J. of Soil Sciences and Agricultural Engineering, Mansoura Univ., Vol. 10 (11):685 - 691, 2019

Journal of Soil Sciences and Agricultural Engineering

Journal homepage: www.jssae.mans.edu.eg
Available online at: www.jssae.journals.ekb.eg

Surge Flow Performance for Furrow Irrigation under Upper Egypt Conditions

EL-Sayed, M. M.*; M. Y. Khalafalla; M. Gebreel and A. S. A. Abdel-Mawgoud

Soils and Water Sci. Dept., Fac. of Agric., Al-Azhar Univ., Assiut, Egypt.

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ABSTRACT

The current study was conducted at The Experimental Farm, Fac. of Agric., Al-Azhar Univ., Assuit, Egypt (27° 12' 16.67" N latitude, 31° 09' 36.86" E longitude and at 51 m altitude) during the winter season of 2018 (September to December). The research work aimed to assess the performance of surge irrigation compared to the continuous one by measuring the advance rate of the wetting front, inflow/ outflow rates, distribution uniformity, application efficiency, suitable furrow length and surge numbers. Surge flow irrigation leads to a decrease in advance time compared to continuous flow. The reduction percentages in advance and recession time are more pronounced under low discharge rate and long furrow length. Surge flow irrigation used less amounts of water than continuous one. Surge flow could save almost one third of the applied water by continuous flow especially into long furrow with 5 surges of medium discharge rate. The larger discharge coupled with large furrow resulted in the maximum water saving of about 28% among all the other combinations. For all possible combinations, the volume ratio remained less than one indicating that less total water is required to complete the advance phase in surged irrigation compared to continuous one. Surge flow showed higher application efficiency than that of continuous one. The higher application efficiency (83%) was observed under 5 surges flow into 100 m furrow length with 1.2 L/S discharge rate. Water losses by deep percolation were more pronounced in short furrow length than that of long one and they were minimized by surge flow. Surge flow realized higher distribution uniformity (DU) than that of continuous one.

Keywords: Surge irrigation, Advance and recession time, Application efficiency, Deep percolation, Water distribution uniformity.

INTRODUCTION

Irrigation technique is the most important practice that can save water particularly in arid and semi arid regions such as Egypt that is suffering from water scarcity. Even though the advanced pressure irrigation methods (drip and sprinkler systems) are in the state of being widely popular, the traditional gravity surface irrigation methods still remain predictable due to their simplicity in layouts and low installation and operational expenses. It is so far the most common form of irrigation throughout the world and has been practiced in many areas almost unchanged for thousands of years. Surface irrigation is often referred to as flood irrigation, implying that the water distribution is uncontrolled and basically inefficient. In reality, some of the irrigation practices grouped under this name involve a significant degree of management such as surge irrigation (Ismail and Depeweg, 2002). The term "Surge irrigation" refers to the delivering irrigation flows into individual long furrows (up to 200 m) in an intermittent manner of programmed ON-OFF time cycles with the design duration of irrigation (Horst *et al*., 2007).

El-Dine and Hosny (2000) found that at the head of the field, the intake opportunity times under surge irrigation are of 3 to 6 times less than continuous irrigation which leads to more uniform infiltration over the entire length of the furrow. Mahmood *et al.* (2003) stated that surge irrigation reduces advance time, increases irrigation uniformity, and reduces deep percolation and runoff. Surge irrigation improves irrigation performance and irrigation water use efficiency. Ismail (2004) found that, for the lowest discharge (0.46 l/s) in sandy clay soil, three out of four trials gave high distribution uniformity when their surge number being 4 or 5 surges. He also, mentioned that most of the results realized a good distribution for water content along the furrow. Rodriguez *et al.* (2004) revealed that the surge flow furrow irrigation with variable time cycles increased the application efficiency by more than six fold compared to continuous one. Sial *et al.* (2006) indicates that 13.92% less time is required to complete advance phase under surge flow compared to continuous flow. Abd El-Hakim (2007) reported that surge treatment which is series of on and off times help to improve infiltration rate and changes in the hydraulic properties of the soil profile between pluses resulted in uniform water distribution. Horst *et al.* (2007) observed that the best irrigation water productivity was achieved with surge flow on alternate furrows, which reduced irrigation water use by 44% and led to high application efficiency (85%). Kifle *et al.* (2008) found that the highest value of application efficiency was by surge flow with small cycle ratio while the lowest application efficiency was observed for continuous irrigation. They also, observed higher distribution uniformity under surge flow than that of continuous one.

