2	CR3
120	95	100	93.4	100.00	100	89.1	99.63	100	90.37
140	94.7	100.00	94.57	96.27	100	86.6	96.03	100	90.27
160	91.83	98.50	91.27	96.6	95.37	84.03	92.27	96.3	86.3
	Q1*CR1	Q1*CR2	Q1*CR3	Q2*CR1	Q2*CR2	Q2*CR3	Q3*CR1	Q3*CR2	Q3*CR3
Means	93.84	99.50	93.08	97.62	98.46	86.58	95.98	98.77	88.98
	L1*CR1	L1*CR2	L1*CR3	L2*CR1	L2*CR2	L2*CR3	L3*CR1	L3*CR2	L3*CR3
Means	98.21	100.00	90.96	95.67	100.00	90.48	93.57	96.72	87.20
	L1*Q1	L1*Q2	L1*Q3	L2*Q1	L2*Q2	L2*Q3	L3*Q1	L3*Q2	L3*Q3
Means	96.13	96.37	96.67	96.42	94.29	95.43	93.87	92.00	91.62
	Q1	Q2	Q3	L1	L2	L3	CR1	CR2	CR3
Means	95.47	94.22	94.57	96.39	95.38	92.50	95.81	98.91	89.55

mean values of ES were 96.39, 95.38 and 92.50 % for furrow length of 120,140 and 160 m respectively. The results showed an decreasing trend with the increase in the furrow length**.**

The effect of cycle ratio on storage efficiency the mean values of ES were 95.81, 98.91and 89.55 % for cycle ratio of 0.33, 0.5 and 0.75 respectively. Except that the cycle ratio is 0.5 the results showed a decreasing trend with the increase in the cycle ratio.

The effect of the interaction between flow rate and furrow length on the storage efficiency was the mean highest value of ES was obtained 100%, while the mean lowest value of ES was obtained 91.62% (at 1.5 l/s and 160 m).

The effect of the interaction between the flow rate and the cycle ratio on storage efficiency was the mean highest value of the ES was obtained 99.50%(at 2.7 l/s and 0.5), while the means lowest value of the ES was obtained 86.58% (at 2 l/s and 0.75).

The effect of the interaction between the furrow length and the cycle ratio on storage efficiency the mean highest value of ES was obtained 100% (at 140m and 0.5), while the mean lowest value of ES was obtained 87.20% (at 160 m and 0.75).

The effect of the interaction between furrow length, flow rate and cycle ratio on storage efficiency where the mean highest value for ES was obtained 100% , while the mean lowest value for ES was obtained 84.03% (at 160m, 2 l/s and 0.75).

Conclusions

In the research, measurement was of inflow/outflow, advance time (during ten stations along the furrow), cross section for furrow (before and after the irrigation), and water width and depth and soil moisture content before and after the irrigation. The application efficiency, surface runoff ratio, deep percolation ratio, distribution uniformity and storage efficiency has been calculated.

The cycle ratio of 0.33 obtained the fastest advance time compared to the cycle ratio of 0.5 and 0.75. The higher application efficiency was obtained at cycle ratio 0.75 and furrow length 120 m with a 2.7 L/S flow rate.

Surge flow under furrow open-end in clay soil condition led to a more uniform distribution where the highest distribution uniformity was obtained at cycle ratio 0.33 and furrow length 140 m were 2.7 l/s. The highest storage efficiency was obtained a at cycle ratio 0.75 and furrow length 160 m were 2 l/s.

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