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SURGE-FLOW IRRIGATION AS INEXPENSIVE TECHNIQUE FOR WATER RATIONALIZATION IN NILE DELTA

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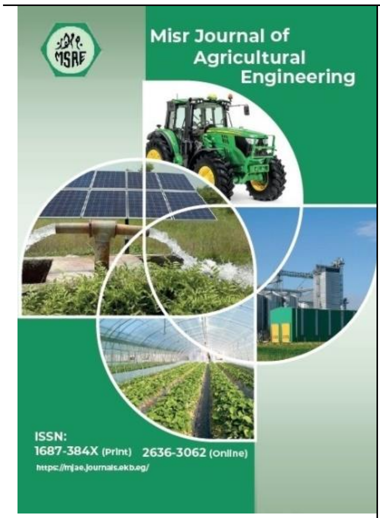

ABSTRACT

This paper examines surge-flow irrigation as a cost-effective strategy for water rationalization in the Nile Delta. The study explores the benefits of this technique compared to traditional continuous-flow irrigation, using field trials to assess its effectiveness. The experiment took place on a private farm located in El- Santa district, Gharbiya Governorate, middle of the Nile Delta, Egypt, cultivated with corn (Zea Maize) during growing season of 2023, 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 (seasonal irrigation requirements,* Q_{req}*; application efficiency,* E_a*; water storage efficiency,* E_r*; water use efficiency,* E_{wu} *and distribution uniformity,* D_{Up} *are measured and/or estimated and discussed. Surge flow with three cycle-ratios was compared to continuous flow to opened long furrows of 120 m length without dikes. Main results cleared out that the water applied during surge treatments advanced faster compared with continuous one. On average, water saving of 18 to 30 percent was observed in surge-irrigated furrows under different levels of discharge and on-off cycles. Performance indicators such as, per each irrigation and seasonal volume of water needed to complete irrigation, distribution uniformity, application efficiency, deep percolation losses and yield of corn, the surge mode of irrigation is convincingly better compared with continuous irrigation.*

Keywords:
Furrow irrigation; Pulse flow; Performance indices; Application efficiency; Water storage efficiency; 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 (Mattar et al., 2017 ; Radmanesh et al., 2023)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. Omori et al., (2020) 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. Okasha et al., (2021) found that surge flow provides the desired crop water requirement at almost 40% saving in water and time as well as improving the distribution uniformity and application efficiency of irrigation to about 90%.

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** (Amer & Attafy, 2017; Mehri et al., 2023; Romay et al., 2024). The surge flow irrigation of the level furrows was successfully managed under the field conditions with decreases in water applications (2-22%) and the water intake (14-25%), except in the treatments of surge (Q_1 CR_1) (at which the flow rate was 0.05 m^3/min and cycle ratio was 0.5) with 9% increase in the latter together with 21-38% decrease in the tail water runoff and 19-70% decrease in the calculated deep percolation below the root zone of 1.20 m depending on inflow rates and cycle ratios Spencer et al., (2019).

Radmanesh et al., (2023) They compared the effects of surge furrow irrigation versus continuous irrigation on water management for various tillage systems. Water savings were obtained utilizing the surge technique with all tillage systems, according to the findings. They found that water applied during surge treatments advanced faster compared with continuous one. On the average, water saving of 8 to 34 percent was observed in surge-irrigated plots under different levels of discharge 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 on surge flow irrigation was conducted on a corn (*Zea Maize*) field during the growing season ٢٠٢٣.The main objective is to assess how far the intermittent irrigation could be followed to improve furrow irrigation Performance.

MATERIAL AND METHODS

This study aimed to evaluate the performance of surge-flow irrigation compared to continuous-flow irrigation under typical conditions in the Nile Delta. Two critical design and management variables were selected for analysis: the initial unit flow rate (Q_0) and cutoff time (t_{ao}). These variables were used to measure key irrigation performance indices, including seasonal irrigation requirements (*Qreq*), application efficiency (*Ea*), water storage efficiency (*Er*), water use efficiency (*Ewu*), and distribution uniformity (*DUp*).

- Experimental Setup

The field experiment was conducted on about 6050m^2 farm located in El- Santa district, Gharbia Governorate, middle of the Nile Delta, Egypt (located on geographical coordinate, latitude 30°.7028' N and longitude 31°. 0966' E). The soil type in the experimental area is a clay loam, which is typical of the region, the conventional applied irrigation method is flood irrigation. Table (1) represents main Soil- water and physical characteristics. The experiment compared surge-flow irrigation with three different cycle ratios to traditional continuous-flow irrigation. The furrow spacing is 0.70 m, the furrow length is 120 m, and the furrow slope is 0.1%.

Table (1) Main Soil - water and physical characteristics of experimental soil.

Depth (cm)	Layer thickness (cm)	Bulk density (g/cm^3)	Porosity (%)	Field capacity		Wilting point		Available soil water	
				($m^3 m^{-3}$)	(mm)	($m^3 m^{-3}$)	(mm)	($m^3 m^{-3}$)	(mm)
0-15	15	1.24	52.3	0.335	83.8	0.170	42.5	0.165	41.3
15- 30	15	1.47	42.5	0.325	65.0	0.165	33.0	0.160	32.0
30- 60	30	1.49	44.5	0.269	51.7	0.137	26. 6	0.133	25.2

- **Treatments**

The field study on surge flow irrigation was conducted in a corn (*Zea Maize*) field during the growing season 2023. 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 (≈ 50.8 mm).