Shock and Welch (2011) found that surge boosts some surface irrigation application efficiencies by as much as 40 percent. Saif (2012) mentioned that, surge flow had better application efficiency and distribution uniformity compared to continuous flow. Gudissa and Edossa (2014) stated that maximum values of application efficiency, storage efficiency and uniformity coefficient were recorded under surge

* **Corresponding author.**
E-mail address: m_eways@yahoo.com
DOI: 10.21608/jssae.2019.67356

treatments, whereas the lowest corresponding values were recorded under continuous. Abdel-Moneim *et al*. (2015) observed that, surge irrigation at the midpoint of the furrow offered greater opportunity for water intake, which in turn resulted in high application efficiency. Allam *et al*., (2015) reported 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 compared to continuous flow. Amer and Attafy (2017) 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. Kifle *et al*. (2017) stated that the surge flow technique caused a great reduction in the total volume of water used compared to the volume used by the continuous flow technique without significant reduction of crop yield. Mattar *et al*. (2017) found that water saving of 8 to 34% in surge-irrigated plots under different levels of flow rate and tillage depth. Mattar *et al*. (2017) found that the 3-surges treatment with the rotary plough was the best one for reducing applied irrigation water. They also, concluded that surge flow required less time to complete the advance phase than continuous flow. Therefore, less water was consumed to achieve a given advance distance. Wood *et al*. (2017) found that the water savings with surge compared with continuous increased by 2% per 100 ft as row length increased from 540 to 1800 ft. Nouri and Ghasempour (2019) stated that the advance of surge down in a channel with the permeable bed is the complicated consequence of the hydraulics of unsteady spatially varied flow. Onishi *et al*. (2019) indicated that a 100 m furrow length is not suitable for shortening the water advance time under high inflow rate.

The research work aimed to assess the performance of surge irrigation compared to the continuous one by measuring the advance rate of the wetting front, inflow/ outflow rates, distribution uniformity, application efficiency, suitable furrow length and surge numbers.

MATERIALS AND METHODS

The current study was conducted at The Experimental Farm, Fac. of Agric., Al-Azhar Univ., Assuit, Egypt (27° 12' 16.67'' N latitude, 31° 09' 36.86'' E longitude and at 51 m altitude) during the winter season of 2018 (September to December) . The study area is characterized by semi-arid climate with almost no rainfall occurs during the year. The experimental site is considered a clay-loam, cultivated with traditional crops irrigated by flooding. The relevant soil chemical and physical properties of the investigated area were determined according to Page *et al.* (1982) & Klute (1986) are shown in Table (1a &b).

Table 1a. Some chemical properties of the investigated soil.

Soil depth (cm)	OM (%)	$CaCO_3$ meq/L	pH (1: 2.5)	SP	ECe (dS/m)	SAR	Available nutrients (ppm)		
							N	P	K
0-30	1.4	2.5	7.85	79	1.15	4.05	70	10	325
30-60	1.19	3.4	7.88	78	1.2	4.06	66	9.8	310

OM = organic matter **SP = saturation %** **SAR = sodium adsorption ratio**

Table 1b. Some physical properties of the investigated soil.

Soil depth (cm)	Percentage			Texture class	O.M (%)	$CaCO_3$ (%)	Moisture content θ v%		A.W (%)	*P*b (g/cm^3)	Inf. rate (cm/h)	H.C (m/day)
	Sand	Silt	Clay				F.C.	W.P				
0-15	25.34	38.67	35.99	Clay Loam	1.4	3.1	44.0	21.0	23.0	1.49	0.1	0.07
15-30	26.32	39.25	34.43	Clay Loam	1.1	2.3	42	20	22	1.39		
30-45	25.2	40	34.8	Clay Loam	0.87	2	40.5	20	20.5	1.36		
45-60	24,5	40.6	34.9	Clay Loam	0.85	1.9	42.53	21	21.53	1.32		

