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# Control of inflow rate using cutback and surge flows for improving furrow irrigation performance in clay soils

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## Abstract

Surge and cutback techniques can be used to control inflow rate for improving irrigation efficiency and save water. This study was conducted for hydraulic assessment of surge flow, cutback and continuous flows (Control) in 160 m field length for analyzing the potential of reducing tail water and deep percolation losses. The experiment included eight treatments for two factors (inflow rate and operating techniques). The furrow discharge rate is taken as main plot at two levels (high 2.70 l/s and low 1.5 l/s) and four inflow control operating techniques as sub-plots two levels of inflow cycle ratios "0.50, 0.75", one cutback at furrow tail, and continuous flow as control. Field data obtained indicated that for all flow rates and at all irrigation times' control of inflow rate by surge technique resulted in remarkably shortest advance rate at furrow end in comparison to other inflow control methods. The results show that the highest application efficiency was obtained under surge flow with 0.75 cycle ratio, the highest distribution efficiency was obtained at a cycle ratio of 0.50 .Advance time to furrow tail for low and high inflow levels is faster with both surge irrigation treatments than with continuous flow treatment. To improve performance of furrow irrigation with 160 m length it is advisable to adopt 0.50 ratio surge flow control technique with high flow rate.

**Key words**: Inflow cutback, Surge flow, Continuous flow, Furrow irrigation performances

### Introduction

Surface irrigation is the oldest method of irrigation. It is practiced by flooding the soil surface (border and basin irrigation) or by running water into small ditches (furrows).

Surge irrigation was first introduced in Utah State University (USA) by Stringham and Keller (1979) as a means to improve surface irrigation systems (Mc Cornick *et al.*, (1988).

In surge irrigation is a water is applied in a series of relatively short "on" and "off" modes of constant or variable time spans (Latif, and Ittfaq, 1998).

Surge irrigation is reported to reduce infiltration resulting in quick advance rate and uniform wetting throughout the entire furrow (Solaimalai and Rajagopal, 2002). A study for comparing surge irrigation (with 0.33 and 0.50 ratios) and continuous furrow methods using two inflow rates (0.0498 and 0.12 $m^3$/min) for cotton in the Harran plain- Turkey was made in 130-160 m furrow length was made by Kanber *et al.*, (2001). The study revealed that surge irrigation treatments resulted in fast advance rate than continuous flow irrigation.

The application efficiency achieved using surge irrigation is low (60%) but slightly better than that attained by continuous flow irrigation. He concluded that although surge irrigation reduced tail water losses it is advisable to conduct more research to acquire more information to aid in establishing the best management practices in the field, including the optimum combination of inflow rates, cycle times, number of surges, and relation with cut-back techniques. Amer *et al.*, (2017) compared continuous flow with 0.5 cycle ratio surge irrigation with two inflow rates (0.37l/s and 0.74 L/s). He claimed that flow control by surge irrigation conserved irrigation water, decreased advance time furrow end and increased distribution uniformity in comparison with continuous flow.

Abdel Moneim *et al*., (2015) compared surge flow, cutback and continuous flow and concluded that surge irrigation outperformed these techniques in terms of overall application efficiency. They reported that water saving by surge irrigation varied from 23 to 60 % over continuous flow for furrow length 82 m and mean stream size of 3 L/s.

El-Said *et al*., (2019)studied hydraulic performance of continuous irrigation and surge irrigation technique using 0.50 cycle ratio at three furrow lengths (20, 30 and 40 m) and three different inlet discharges (12.24, 24 l/min). The results indicated that for all furrow lengths increasing inflow rates decrease the advance time under surge irrigation system. They attributed the fast advance rate to the soil sealing during surge flow and to the long off time made by 0.50 ratio that give more water intake before the second surge start. Mc Cornick *et a l*(1988) made field study for the assessment of surge and continuous furrow irrigation methods in relation to tillage systems.