- **Irrigation Variables**
  - **Initial Unit Flow Rate (Q_0):** The initial flow rate was maintained at 20 liters per second for both surge and continuous-flow irrigation systems. This flow rate was selected based on previous studies that recommend it for furrow irrigation in the region.
  - **Cutoff Time (t_{ao}):** The cutoff time for each irrigation event was determined based on soil moisture depletion and crop water requirements. The same cutoff time was applied to both the continuous-flow and surge-flow treatments to ensure comparability.

- **Performance Indices**

1. **Seasonal Irrigation Requirements (*Qreq*):** The seasonal irrigation requirements were calculated by measuring the total volume of water applied over the entire growing season for each treatment. These values were compared to determine the water-saving potential of surge-flow irrigation.

The volume of water applied for each irrigation event was measured by the following formula:

$$q = c_d . A . \sqrt{2gh} . t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where:

q = the rate of discharge ($L^3 t^{-1}$)
c_d = coefficient of discharge (≈ 0.65)
A = cross- sectional area of siphon (L^2)
g = acceleration due to gravity (Lt^{-2})
h = effective head (L)

For each irrigation event, the outflow discharges (Tail water or Surface Runoff) were measured by calibrated steel V- notch with internal angle of 90° constructed at the exit of middle furrow of each treatment. The following formula was applied:

$$V = \left(\frac{8}{15} c_d \sqrt{2g} \tan\frac{\theta}{2} H^{\frac{5}{2}} \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where:

V= the volume of water in m^3 (L^3)
c_d = coefficient of discharge (≈ 0.60)

g = acceleration due to gravity (Lt^{-2})
Θ = the internal angle of V- notch = 90°
H = effective head (L)

When (Θ) = 90° and c_d = 0.6, the volume of runoff will be:

$$v = 1.417 H^{\frac{5}{2}} \times t \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where:

t = time interval (minutes)

Field data measurements:

Evaluation of continuous and surge irrigation systems can be concluded from several perspectives according to several irrigation parameters.

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 (seasonal irrigation requirements, Q_{req}; application efficiency, E_r; water storage efficiency, E_r;; and distribution uniformity, D_U water use efficiency, E_{wu} are measured and/or estimated and discussed.

- Soil water content measurements were performed before and 2 days after irrigation. The methodology applied is referred by (Genemo Kore, n.d., 2020) As the following:

$$GWC = \frac{W_w - W_d}{W_d} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

1. **Application Efficiency (*Ea, %*):** Application efficiency was calculated as the percentage of applied water that was stored in the root zone and available for plant use, following the equation

$$E_a = \frac{Z_{avg(root-zone)}}{Z_{req}} \times 100 \qquad \text{(Genemo, 2020)} \quad (5)$$

Where:

$Z_{avg(root-zone)}$: Water stored in root zone

Z_{req}: Water applied

The average depth of water applied, D (mm), was computed from:

$$D = \frac{q_{avf} \times 60 \times t_{co}}{L \times s} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Where q_{avf} is the average furrow inflow rate (L/s) during an irrigation event, t_{co} is the cutoff time or duration of the inflow (min), and s is the furrows spacing (m).

2. **Water Storage Efficiency (*Er*):** Water storage efficiency refers to the proportion of water required by the crop that was actually stored in the root zone. This index was calculated as:

$$\mathrm{Er} = \frac{\text{Water stored in root zone}}{\text{Water required by crop}} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

The treatments shown in table (2) were applied:

Table (2): The applied treatments

No	Treatment	Descriptions
1	S_1Q_1	At which, the water was applied through one siphon tube (Q_1) and permitted to advance over one fourth of the furrow length (30m), (S_1), where the flow was cut off. The time of advance was recorded and the flow was cut off for equal time. The same cycle was repeated for the second fourth and so on up to completing the furrow length.
2	S_2Q_1	At which, the water was applied through one siphon tube (Q_1) and permitted to advance over one third of the furrow length (40m) (S_2), where the flow was cut off. The time of advance was recorded and the flow was cut off for equal time. The same cycle was repeated for the second third and so on up to completing the furrow length.
3	S_3Q_1	At witch, the water was applied through one siphon tube (Q_1) and permitted to advance over first half of the furrow length (60m), (S_3), where the flow was cut off. The time of advance was recorded then the flow was cut off for equal time, then the furrow length was irrigated.
4	CQ_1	At witch, the water was applied through one siphon tube (Q_1) and permitted to advance over full length of the furrow. The time of advance was recorded.
5	S_1Q_2	At witch, the water was applied through two siphon tubes (Q_2) (Twice of Q_1) and permitted to advance over one fourth of the furrow length (30m), (S_1), where the flow was cut off. The time of advance was recorded and the flow was cut off for equal time. The same cycle was repeated for the second fourth and so on up to completing the furrow length.
6	S_2Q_2	At witch, the water was applied through two siphon tubes (Q_2) (Twice of Q_1) and permitted to advance over one third of the furrow length (40m), where the flow was cut off. The time of advance was recorded then the flow was cut off for equal time. The same cycle was repeated for the second third and so on up to completing the furrow length.
7	S_3Q_2	At which, the water was applied through two siphon tubes (Q_2) (Twice of Q_1) and permitted to advance over first half of the furrow length (60m), (S_3), where the flow was cut off. The time of advance was recorded then the flow was cut off for equal time, then the furrow length was irrigated.
8	CQ_2	At which, the water was applied through two siphon tubes (Q_2) (Twice of Q_1) and permitted to advance over full length of the furrow. The time of advance was recorded.