The experiment was laid out on an area of about 0.75 acre (30 m width by 103 m length) with 70 cm furrow spacing and 100 m length with gentle slope of 1‰. The furrows were prepared manually immediately following the primary and secondary tillages. Three consecutive furrows were used for each treatment with plot area of 2.25 by 103 m. Additional 25 cm free spacing was left among the respective treatments. All the required data were collected from the middle furrows, whereas the two outer furrows were used as buffers to reduce border effects (Latif and Ittifaq, 1998). The experiment consisted of three factors, irrigation water flow with four treatments (continuous, 4, 5 and 6 surges), discharge rate with three treatments (0.75, 1.00 and 1.20 L/ S) and furrow length with two treatments (50 and 100 m). The irrigation water is coming from the main water pump (that served all the experimental station) into a 3 inch PVC pipeline to the head of experimental location. This PVC pipeline was connected to another one 1.5 inches in diameter that conveyed the water flow to the furrows and placed perpendicular on furrows direction. Adjoining to the connection point, a 3/4 inch valve was inserted into the 1.5 inch PVC to control the amount of water flow. The 1.5 inch PVC pipeline was perforated using a driller at 70 cm apart (at furrow spacing). A clip was mounted on each hole and supported by a plug that could be removed to let the water flow into a specific furrow. The amount of water discharge was measured volumetrically using container and measured cylinder with the recorded time. Continuous flow treatments got water once at a time for the entire furrow whereas the surge flow treatments got water by cutting fourth, fifth and sixth times. The advance phase is completed in 4 to 6 surges. The next to the last advance phases is stopped just short of the end of the field. The cycle times are such that individual surges do not overlap or coalesce. The discharge rates are being near the maximum non-erosive value. The on-time during the advance phase is set so that the advance progresses a set distance during every surge (such as1/4, 1/5 and 1/6 of the total furrow length for 4, 5 and 6 surges, respectively). Upon completion of the advance, the on-time is reduced for the post-advance surges so the wetted advance reaches 80-85% of the furrow length by cutoff, thus allowing the advance to "roll-on" to the tail. In order to evaluate furrow surge irrigation, the furrow inflow and outflow discharges, advance and recession time, and infiltration rate were measured. After five days from completion of the first irrigation, all the experimental furrows were hoeing using a multi function hand push ripper hoeing machine (52/1900 w). Then the experimental location was left for twenty days to be ready for the second irrigation. After completion of the second irrigation the experimental location was left for twenty five days without hoeing to be ready for the third irrigation. Furrow length was divided into 4 equal stations by marked sticks between each two successive stations (the sticks were placed at 12.5 or 25 m apart according to the furrow length (50 or 100 m). Advance and recession time at every station as well as the total irrigation water at end of the furrow were recorded. The same technique was followed in surge flow with equal station of 1/4, 1/5 and 1/6 furrow length for 4, 5 and 6 surges, respectively either for 100 or 50 m furrow length. Flow rate for each irrigation event was measured by volumetric method according to James (1988). The soil moisture content were performed directly before and one day after irrigation at fourth and 1/4, 1/5 and 1/6 furrow length for continuous and 4, 5 and 6 surges, respectively. At each point, soil moisture contents were measured at consecutive four depths with 15 cm increment down to 60 cm. The soil moisture contents were gravimetrically determined. Field capacity, permanent wilting point and available water were determined according to Black (1965). Application efficiency is measured according to the formula proposed by Walker (1989). Distribution uniformity (DU) was determined according to Micheal (1978). Deep percolation ratio was computed according to James (1988). The amount of saved water was calculated according to Horst (1989). The volume ratio was computed using the equation proposed by Humpherys (1989).

RESULTS AND DISCUSSION

In view of minimizing the land and water loss and to accomplish high level of irrigation a relatively new surface irrigation method called "surge irrigation" was practiced with extensive experimental trials on its hydraulic performance evaluation.

1- Water advance rate

The average advance time of the three irrigation occasion for different furrow lengths and discharge rates are shown in table (2) and figures (1 & 2). The average values of time required for water to advance to the end of the furrow in the continuous flow case were 82.67, 59.33 and 46 min. for the 0.75, 1.0 and 1.2 L/S discharge rate, respectively under 100 m furrow length (table 2 and fig.1). The corresponding values were 34, 31.83 and 23 min. under 50 m furrow length (table 2 and fig.2). Under surge irrigation, the average values of time required for water to reach the end of the furrow in 4 surges were 22.45, 17.33 and 16 min. for the 0.75, 1.0 and 1.2 L/S discharge rate, respectively under 100 m furrow length (table 2 and fig.1). The corresponding values were 17.03, 10.08 and 4.35 min. under 50 m furrow length (table 2 and fig.2). The average values of time required for water to reach the end of the furrow in 5 surges were 16.67, 14.78 and 12 min. for the 0.75, 1.0 and 1.2 L/S discharge rate, respectively under 100 m furrow length (table 2 and fig.1). The corresponding values were 13.62, 9.99 and 6.13 min. under 50 m furrow length (table 2 and fig.2). Under 6 surge flow, the average values of time required for water to reach the furrow tail were 14.7, 14.44 and 12.33 min. for the 0.75, 1.0 and 1.2 L/S discharge rate, respectively under 100 m furrow length (table 2 and fig.1). The corresponding values were 11.24, 7 and 6.47 min. under 50 m furrow length (table 2 and fig.2).

It could be concluded that the saved time to irrigate 100m furrow length decreased as the discharge rate increase under surge irrigation while the opposite trend was true for continuous irrigation. The saved time to irrigate 50m furrow length increased as the discharge rate increase regardless the irrigation manner. This means that it took more time to irrigate 100 m furrow length at high discharge and the reverse was true for 50 m furrow length. In general, the surge flow treatments had a faster advance rate than the continuous ones. Since the surge flow decreases infiltration loss by reducing soil permeability through cyclic irrigation. The first water supply reduces soil permeability, speeding up water flow during the second water supply. Four physical processes cause the reduction in infiltration: consolidation, owing to soil particle migration and reorientation; air entrapment; the redistribution of water; and channel smoothing. These findings are in accordance with those obtained by Kifle *et al.*, 2008; Shock and Welch, 2011 and Mattar *et al.*, 2017).

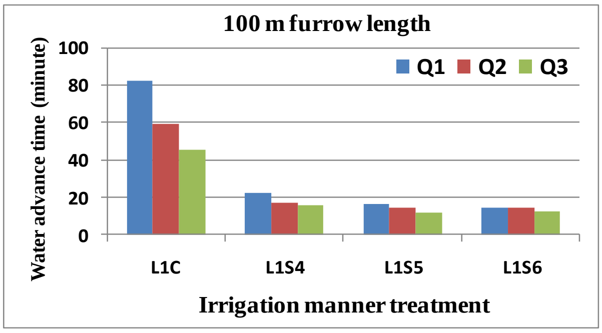

Fig. 1. Water advance time to irrigate 100 m furrow length under different discharge rate for continuous and surges irrigation.