The study was conducted on 95 m long furrows having a slope of 0.04% and 1.5 l/s inflow rate with four surge cycles. It showed that the highest water application efficiency (88.13%) was obtained from using mould board plough. whereas the highest distribution uniformity (85.01%) was obtained using three cycles with the rotary plough. Karim and Karim, (2020) studied surge flow at different cycle ratio (0.33, 0.66 and 1.0) and different cycle number (3, 4 and 5) and cutback irrigation in a cracking soil, for enhancing furrow irrigation performance and water productivity through better design and water management. The experiments were conducted using furrows lengths in the range of 10 – 70 m, constant inflow rate of 0.4l/sand four depletion levels (25%, 50%, 75%, and 100%).The experiment revealed that the surge flow with a cycle ratio of 0.33 advanced faster than the others ratio and continuous flow. The cycle ratio of 0.66 offered the highest value for Ea and Ed, followed by the cycle ratio of 0.33.

The main aim of this study is to evaluate the hydraulic performance of conventional furrow irrigation in comparison to surge and cutback, while the specific aim is to evaluate furrow irrigation performance under surge and cutback techniques.

## MATERIALS AND METHODS

**Experiment site:** This study was conducted at Faculty of Agricultural Technology and Fish Sciences, Al Neelain University in Khartoum state (15°23'N, 32°54'E; altitude: 384m) during the 2021summer season.

A semi-desert /arid climate prevails in this area, with warm winters and hot and dry summers. The average temperature is 29.90 °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.

**Experimental Layout:** A field area measuring 3584 $m^2$ (160 x 22.4 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 four plots with three replications (irrigation frequency) of each plot; each plot was 5.6 m wide and 160 m long.

Each plot was used for a specific treatment. The area of each plot was 896 $m^2$. Each treatment involved five furrows; three middle furrows for monitoring irrigation events and the other two furrows as buffer.

**Treatments:** This study was conducted for hydraulic assessment of inflow rate and inflow operating techniques (surge flow, cutback and continuous flows as control) in 160 m field length for analyzing the potential of reducing tail water and deep percolation losses.

The treatment of include two inflow rates of 1.50l/s (Q1)and 2.7l/s (Q2) and two surge flow cycle ratios of 0.5(CR1 with 30min length)and 0.75 (CR2with 54 min length) compared with continuous (C) and cutback flows (CB).

The discharge rate is taken as main plot at two levels (high 2.70 l/s and low 1.5 l/s) and four inflow control operating techniques as sub-plots (two levels of inflow cycle ratios "0.50, 0.75", one cutback at furrow tail, and continuous flow as control).Eight irrigation treatments with three replications were distributed randomly over the study field..

**Field measurements:** Data for advance and recession times was determined by stopwatch at 16 m spaced stations).

Measurements includes: water inflow rate, advance time; furrow geometry; cut-off time, surface storage (water depth and top width), tail runoff data were collected from the middle adjacent furrows(Walker, and Skogerboe, 1987**)**.The furrow length is 160 m with 1.4 m spacing. 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).

Furrows 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).

**Soil Moisture Content:** Soil moisture was determined before irrigation and after irrigation by the gravimetric oven-dry method (Merriam, et al1980, Jensen, 1980) such as:

$$\theta\mathrm{m} = 100\left[\frac{(\mathrm{M_w}-\mathrm{M_d})}{\mathrm{M_d}}\right] = 100\left(\frac{\mathrm{M_w}}{\mathrm{M_d}}-1\right) \text{ …………… (1)}$$

Where; θ m = Moisture content on mass basis (%), Mw = Mass of wet sample (gm), Md = Mass of dry sample (gm).