*Each of those treatments was replicated three times, that produced 24 replicates.

3. **Water Use Efficiency (*Ewu*):** Water use efficiency was determined by measuring the crop yield per unit of water applied. This efficiency index is important for assessing how effectively water contributes to crop production:

$$\mathrm{Ewu} = \frac{\text{Crop yield}}{\text{Total water applied}} \quad \text{..........................} \quad (8)$$

- **The uniformity of distribution (DUp)**

The distribution uniformity represents the spatial evenness of the applied water across a furrow. The USDANRCS (formerly, the Soil Conservation Service) has widely used the Low-Quarter Distribution Uniformity rule D_{Ulq} (p = ¼) for surface irrigation to access the uniformity applied to a field, i.e., by the irrigation volume (amount) received by the lowest one-quarter of the field (or furrow) from applications for the whole field. The general form of the distribution uniformity can be given by the formula offered by (Genemo , 2020) as:

$$\mathrm{D}_{Up} = \frac{\mathrm{v}^{-}}{\mathrm{v}} \times 100 \quad \text{......................................} \quad (9)$$

Where: DUp = distribution uniformity (%) for the lowest *p* fraction of the furrow (lowest one-quarter p = ¼), v^{-} = is the mean application volume (m^3), and v_f = is the mean application volume (m^3) for the furrow.

- Soil water data were used through a simplified soil water balance to estimate the irrigation depths required (Z_{recq}). The maximum soil moisture deficit, SMD (mm), observed was assumed as the best estimate of Z_{recq}. For all irrigation events, the root zone depth, RD (m), was assumed equal to 0.6 m based on phenological estimations of the maximum development of corn roots.The average outflow depth at the tail end of the furrow, V_{out} (mm), was calculated from:

$$V_{out} = \frac{q_{out} \times 60 \times t_{out}}{L \times s} \quad \text{...........................} \quad (10)$$

Where q_{out} is the average runoff rate at the tail end of the furrow (l/s) during the runoff time t_{out} (min). TWR was computed from V_{out}.

Statistical Analysis

The data were analyzed using analysis of variance (ANOVA) to determine if significant differences existed between the surge-flow and continuous-flow treatments. Post-hoc tests were conducted to compare the performance of different surge cycle ratios.

RESULTS AND DISCUSSION

- Effect of stream discharge on irrigation advance speed

Cumulative water advance times for the two discharges levels are given in Figures (1) and (2). Figure (1) presents the advance speed (m/min) for each of the four treatments—S_1Q_1, S_2Q_1, S_3Q_1, and CQ_1—as a function of inlet distance (m). As the distance from the inlet grows, the water's progress speed diminishes. This shows that water rushes quicker near the inlet and slows down as it moves deeper into the field. This is a common pattern in furrow irrigation, where resistance and infiltration cause the water velocity to decrease.

Particularly when compared to the continuous irrigation treatment (CQ_1), the three surge irrigation treatments (S_1Q_1, S_2Q_1, and S_3Q_1) appear to have somewhat faster advance rates, particularly when they are closer to the intake (30 m). The differences between the treatments become less noticeable and all of them converge to comparable advance speeds beyond 40 meters from the intake. When opposed to continuous irrigation (CQ_1), surge irrigation (S_1Q_1, S_2Q_1, and S_3Q_1) often maintains a higher initial advance pace. This is probably due to the fact that surge irrigation enables more effective infiltration management, which lowers water loss through deep percolation and speeds up initial water circulation. The difference between surge and continuous flow disappears after 40–50 meters, suggesting that the benefits of surge irrigation for advance speed are greatest close to the inlet and become less significant farther down the furrow due to infiltration and soil moisture balance. There is a slight variance in the advance pace among the surge treatments (S_1Q_1, S_2Q_1, S_3Q_1), with S_1Q_1 often exhibiting the fastest speed, followed by S_2Q_1 and S_3Q_1 having the slowest advance rates. This may indicate that earlier water travel is accelerated by higher cycle ratios (S_1Q_1, for example), maybe as a result of fewer water flow interruptions.