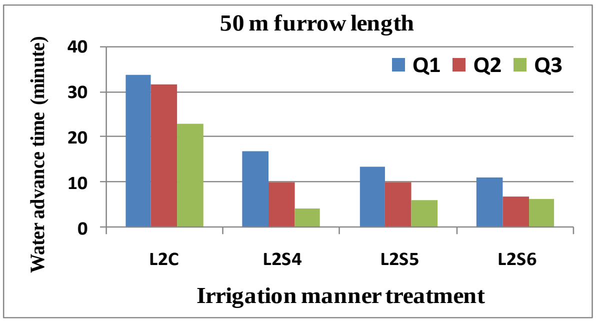

Fig. 2. Water advance time to irrigate 50 m furrow length under different discharge rate for continuous and surges irrigation.

2- Advance and recession times for continuous and surge flow

On the average basis of three irrigations, for continuous flow in 100 m furrow length, the advance and recession time were 82.67 and 116 minute, respectively under 0.75 L/S discharge rate (L_1Q_1C). The corresponding times were 59.33 and 86.67 minute and they were 46 and 66.33 minute for 1.0 and 1.2 L/S discharge rate (L_1Q_2C and L_1Q_3C), respectively (Table 3). The advance and recession time were 43.22 & 54.22, 31.93 & 44.27 and 23 & 37.67 for L_2Q_1C, L_2Q_2C and L_2Q_3C, respectively (table 3). On the average basis of three irrigations, for surge flow in 100 m furrow length, the advance and recession time were 22.53 and 37.86 minute, respectively under 0.75 L/S discharge rate with 4 surges (L_1Q_1S4). The corresponding times were 16.67 and 33.32 minute and they were 14.72 and 30.61 minute with 5 and 6 surges (L_1Q_1S5 and L_1Q_1S6), respectively (table 3). The advance and recession time were 17.33 & 28, 14.85 & 28.27 and 14.51 & 25.18 minute for L_1Q_2S4, L_1Q_2S5 and L_1Q_2S6, respectively (table 3). The advance and recession time were 16 & 26, 12 & 19.56 and 12.33 & 24 minute for L_1Q_3S4, L_1Q_3S5 and L_1Q_3S6, respectively (table 3).

Table 2. The average advance time of the three irrigation occasion for different furrow lengths and discharge rates.

Irrigation type	Furrow length (m)	Discharge rate (L/ S)	Irrigation occasion (min) First	Second	Third	average	Saved time (%)	treatment lable
Continuous	100	0.75	104.00	90.00	54.00	82.67	,-------	L1Q1C
		1.00	75.00	68.00	35.00	59.33	28.23	L1Q2C
		1.20	58.00	52.00	28.00	46.00	44.35	L1Q3C
	50	0.75	25.00	45.00	32.00	34.00	,--------	L2Q1C
		1.00	40.00	35.00	20.48	31.83	6.39	L2Q2C
		1.20	27.00	23.00	19.00	23.00	32.35	L2Q3C
4 surges	100	0.75	26.18	23.17	18.00	22.45	72.84	L1Q1S4
		1.00	21.00	19.00	12.00	17.33	70.79	L1Q2S4
		1.20	20.00	17.00	11.00	16.00	65.22	L1Q3S4
	50	0.75	22.00	17.00	12.10	17.03	49.90	L2Q1S4
		1.00	12.29	11.49	6.47	10.08	68.32	L2Q2S4
		1.20	4.51	4.20	4.34	4.35	81.09	L2Q3S4
5 surges	100	0.75	17.00	18.00	15.00	16.67	79.84	L1Q1S5
		1.00	18.00	15.33	11.00	14.78	75.10	L1Q2S5
		1.20	15.00	12.00	9.00	12.00	73.91	L1Q3S5
	50	0.75	13.13	14.16	13.56	13.62	59.95	L2Q1S5
		1.00	14.30	11.37	4.30	9.99	68.61	L2Q2S5
		1.20	6.21	6.18	6.00	6.13	73.35	L2Q3S5
6 surges	100	0.75	13.10	18.00	13.00	14.70	82.22	L1Q1S6
		1.00	18.00	16.32	9.00	14.44	75.66	L1Q2S6
		1.20	15.00	14.00	8.00	12.33	73.19	L1Q3S6
	50	0.75	11.16	10.56	12.00	11.24	66.94	L2Q1S6
		1.00	9.30	8.40	3.30	7.00	78.01	L2Q2S6
		1.20	7.30	7.00	5.12	6.47	71.86	L2Q3S6

Table 3. The advance and recession time of different irrigation treatments of both furrow length under different water discharges as average of three irrigations.