Surge irrigation time parameters are estimated following (Podmore, *et al*1983; Rodrigues, 1989.and Izuno, and Podmore, 1986) as follows:

**Cycle time:** The Cycle time of a single surge is given by

$$\mathrm{T_c} = \mathrm{T_{on}} + \mathrm{T_{off}} \text{ ……………………………….….. (2)}$$

In which: $T_c$ = Surge cycle time, min, $T_{on}$ = Surge on-time, min and $T_{off}$ = Surge off-time, min

**Net irrigation time**: The net irrigation times were calculated from the following equation.

$$\mathrm{T_n} = \frac{\mathrm{W}\times\mathrm{L}\times\mathrm{d}}{60\mathrm{Q}} \text{ …………………………………..…. (3)}$$

Where, W = Furrow spacing, m, L= Length of furrow, m, d = Depth of irrigation, mm and Q = Inflow discharge, l/s

**On-time and off-time for cycle:** The duration of on-time for surge cycles were determined using the following relationships.

$$T_{on} = T_n/n \text{ ……………………………………..……. (4)}$$

Where,$T_{on}$= cycle on-time, min;$T_n$= net duration of irrigation, min, and n=number of surges.

The cycle ratio defined Rc=$T_{on}$/$T_c$ can be expressed as

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

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

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

The gross time $T_g$ irrigation is given by

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

**Applied irrigation water**: The applied amount of irrigation water was calculated with the following formula (El-Said *et al*. 2019, Walker, and Skogerboe, 1987**)**.

$$\mathrm{Q} = \mathrm{q}\times\mathrm{t_{co}} \text{ ……………………………………… (8)}$$

Where Q: Applied irrigation water ($m^3$); q: Discharge ($m^3$/min) and $t_{co}$: Total irrigation time (min).

**Application efficiency:**Application efficiency was determined from the ratio of average volume of irrigation water infiltrated and stored in the root zone to volume of irrigation water applied according follows equation (Walker, and Skogerboe, 1987**).**:

$$E_a = \frac{Z_{req}L}{Q_0 t_{co}} \times 100 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (9)$$

WhereEa= Application Efficiency (%), $Z_{req}$= required infiltrated volume per unit length (m3/m), L=field length (m),$Q_o$= field inflow ($m^3$/min) and $t_{co}$= time cut off (min).

**Distribution Efficiency (%):** The distribution efficiency was computed form the ratio between the mean of numerical deviations from the average depth of water stored during irrigation (Y) and the average depth stored during irrigation (d). It is mathematically expressed as (Walker, and Skogerboe, 1987**).**:

$$E_d = \left(1 - \frac{Y}{d}\right) \times 100 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ \ (10)$$

**Statistical analysis**: The study data were subjected to analysis of variance (ANOVA) in a randomized complete design using Statistix (Version 8.0, Copyright, USA, 1985-2003). Means were compared by LSD test at 5 % level of significance.

The mean values of each treatment were designated letter (A, B, C etc.) which represent the significance degree of the difference between the means. Means represented by two letters indicate that the difference is not significant or weakly significant.

## RESULTS AND DISCUSSION

**Advance time ($t_L$):** The effect of continuous, cutback and surge flows at different cycle ratios on advance time at furrow end ($t_L$) was recorded along the furrow length during three successive irrigations.

Data from figures (1-6) revealed that, for all irrigations, surge flow (with a 0.50 or 0.75 cycle ratio) had the shortest advance time ($t_L$) compared to continuous or cut back flows.

Observe there was a slight increase in advance time with an increase in cycle ratio from 0.50 to 0.75. That implies that among the treatments, the surge flow with a cycle ratio of 0.50 advanced faster than the others.

It was also observed that the advance time at field end ($t_L$) by the surge flow with a cycle ratio of 0.50 was about 6% and 8.95 % less than the respective continuous flow treatment with flow rates of 2.70 and 1.5 l/s. Increasing the flow rate from 1.50 to 2.70 l/s decreased advance time ($t_L$) with all flow control techniques. This result is in agreement with Kanber *et al*(2001).

For first irrigation, the lowest advance time was 120 and 94 min under flow rates of 1.50 and 2.70 l/s respectively.

For the second irrigation, the cycle ratio of 0.50 decreased advance time less than continuous flow by 2.67 and 5 % under flow rates 2.70 and 1.5 l/s respectively.