In the early phases of irrigation, faster initial advance rates may result in improved water distribution and shorten the time it takes for the water to reach the end of the furrow. This may help lessen runoff or deep percolation losses and improve the overall efficiency of water consumption. After 50 meters, all treatments converge, indicating that field characteristics like infiltration capacity and the soil take center stage in the passage of water. It shows that although surge irrigation can move water farther more quickly at first, soil interactions in the latter phases determine the final advance pace. The distance of the field to be irrigated and the intended water distribution may influence the decision between surge and continuous flow. Surge irrigation may give considerable advantages in minimizing water loss and boosting advance speed at shorter distances but exhibits declining results further down the furrow.

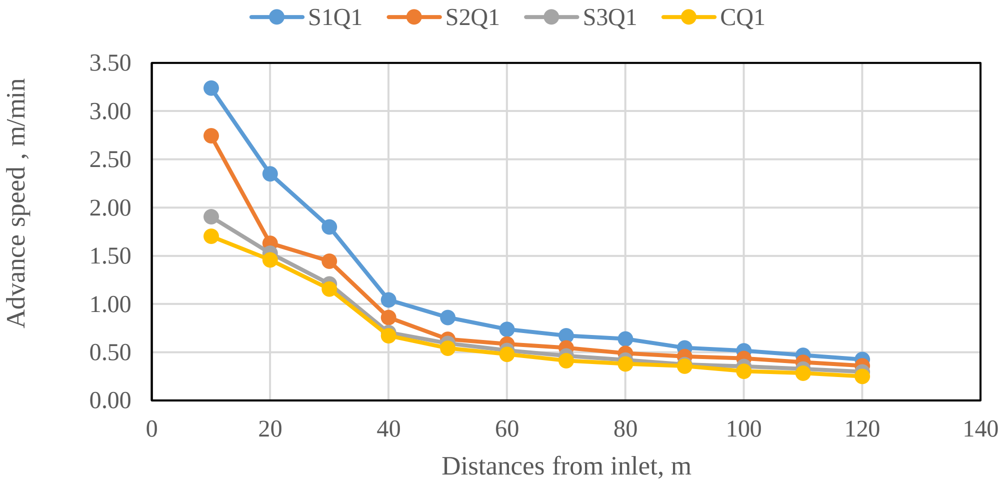

Figure (1) The advance speed (m/min) for different treatments using one siphon tube

Using two syphon tubes, Fig. (2) displays the advance speed (m/min) for four distinct irrigation treatments as a function of the inlet's distance (m). The progress speed of the water decreases sharply with increasing distance from the intake for all four treatments. This is to be expected since resistance and infiltration along the furrow cause the water to slow down. Starting at the fastest advance speed (~3.75 m/min), the S_1Q_2 therapy keeps up a faster pace than the others for around 60 meters. Similar to the other treatments, the progress speed stabilizes after 60 meters at 0.5–0.6 m/min. According to this, S_1Q_2 appears to have the greatest initial water movement, which might help during the early phases of irrigation by forcing water deeper into the field.

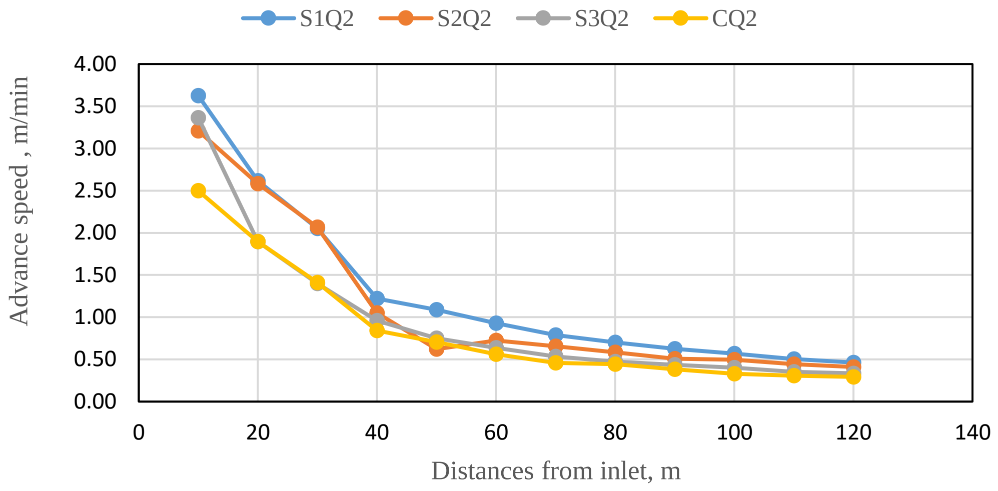

Figure (2) The advance speed (m/min) for different treatments using two siphon tubes

The progress speed in S_2Q_2 begins at a slower rate than in S_1Q_2, approximately 3.0 m/min, and declines gradually. It has dropped to around 1.0 m/min by 60 meters, which is comparable to S_1Q_2 but marginally less. This suggests that S_2Q_2 slows down with distance in a similar way as S_1Q_2, although at a little slower pace. S_3Q_2's advance pace starts off slower than the other surge therapies, at around 2.5 m/min, and it gradually decreases. At around 60 meters, it reaches speeds comparable to S_1Q_2 and S_2Q_2, but it begins at a significantly slower beginning speed. S_3Q_2 seems to have the slowest initial water progress, which might lead to longer irrigation durations so that the water can go to more furrow regions. The treatment of continuous flow, which begins at around 2.75 m/min and decreases in a manner akin to that of surge flow treatments. CQ_2 converges to around 0.5 m/min beyond 60 meters, at which point it approaches the same advancement speed as the other treatments after 40 meters. A slower starting advance than S_1Q_2, CQ_2 begins at a moderate pace and performs similarly to the surge treatments after 40 meters.