Furrow length 100 m at Q = 0.75 L/S												Furrow length 50 m at Q = 0.75 L/S											
Distance from stream	Continuous flow (min)		Surge flow (min) 4 surges			5 surges			6 surges			Distance from stream	Continuous flow (min)		Surge flow (min) 4 surges			5 surges			6 surges		
	advance	recession	Distance from stream	advance	recession	Distance from stream	advance	recession	Distance from stream	advance	recession		advance	recession	Distance from stream	advance	recession	Distance from stream	advance	recession	Distance from stream	advance	recession
1/4	82.67	116	1/4	9.32	15.71	1/5	6.53	10.67	1/6	5.72	8.43	1/4	43.22	54.22	1/4	3.49	5.84	1/5	2.38	4.33	1/6	2.98	5.26
2/4			2/4	12.71	19.38	2/5	9.72	14.80	2/6	13.53	14.60	2/4			2/4	10.23	16.12	2/5	5.68	10.16	2/6	3.89	6.64
3/4			3/4	20.12	27.76	3/5	12.29	18.14	3/6	14.30	21.36	3/4			3/4	11.94	25.54	3/5	6.97	12.44	3/6	5.86	10.20
4/4			4/4	22.53	37.86	4/5	16.18	26.87	4/6	16.89	25.65	4/4			4/4	17.06	34.12	4/5	10.00	17.33	4/6	6.47	11.67
						5/5	16.67	33.32	5/6	15.61	26.39							5/5	13.81	27.85	5/6	8.19	15.27
									6/6	14.72	30.61										6/6	11.40	20.83
Furrow length 100 m at Q = 1.0 L/S												Furrow length 50 m at Q = 1.0 L/S											
1/4	59.33	86.67	1/4	6.83	11.06	1/5	4.83	7.83	1/6	4.07	6.11	1/4	31.93	44.27	1/4	2.45	4.48	1/5	2.20	3.81	1/6	1.27	2.38
2/4			2/4	9.67	15.00	2/5	7.24	11.65	2/6	10.48	11.22	2/4			2/4	4.03	7.09	2/5	3.39	6.24	2/6	2.31	4.12
3/4			3/4	14.67	22.06	3/5	9.94	16.10	3/6	8.74	14.39	3/4			3/4	6.80	16.45	3/5	5.69	10.35	3/6	4.95	9.28
4/4			4/4	17.33	28.00	4/5	12.55	20.22	4/6	10.76	17.30	4/4			4/4	10.36	24.02	4/5	7.97	14.13	4/6	5.01	9.68
						5/5	14.85	28.27	5/6	12.61	20.94							5/5	10.21	22.87	5/6	7.34	13.89
									6/6	14.51	25.18										6/6	7.22	18.56
Furrow length 100 m at Q = 1.2 L/S												Furrow length 50 m at Q = 1.2 L/S											
1/4	46	66.33	1/4	4.96	7.96	1/5	3.50	5.39	1/6	2.83	4.64	1/4	23	37.67	1/4	2.46	4.46	1/5	1.45	2.79	1/6	1.28	2.00
2/4			2/4	8.06	12.28	2/5	5.03	7.86	2/6	4.99	6.69	2/4			2/4	5.37	9.21	2/5	2.74	5.38	2/6	2.81	5.46
3/4			3/4	12.67	18.76	3/5	7.09	10.96	3/6	5.46	8.89	3/4			3/4	5.85	18.14	3/5	5.35	9.91	3/6	4.46	7.80
4/4			4/4	16.00	26.00	4/5	9.26	14.74	4/6	7.77	12.14	4/4			4/4	4.58	13.89	4/5	5.85	11.27	4/6	5.96	10.75
						5/5	12.00	19.56	5/6	10.14	16.08							5/5	6.21	25.21	5/6	6.14	11.70
									6/6	12.33	24.00										6/6	6.57	18.26

On the average basis of three irrigations, for surge flow in 50 m furrow length, the advance and recession time were 17.06 and 34.12 minute, respectively under 0.75 L/S discharge rate with 4 surges (L_2Q_1S4). The corresponding times were 13.81 and 27.85 minute and they were 11.4 and 20.83 minute with 5 and 6 surges (L_2Q_1S5 and L_2Q_1S6), respectively (table 3). The advance and recession time were 10.36 & 24.02, 10.21 & 22.87 and 7.22 & 18.56 minute for L_2Q_2S4, L_2Q_2S5 and L_2Q_2S6, respectively (table 3). The advance and recession time were 4.58 & 13.89, 6.21 & 20.21 and 6.57 & 18.26 minute for L_2Q_3S4, L_2Q_3S5 and L_2Q_3S6, respectively (table 3). It could be concluded that surge flow irrigation leads to a decrease in advance time compared to continuous flow. The reduction percentages in advance and recession time are more pronounced under low discharge rate and tall furrow length. These results are in harmony with those obtained by Nouri and Ghasempour (2019) who stated that the advance of surge down in a channel with the permeable bed is the complicated consequence of the hydraulics of unsteady spatially varied flow. Onishi *et al.* (2019) indicated that a 100 m furrow length is not suitable for shortening the water advance time under high inflow rate.