Comparison of advance time at furrow end ($t_L$) for first and second irrigations indicated that the first irrigation had a higher advance time than the second irrigation.

This may be due to soil surface smoothing by running water in the latter irrigation (Coolidge *et al*.1982).

For the third irrigation, advance time for cycle ratio 0.50 decreased by 2.51 and 4.84 % the under 2.70 and 1.5 l/s flow rates respectively, in comparison to ($t_L$) reached by irrigation with continuous flow.

Cutback inflow rate resulted in a significant increase of time to reach the furrow end compared to continuous flow or any one of the two surge treatments, resulting in more opportunity for soil water intake. Advance time to furrow tail for low and high inflow levels is faster with both surge irrigation treatments than treatments with continuous inflow rate.

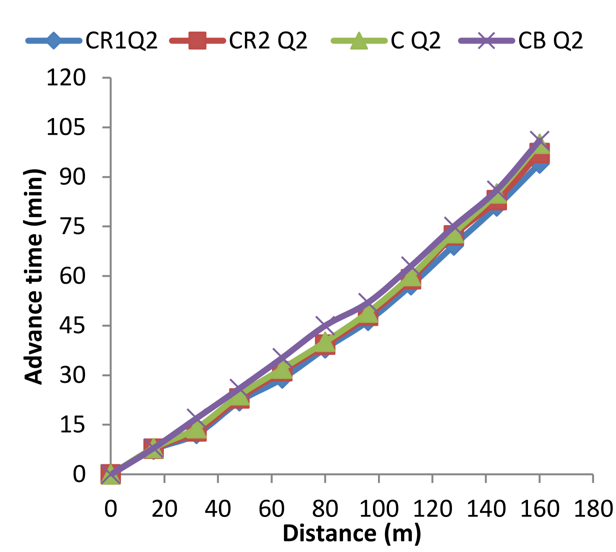


Fig.1. Advance time at first irrigation for 2.7 l/s

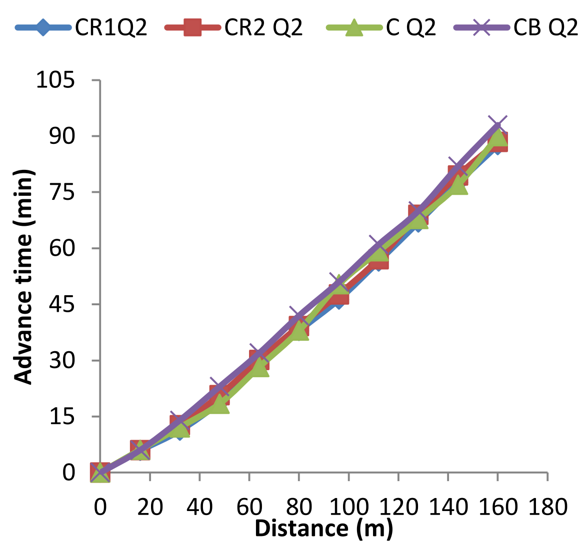


Fig.2. Advance time at 2nd irrigation for 2.7 l/s

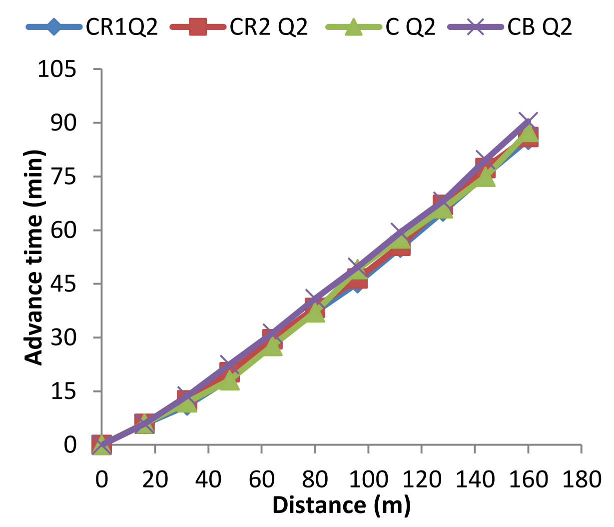


Fig.3.Advance time at 3rd irrigation for 2.7 l/s

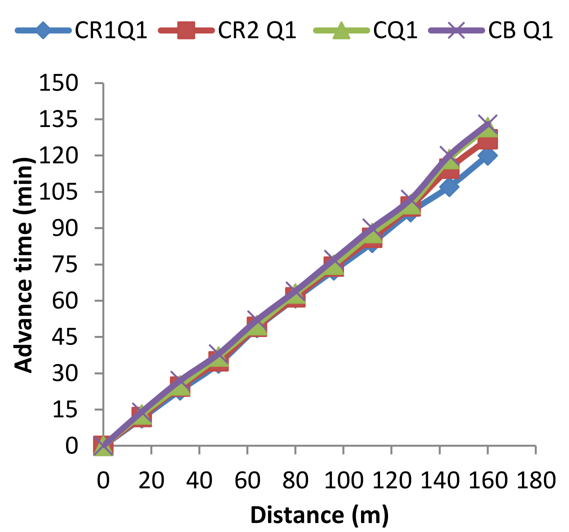


Fig.4. Advance time at first irrigation for 1.5l/s

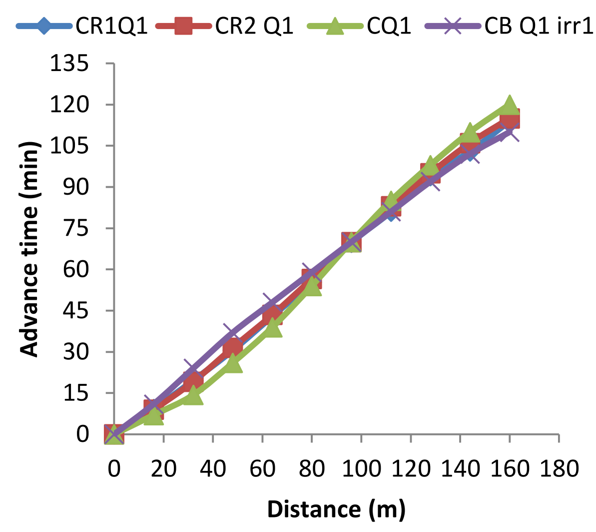


Fig.5. Advance time at 2nd irrigation for 1.5l/s

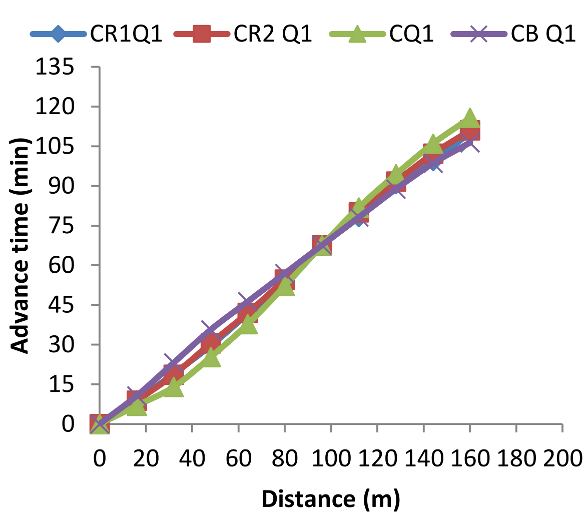


Fig.6.Advance time at 3rd irrigation for 1.5 l/s

**Application efficiency:** The results of analysis of application efficiency "Ea" are shown in Tables 1. The table shows that there are two techniques (Surge 0.75 ratio and Cutback) in which the Ea means are not significantly different (at p>0.05).from one another.