When compared to continuous flow (CQ_2), surge treatments (S_1Q_2, S_2Q_2, and S_3Q_2) often exhibit greater starting advance speeds, particularly for S_1Q_2. Surge irrigation's increased starting speed is probably caused by the water cycle, which helps drive water down the furrow more quickly in the beginning. Surge irrigation has an advantage over continuous flow in terms of faster initial advance, but beyond 40–60 meters, all treatments gradually converge to identical rates. This implies that, above a certain threshold, soil characteristics, infiltration, and furrow length have a greater impact on the pace of advancement than flow type.

In fields that require quick initial water coverage, surge irrigation especially S_1Q_2—may be helpful in distributing water uniformly over the field without requiring an extended period of time close to the intake. Although CQ_2 is slower at first, it appears to operate similarly to surge irrigation after the initial distance, therefore depending on the goals of water management (such simplifying processes or requiring less equipment), it could be a good alternative. There is a definite benefit to surge irrigation, especially S_1Q_2, in terms of initial progress speed. But the benefit decreases with increasing distance, and all treatments converge at roughly the same rate. This suggests that while continuous irrigation might eventually produce outcomes comparable to those of surge irrigation, it may be more effective in the first phases of water distribution.

- Effect of stream discharge on Application efficiency (Ea, %) and runoff:

The relationship between Application Efficiency (Ea%) and Runoff (mm) for each of the four treatments—S_1Q_1, S_2Q_1, S_3Q_1, and CQ_1—is depicted in Fig. (3). The y-axis on the left shows the Ea%, while the y-axis on the right shows the Runoff (mm). The x-axis is used to plot each treatment, and error bars are used to show variability.

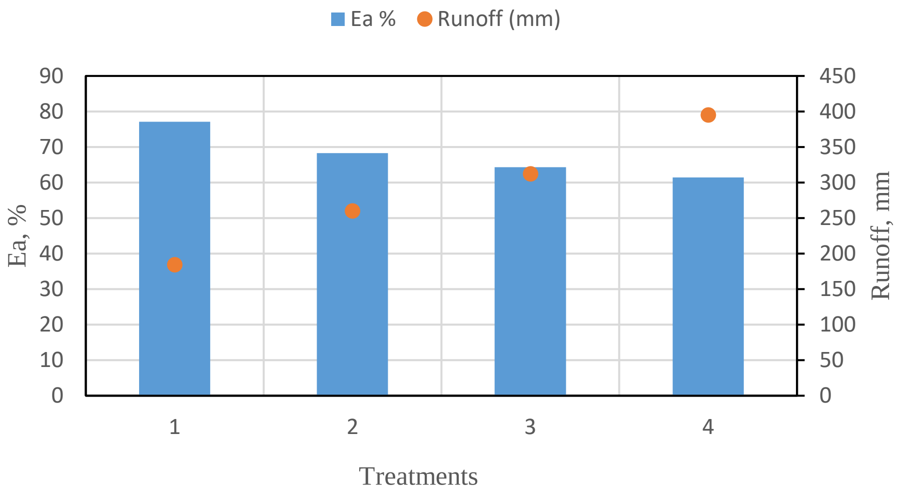

Figure (3): Relationship between stream discharge using one siphon tube and Application efficiency (Ea, %) and runoff

- **Application Efficiency (Ea%):**

S_1Q_1 has the highest application efficiency (~80%), suggesting that the water applied is effectively used with minimal losses. As we move from S_1Q_1 to CQ_1, the application efficiency gradually declines. For S_2Q_1, Ea is around 70%, while S_3Q_1 and CQ_1 show the lowest values (~60%). S_1Q_1 being a surge irrigation treatment, demonstrates the highest efficiency, possibly because the cyclic nature of surge flow allows for better infiltration and reduced water loss, especially near the inlet.

- **Runoff (mm):**

Throughout the treatments, the runoff grows gradually, culminating at CQ_1 (about 400 mm) and beginning at S_1Q_1 (about 250 mm). The continuous flow treatment (CQ_1) exhibits the largest runoff, whereas the surge treatments (S_1Q_1, S_2Q_1, and S_3Q_1) show increasing runoff. According to the connection, irrigation with continuous flow produces more runoff, which means that water is not absorbed as well and escapes the furrows, potentially causing soil erosion and water waste. It is evident that runoff and application efficiency are inversely related. The application efficiency falls with increasing runoff, suggesting that increased runoff is linked to less effective water usage.