3- Total amount of applied water

On the average basis of all irrigations, the amount of applied water under continuous flow in 50 m furrow length represented about 56, 53 and 51% of that required for 100 m furrow length for 0.75, 1.0 and 1.2 L/S discharge rate, respectively (Table 4). The four surge flow, the water inflow to 50 m furrow length represented about 62, 58 and 53% of that required for 100 m furrow length for 0.75, 1.0 and 1.2 L/S discharge rate, respectively (Table 4). The corresponding values for 5 surges were 69, 59 and 62% and they were 62, 58 and 63% for 6 surges (Table 4). These results indicated that surge flow irrigation used less amounts of water than continuous one.

Table 4. The total amount of water applied and saving water in relation to furrow length and irrigation manner with different discharge rate as average of three irrigations.

Furrow length	irrigation method	No. Of surges	discharge (L/S)	time (min)	water volume (M^3)	volume ratio (V_s/V_c)	water saving (%)
50 m	surge	4	0.75	2.38	1.94	0.93	7.18
			1.00	1.00	1.70	0.91	9.27
			1.20	1.20	1.45	0.87	12.80
		5	0.75	2.88	1.95	0.93	6.86
			1.00	1.00	1.58	0.84	15.51
			1.20	1.20	1.56	0.94	6.20
		6	0.75	3.38	1.72	0.82	17.54
			1.00	1.00	1.53	0.82	18.36
			1.20	1.20	1.51	0.91	9.20
	continuous	1	0.75	0.88	2.09	1	-------
			1.00	1.00	1.87	1	-------
			1.20	1.20	1.67	1	--------
100 m	surge	4	0.75	2.38	3.13	0.84	15.72
			1.00	1.00	2.92	0.83	16.67
			1.20	1.20	2.73	0.83	17.00
		5	0.75	2.88	2.84	0.76	23.54
			1.00	1.00	2.66	0.76	24.10
			1.20	1.20	2.52	0.77	23.48
		6	0.75	3.38	2.78	0.75	25.07
			1.00	1.00	2.62	0.75	25.14
			1.20	1.20	2.38	0.72	27.83
	continuous	1	0.75	0.88	3.71	1	-------
			1.00	1.00	3.50	1	-------
			1.20	1.20	3.29	1	--------

Abou-El-Hassan (2006) found that the values of applied water were higher for continuous flow than those for surge flow treatments. The most probable explanation for these finding that more available soil moisture provide a chance for more luxury water use, which ultimately resulted in increasing transpiration. Also, He mentioned that in general, increasing irrigation discharge decreased applied water for the surge and/or continuous flow irrigation.

Water saving

On the average basis of all irrigations, the saved amount of applied water for 4 surges flow into 50 m furrow length were about 7.18, 9.27 and 12.8% for 0.75, 1.0 and 1.2 L/S discharge rate, respectively compared to continuous flow (Table 4 & Fig.3). The corresponding values for five surges flow were 6.86, 15.51 and 6.2% and they were 17.54, 18.36 and 9.2% (Table 4 & Fig.3). the saved amount of applied water for 4 surges flow into 100 m furrow length were about 15.72, 16.67 and 17% for 0.75, 1.0 and 1.2 L/S discharge rate, respectively compared to continuous flow (Table 4 & Fig.3). The corresponding values for five surges flow were 23.54, 24.1 and 23.48% and they were 25.07, 25.14 and 27.83% for six surges.

These findings confirmed that surge flow could save almost one third of the applied water by continuous flow especially into long furrow with 5 surges of medium discharge rate. The result reveals that a larger discharge coupled with large furrow resulted in the maximum water saving of about 28% among all the other combinations. Wood *et al.* (2017) found that the water savings with surge compared with continuous increased by 2% per 100 ft as row length increased from 540 to 1800 ft. Onishi *et al.* (2019) found that surge flow saved around 10% of applied water compared to continuous flow. Also, they indicated that shortening furrow length might be an effective way to save water using simplified surge flow with a low inflow rate. In contrast, it is necessary to extend furrow length with a high inflow rate. They presumed that irrigation water could rapidly reach the ends of the furrows, but the total volume of water applied might increase.

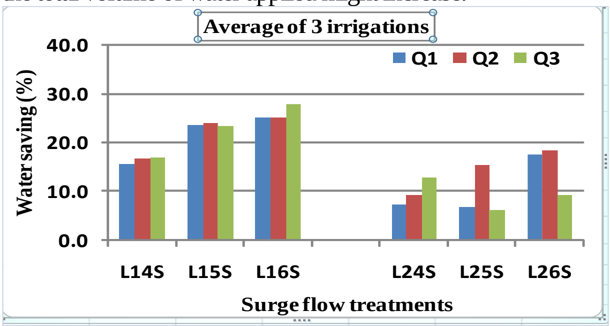

Fig. 3. Water saving percentage for different furrow length and surge numbers under various discharge rates as average of three irrigations

Volume ratio

For all possible combinations of furrow length, surge numbers and discharge levels, the volume ratio remained less than one (Table 4). This clearly indicates that less total water is required to complete the advance phase in surged irrigation compared to continuous one. Also, the results illustrated that small volume ratio means great water saving. On the average basis of the three irrigations, the volume ratio varied from 0.72 to 0.94 for all possible combinations of furrow length, surge numbers and discharge levels (Table 4). These finding in accordance with those obtained by Abou-El-Hassan (2006) who stated that values of the volume ratio less than one indicate that less water was required for surge than for continuous advance.