These two techniques (Surge 0.75 ratio and Cutback), Surge 0.50 ratio, continuous flow differ significantly from one another (p>0.05).

It is thus evident that urge flow increased application efficiency compared with continuous flow and within surge flow increasing the cycle ratio from 0.50 to 0.75 increased Ea significantly.

The flow cutback resulted in significant increase in Ea compared to continuous flow. As depicted increasing flow rate from 1.50 to 2.7 l/s with all flow control methods except using continuous flow technique resulted on no significant differences in Ea values, but all control methods with increasing flow rate improved Ea significantly compared to continuous flow technique.

The highest application efficiency was 76.2 % obtained at cycle ratio 0.75, 2.70 l/s, while the lowest application efficiency was 36.8 % obtained at continuous treatment with 2.70 l/s. From such results controlling flow rate did not result in high improvement of Ea and this result calls for investigating other operating parameters. However, these results are in agreement with that found by Amer *et al*. (2017), Abdel Moneim *et al*., (2015) and Kanber *et al.*, (2001).

**Table 1: Effect of irrigation techniques on application efficiency and tail water**

| **Methods** | **Application efficiency (%)** | | **Means** | **Tail water losses (%)** | | **Means** |
|---|---|---|---|---|---|---|
| | 2.7 L/s | 1.5 L/s | | 2.7 L/s | 1.5 L/s | |
| Surge ¾ | 76.20 | 70.60 | 73.4 | 22.23 | 29.40 | 25.8 |
| Surge ½ | 61.57 | 59.40 | 60.5 | 35.87 | 38.90 | 37.4 |
| Cutback | 68.23 | 63.27 | 65.8 | 11.07 | 35.57 | 23.3 |
| continuous | 36.80 | 55.77 | 46.3 | 63.20 | 43.80 | 53.5 |
| Means | 60.7 | 62.3 | Means | 33.1 | 36.9 | |

**Surface Runoff losses (%):** The analysis of variance for surface runoff or tail water loss is depicted in table1. The table shows that cut back of the high flow rate resulted in the lowest water losses compared to all other flow control methods.

In the table it is clear that there are five groups in which the means are not significantly different ($p>0.05$) from one another.

Water losses is highest (63.20%) with no flow control is used (Continuous at 2.7l/s). Similar results were reported by Kanber *et al.,* (2001) Increase of inflow rate in general resulted in increase of tail water losses except with cutback which reduced the tail water losses tremendously.

The control of flow rate by surge and cut back techniques at low flow rate resulted in significant low water losses compared to uncontrolled continuous flow (Westendorp, and., Podmore, 1987, Westfall, 1987).

**Deep percolation ratio**: The effect of the interaction between irrigation techniques and flow rate on the deep percolation at a significant level ($p>0.05$) is shown in Table 2.

There are two groups in which the means are not significantly different from one another and the highest value of deep percolation was obtained 20.7% at 2.7l/s for cut back flow, while the lowest value of deep percolation was obtained 0.0% at (2.7l/s for continuous flow) and surge 0.75 for 1.5 l/s.

Regarding the effect of flow rate on deep percolation, all two means are significantly different from one another and the mean values for deep percolation were 6.2 and 0.8% for flow rate 2.7 and 1.5l/s respectively.

**Distribution efficiency:** Analysis of variance for distribution efficiency (Ed) with statistical significant ($p>0.05$) shown in table 3 reveal that Ed increase with increase of flow rate but these difference were not significant at all proposed flow control methods.

The results showed that in general obtained values of Ed are high.

**Table 2: Effect of irrigation techniques on deep percolation ratio**

| Methods | deep percolation ratio | | Means |
|---|---|---|---|
| | 2.7 L/s | 1.5 L/s | |
| Surge ¾ | 1.6 | 0.0 | 0.8 |
| Surge ½ | 2.6 | 1.70 | 2.2 |
| Cutback | 20.7 | 1.17 | 10.9 |
| Continuous | 0.0 | 0.43 | 0.2 |
| Means | 6.2 | 0.8 | |

The highest value of application uniformity were 89.03 % which obtained by cycle ratio 0.50, at 1.5l/s while the lowest value were 81.17 which obtained by cutback with flow rate 1.5l/s. The results showed that, flow rate, cycle ratio and there were found to be statistically significantly affecting the distribution efficiency.