When compared to continuous flow (CQ_1), the surge treatments (S_1Q_1, S_2Q_1, and S_3Q_1) perform somewhat better in terms of balancing efficiency and runoff. This lends credence to the idea that surge irrigation might improve water efficiency by managing runoff. There appears to be a trade-off between minimizing water loss from runoff and saving water through efficient application. The treatments with higher efficiency (S_1Q_1) had lower runoff, whereas those with lower efficiency (CQ_1) likely to have significantly larger runoff. Surge irrigation is beneficial for efficient water usage, as S_1Q_1 has the least amount of runoff and the most efficient water application. The continuous flow treatment, or CQ_1, performs the poorest in terms of efficiency and runoff, indicating the possibility of wasting water while utilizing this technique.

This graph makes it abundantly evident that surge flow—specifically, S_1Q_1—is a more effective irrigation technique for cutting down on water loss and increasing application efficiency, making it a more sustainable choice for irrigation in regions with limited water resources, such as the Nile Delta.

Fig. (4) illustrates the relationship between Ea % (Application Efficiency) and Runoff **(mm)** across four different treatments labeled S_1Q_2, S_2Q_2, S_3Q_2, and CQ_2. The two measured variables, Ea % and Runoff, show contrasting trends.

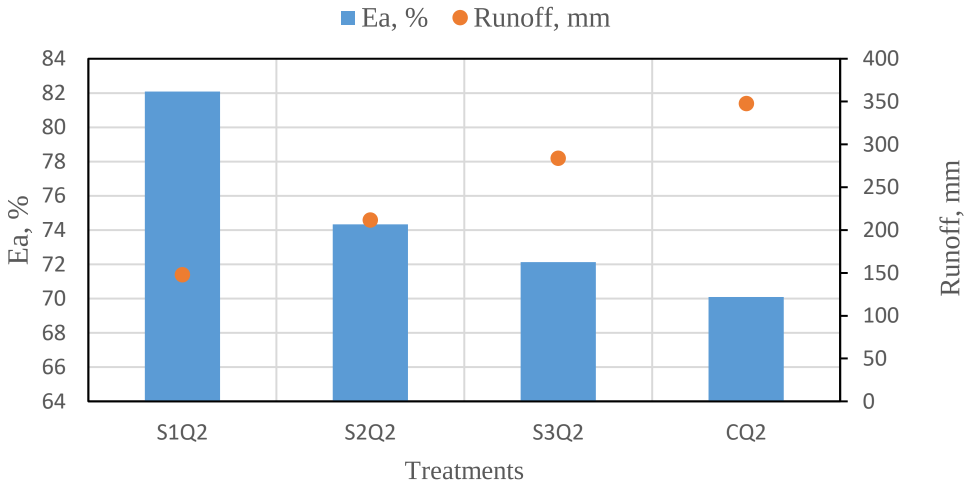

Figure (4): Relationship between stream discharge using two siphon tubes and Application efficiency (Ea, %) and runoff

- **Ea % (Efficiency of Application)**:

Ea is shown as a percentage on the left y-axis. The Ea% begins at a high point (about 80%) in treatment S_1Q_2 and gradually decreases over the course of the treatments, peaking at roughly 70% in CQ_2. This implies that the effectiveness of water application diminishes somewhat as the treatments advance. Reduced efficiency might be a sign of increased water waste or irregular water distribution in the subsequent treatments.

- **Runoff (mm)**:

The runoff (mm) is indicated by the right y-axis. The runoff peaks at roughly 350 mm in CQ_2 after increasing gradually throughout the treatments from a very low starting point of about 30 mm in S_1Q_2. This sudden rise in runoff suggests that more water is being lost as runoff rather than being effectively absorbed or used by the system as a result of changes in the treatments. The connection between runoff and application efficiency (Ea%) appears to be inverse. Runoff increases when the Ea % falls. This inverse link most likely results from more water being wasted, which manifests as runoff, due to less effective water application (lower Ea %). The lowest efficiency in treatment CQ_2 is correlated with the largest runoff, indicating a notable decline in water-use efficiency.

The declining Ea% indicates that more water is wasted as runoff as a result of less effective water application as the treatments advance. The system's capacity to absorb or regulate water is deteriorating, as seen by the growing runoff throughout the treatments. This might result in water waste and soil erosion in subsequent treatments (CQ_2). The variations between treatments may be the result of various soil types, irrigation techniques, or environmental elements that influence the effectiveness of water application and absorption.

- **Effect of stream discharge on Storage efficiency (%):**

Fig. (5) illustrates the storage efficiency (%) across different irrigation treatments: S_1Q_1, S_2Q_1, S_3Q_1, CQ_1, S_1Q_2, S_2Q_2, S_3Q_2, and CQ_2. According this figure, the storage efficiency for treatment S_1Q_1 begins at around 80% and steadily decreases through S_2Q_1 and S_3Q_1, ultimately reaching roughly 70% at CQ_1. This suggests that resource storage efficiency decreases with treatment, with CQ_1 exhibiting the lowest efficiency. A drop in storage efficiency is also seen in Fig. (5), while the beginning values are slightly higher (around 80%), and the trend towards CQ_2 is the same, finishing below 70%. Even if the fall appears to be a little less severe, the tendency is fairly similar.