4- Irrigation performance indicators

Water Application Efficiency

On the average basis of the three irrigations, the application efficiency values ranged from 56 to 64, 61 to 73, 64 to 70 and from 61 to 68% for continuous, 4 surges, 5 surges and 6 surges flow in 50 m furrow length, respectively (Fig. 4). The application efficiency values for 100 m furrow length ranged from 53 to 58, 66 to 74, 66 to 74 and from 66 to 67% for continuous, 4 surges, 5 surges and 6 surges flow, respectively (Fig. 4). It could be noticed that all the surge flow irrigation treatments showed higher application efficiency than that of continuous flow. The higher application efficiency (83%) was observed under 5 surges flow into 100 m furrow length with 1.2 L/S discharge rate in the second irrigation. Wood *et al.* (2017) stated that at the farm scale, improved irrigation application efficiency provided by surge on clay-textured soils reduces the time required for a well to be committed to an irrigation set. Surge irrigation improves on-farm irrigation capacity, thereby allowing additional acres to be irrigated by a single well in a more timely manner. Onishi *et al.* (2019) found that application efficiency of surge flow at 5 L/S was 8% lower than that of continuous flow at 5 L/S rate. Contrarily, application efficiency of surge flow at 1.7 L/S was 10% higher than that of continuous flow at 1.7 L/S rate. In 50 m furrow length, the surge flow at 1.7 L/S was 16% higher than that of continuous flow at 1.7 L/S. These results suggest that the high inflow rate did not have a water-saving effect on 100 m furrow length.

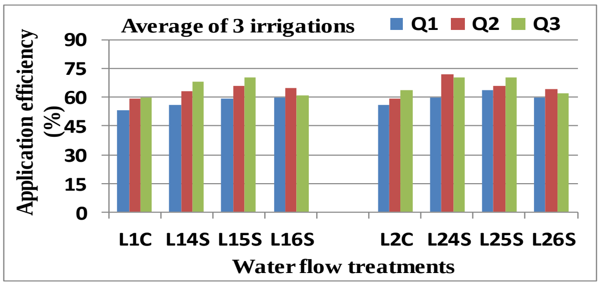

Fig. 4. Application efficiency percentage for different furrow length and surge numbers under various discharge rates as average of three irrigations.

Deep water percolation

On the average basis of the three irrigations, the deep water percolation (D_p) values ranged from 36 to 44, 27 to 39, 30 to 36 and from 31 to 39% for continuous, 4 surges, 5 surges and 6 surges flow in 50 m furrow length, respectively (Fig. 5). The D_p values for 100 m furrow length ranged from 42 to 47, 26 to 34, 26 to 34 and from 33 to 34% for continuous, 4 surges, 5 surges and 6 surges flow, respectively (Fig. 5). In general, it was noticed that under continuous flow, the water losses by deep percolation was more than that under surge flow.

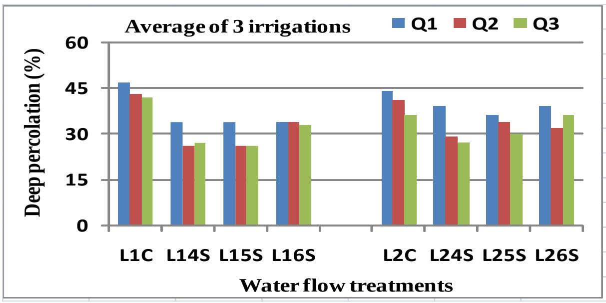

Fig. 5. Deep percolation percentage for different furrow length and surge numbers under various discharge rates as average of three irrigations.

It was noticed that water losses by deep percolation was more pronounced in short furrow length than that of long one. Also deep water percolation decreased as the discharge rate increased. Kifle *et al.* (2017) indicated that irrigation application system was significantly affected deep percolation losses. Conventional furrow (25.4%) has higher loss compared to the alternate furrow (23.4%). This may be because of the clay nature of the soil and intermittent application of water temporarily changes of the soil physical property.