Surge flow increased distribution efficiency comparing with continuous and cut back flows; under surge flow an increase cycle ratio from 0.50 to 0.75 led to decrease distribution efficiency. Increasing flow rate from 1.5 to 2.7l/s decreased distribution efficiency for surge flow.

The cycle ratio led to a slight increase in distribution efficiency by 0.73 % for flow rate 2.7 l/s comparing with continuous.

This result is in agreement with Mostafazadeh, and Mousavi (1989). Under surge flow increasing cycle ratio from 0 .50 to 0.75 decreased distribution efficiency by 1.97% for flow rate 1.5 l/s.

**Table 3: Effect of irrigation techniques on distribution efficiency and Storage efficiency**

| Methods | Distribution efficiency (%) | | Means | Storage efficiency (%) | | Means |
|---|---|---|---|---|---|---|
| | 2.7 L/s | 1.5 L/s | | 2.7 L/s | 1.5 L/s | |
| Surge ¾ | 86.80 | 87.27 | 87 | 91.3 | 86.3 | 88.8 |
| Surge ½ | 87.17 | 89.03 | 88.1 | 98.5 | 96.3 | 97.4 |
| Cutback | 86.57 | 81.17 | 83.9 | 100.0 | 89.2 | 94.6 |
| continuous | 86.53 | 86.47 | 86.5 | 74.6 | 97.2 | 85.9 |
| Means | 86.8 | 86 | Means | 91.1 | 92.3 | |

**Storage efficiency:** The results of statistical analysis for the effect of continuous cut back and surge flows on storage efficiency were shown in tables 3.

The results indicated that treatments are significantly different ($p>0.05$) for flow control techniques while it is not significantly different for increasing inflow rate.

There is four groups in which the means are not significantly different from one another. Surge flow (0.75 ratio) increased storage efficiency compared with continuous flow.

Under surge flow, an increasing cycle ratio from 0.50 to 0.75 led to decreased storage efficiency.

Increasing the flow rate from 1.5 to 2.7l/s increased storage efficiency under cutback and surge flow, while an increase the flow rate from 1.5 to 2.7l/s led to a decrease in the storage efficiency for continuous flow.

The cycle ratio 0.50 led to an increase in storage efficiency by 24.26% for flow rates 2.7l/s compared with continuous flow.

Increasing the cycle ratio from 0.50 to 0.75 decreased storage efficiency by 10.38 and 7.31% for flow rates of 1.5 and 2.7l/s respectively. Cutback flow increased storage efficiency by 25.4 % for flow rate 2.7 compared with continuous flow.

The highest storage efficiency was 100% obtained at cutback, 2.7l/s, while the lowest storage efficiency was 74.6%, obtained at continuous, 2.7l/s.

This result is in agreement with Abdelmoneim *et al*. (2015), who reported that the highest storage efficiency was obtained under surge irrigation.

**RECOMMENDATION:**

Conduct more studies on surge and cutback techniques by choosing economical crops to evaluate the impact of surge and cutback techniques on water use efficiency.

**CONCLUSIONS**

1.Generally, the surge flow advanced faster than the cutback and continuous flows.

2. The surge flow treatments give the highest values for application efficiency and distribution efficiency compared with continuous flow.

3. Within surge flow treatments, the cycle ratio of 0.5 to faster advanced than the cycle ratio of 0.75.

4. Improvements in application efficiency obtained under surge flow for furrow length of 160 m is rather low, calling for investigating the impact of other design and operating parameters (application depth, furrow length, application time, furrow cross-sectional area and slope).

5. In this study, tail water losses were greater than the deep percolation losses.

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