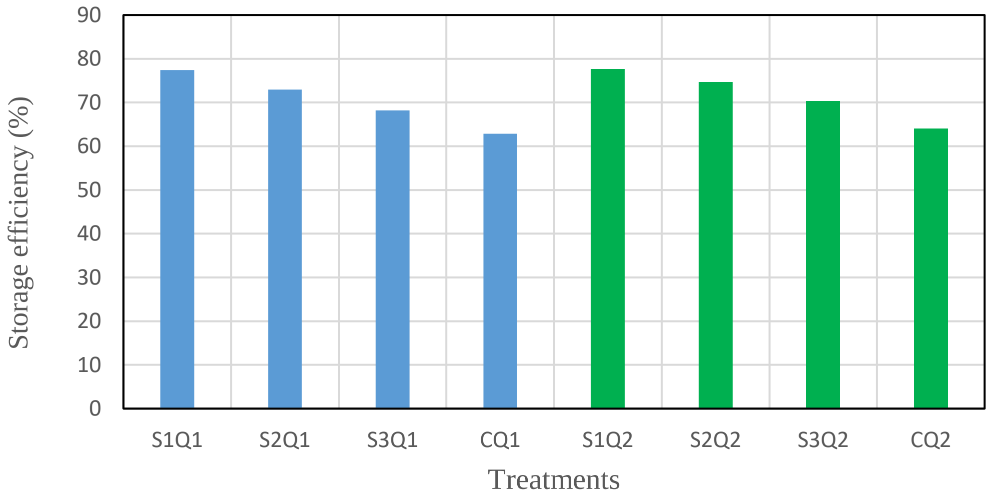

Figure (5): Relationship between stream discharge and Storage efficiency (%) under using:) one siphon tube and two siphon tubes

Treatments ending with "Q_1" (S_1Q_1, S_2Q_1, S_3Q_1, CQ_1) are associated with lower storage efficiencies, ranging from approximately 65-75%.

Treatments ending with "Q_2" (S_1Q_2, S_2Q_2, S_3Q_2, CQ_2) exhibit higher storage efficiencies, falling within the 75-80% range. There is a clear improvement in storage efficiency from Q_1 to Q_2 treatments for each series (S_1, S_2, S_3, and C).

This suggests that the irrigation method used in Q_2 treatments leads to better water or resource utilization, possibly reducing losses or improving yield stability. The Q_2 irrigation treatments, consistently outperforming their Q_1 counterparts, may involve a more effective water delivery method, higher water conservation, or optimized scheduling. The control treatments (CQ_1 and

CQ_2) follow a similar trend, showing that even baseline irrigation practices improve significantly under Q_2 conditions. This figure highlights that the Q_2 irrigation methods are more efficient in maintaining storage capacity or yield sustainability compared to the Q_1 methods across all treatment types. It implies that shifting irrigation strategies from Q_1 to Q_2 can result in more effective water management and potentially higher agricultural productivity.

- **Effect of stream discharge on water productivity:**

The relationship between different treatments and how they impact water productivity is shown in Figure (6). It seems that water productivity decreases continuously from treatment S_1Q_1 to CQ_1. The value for S_1Q_1 starts at around 1.0 mm/kg and decreases to little less than 0.8 mm/kg for CQ_1. This might suggest that the CQ_1 treatment produces less water.

Figure (6) illustrates the link between various treatments and their effects on water productivity. It seems from Fig. 6-a that water productivity constantly drops from treatment S_1Q_1 to CQ_1. For S_1Q_1, the value is around 1.0 mm/kg, while for CQ_1, it is somewhat less than 0.8 mm/kg. This might imply that less water is produced by the CQ_1 treatment. Q_2 treatments consistently outperform Q_1 treatments in terms of water productivity. This indicates that Q_2 irrigation methods are more efficient in converting water into yield (per kg), possibly due to better water retention, optimized irrigation timing, or improved nutrient uptake.

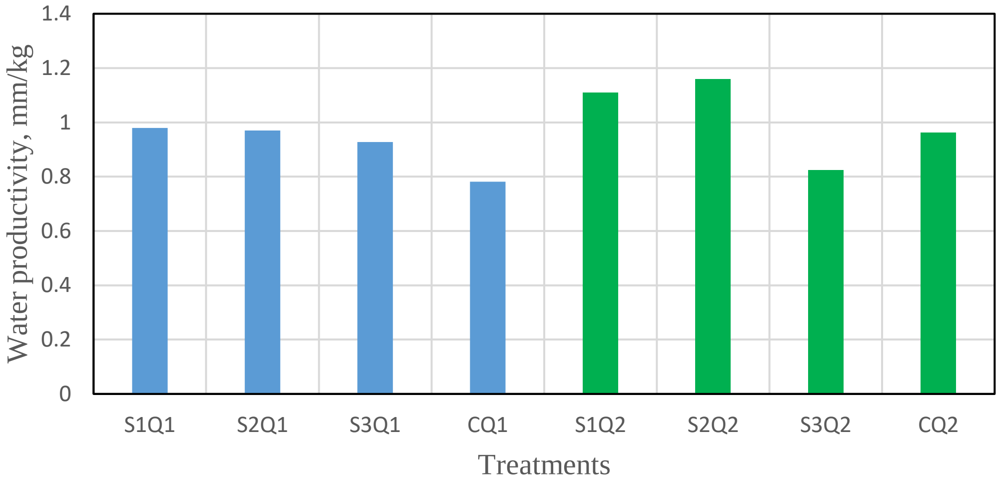

Figure (6): Relationship between stream discharge and water productivity under using: one siphon tube and two siphon tubes

The control treatments (CQ_1 and CQ_2) follow a similar trend, where CQ_2 has significantly higher water productivity than CQ_1. The figure highlights that Q_2 irrigation treatments result in higher water productivity than Q_1 treatments across all scenarios. This suggests that Q_2 methods are more efficient in using water resources, making them more suitable for maximizing agricultural yield while minimizing water input.