Water distribution uniformity

On the average basis of the three irrigations, the Water distribution uniformity (DU) values ranged from 76 to 82 and from 88 to 93% for continuous and surges flow in 50 m furrow length, respectively (Fig.6). The DU values for 100 m furrow length ranged from 76 to 83 and from 86 to 94% for continuous and surges flow, respectively (Fig. 6). It might be observed that the distribution uniformity (DU) was more obvious for 100 m furrow length than that of 50 m furrow length. In general, the results revealed that the surge flow realized higher DU than that of continuous one. Also, the DU increased as the discharge increased under continuous flow in both furrow length through all irrigation. Increased irrigation discharge led to increased water application efficiency and improved water distribution uniformity. This means increasing irrigation discharge enhanced the uniformity of water distribution and is expected to provide good conditions for distributing irrigation water along and within the irrigation run. The surge flow treatments were more effective in improving the uniformity of soil moisture distribution along the field than continuous flow treatment. This might attributed to that surge flow irrigation leads to higher water distribution efficiency, due to less water losses by deep percolation and less amount of applied water during irrigation (El-Dine and Hosny, 2000). Kifle *et al.* (2017) found that the highest distribution uniformity was obtained for 3 surges flow (86.2%) and the least one was for continuous (67.1%). This could be due to the soil macro pores are sealed with the soil silt particles for the surge flow treatments.

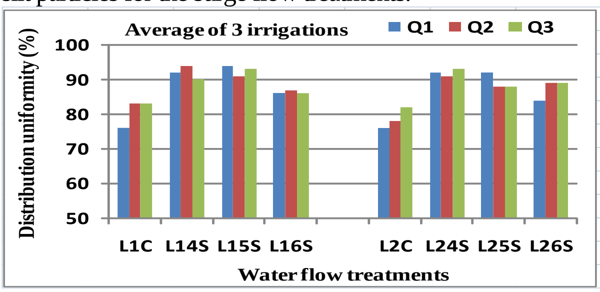

Fig. 6. Distribution uniformity percentage for different furrow length and surge numbers under various discharge rates as average of three irrigations.

It could be concluded that the surge flow had a faster advance rate than that of continuous ones. The saved time to irrigate short furrow length increased as the discharge rate increase regardless the irrigation manner. The amount of applied water decreased as the discharge rate increased nevertheless the furrow length or irrigation manner is. It decreased as the surge numbers increase. The consumed water is higher under continuous flow than that of surge one. Surge flow irrigation on clay-textured soils will reduce irrigation water applied and the time required to irrigate a given site. Surge flow could save almost one third of the applied water by continuous flow especially into long furrow with 5 surges of medium discharge rate. A larger discharge coupled with large furrow resulted in the maximum water saving of about 28% among all the other combinations. The volume ratio remained less than one indicating that less total water is required to complete the advance phase in surged irrigation compared to continuous one. The small volume ratio means great water saving. The application efficiency of continuous flow was less than that of surge flow and it increased as the discharge increased and with long furrow.

Deep water percolation (D_p) of continuous flow was more than that of surge flow and it decreased as the discharge increased and with long furrow. Surge flow realized higher distribution uniformity (DU) than that of continuous one with high discharge rate.

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فاعلية التدفق النبضى لريي الخطوط تحت ظروف مصر العليا

محمود محمد السيد *، مصطفى يونس خلف الله ، مصطفى جبريل أحمد وعلي سيد علي عبد الموجود

قسم الأراضي والمياه كلية الزراعه جامعة الأزهر بأسيوط

أقيمت تجربة حقلية بالمزرعة البحثية لكلية الزراعة جامعة الازهر باسيوط , مصر والتي تقع بين خطي طول وعرض 36.86 و 31.09 وترتفع عن سطح البحر حوالي 51 متر خلال الفترة من شهر سبتمبر حتى ديسيمبر 2018 بهدف تقييم أداء وفاعلية الرى النبضى بالمقارنة بالري المستمر (التقليدي) عن طريق قياس معدل التقدم في جبهة الابتلال ومعدل تدفق المياه الى الخطوط ومعدل خروجها وكذلك تجانس توزيع المياه وكفاءة الاضافة واختيار أنسب طول للخط مع أنسب عدد من النبضات مع معدل التصرف. وقد أظهرت النتائج أن استخدام نظام الري بالنبضات يؤدي الى تقليل الوقت اللازم للري مقارنة بالري المستمر وينخفض وقت تقدم وانحسار الماء بشكل واضح تحت استخدام معدل تصرف أقل وخط أطول. وقد أدى استخدام الري بالنبضات الى توفير كمية مياه الرى المضافة بالمقارنة مع الري المستمر وقد أدى استخدام الرى ب 5 نبضات مع معدل تصرف متوسط الى توفير ما يقرب من ثلث كمية المياه المستخدمة بالمقارنة مع الري المستمر خاصة في الخطوط الطويلة. وقد أدى تطبيق التصرف الأعلى بالخطوط الطويلة الى توفير ما يقرب من 28 % من المياه المضافة بالمقارنة مع باقي المعاملات. وكانت كمية المياه المضافة بالري النبضي حتى تصل الى نهاية الخط أقل بالمقارنة مع الري المستمر وقد حقق استخدام الرى ب 5 نبضات بتصرف 1.2 لتر/ث فى الخطوط الأطول اعلى كفاءة اضافة للمياه (83%). وقد حقق الري بالنبضات أعلى تجانس لتوزيع المياه على طول الخطوط بالمقارنة مع الرى المستمر.