- **Relationship between the seasonal applied and stored water under different treatments**

The comparison of seasonal applied water (mm) and conserved water (mm) for different treatments is displayed in Figures 7. The water applied seasonally, as seen in Figure (7). The chart illustrates a progressive rise from around 800 mm in S_1Q_1 to slightly over 900 mm by CQ_1. The water that has been stored, which begins at 600 mm in S_1Q_1 and gradually drops, staying mostly steady at 580–600 mm through CQ_1. This implies that although the amount of water sprayed varies seasonally between treatments, it stays relatively constant in terms of storage capacity.

The trends under using two siphon tubes was similar to the trend for the same treatments with using one siphon tube as shown in fig. (7), the seasonal applied water increases steadily from S_1Q_2 to CQ_2, reaching nearly 900 mm by CQ_2. The stored water stays nearly constant around 600 mm across all treatments, with only minor fluctuations. This pattern mirrors that of Fig. (7), showing an increase in applied water without a corresponding increase in stored water. While the amount of water stored stays mostly same, both figures demonstrate a large rise in the amount of water administered across the treatments (from S_1 to CQ). This could point to inefficient water storage despite the higher application, either as a result of runoff, evaporation, or inadequate water retention.

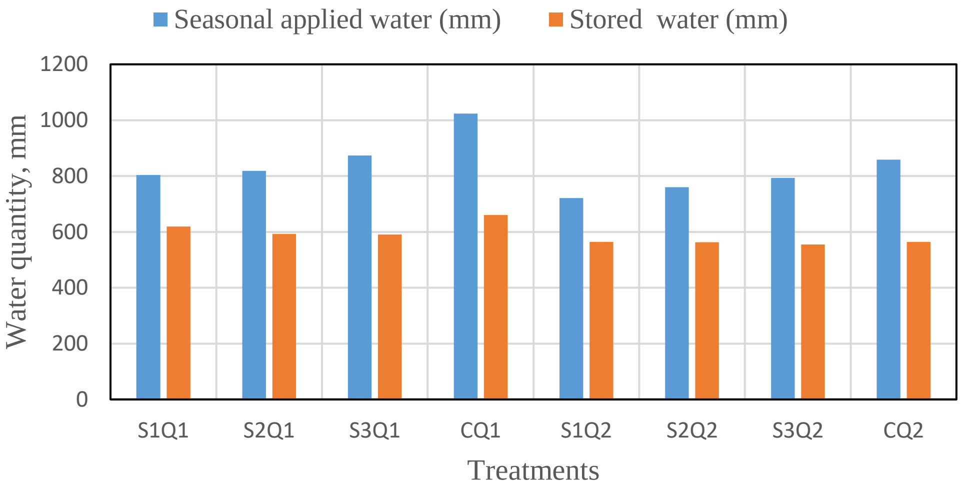

Figure (7): Relationship between the seasonal applied and stored water under different treatments: (a) one siphon tube and (b) two siphon tubes

Treatments ending in "Q_1" (S_1Q_1, S_2Q_1, etc.) tend to have slightly higher seasonal applied water and stored water compared to "Q_2" treatments. This could indicate differences in irrigation frequency, timing, or efficiency between the Q_1 and Q_2 groups.

The control treatments (CQ_1 and CQ_2) show the highest seasonal applied water among all treatments, with a corresponding increase in stored water. This might suggest that the control receives maximum irrigation, or that it operates under standard irrigation practices as a benchmark.

Efficiency of Irrigation Treatments: Comparing the ratio of stored water to applied water across treatments could provide insight into which irrigation schedules are more efficient in retaining water. Impact of Treatment Differences: Exploring why Q_1 treatments generally store more water than Q_2 treatments could reveal underlying factors like soil moisture capacity, crop demand, or climate conditions during each period. The higher water quantities in the control treatments suggest that alternative treatments might conserve water while maintaining similar storage levels.

CONCLUSION

The findings suggest that merely applying more water will not always result in higher water production or storage. Beyond a certain saturation threshold, it is possible that more water may be squandered rather than saved or used efficiently.

The decrease in storage efficiency emphasizes the necessity of looking into other kinds of treatments or methods of management that concentrate on increasing water retention and decreasing losses. Mitigating factors like as irrigation timing, procedures, and soil structure may aid in reducing the reported inefficiencies. In agricultural or environmental management contexts, increasing water productivity and efficiency requires striking a balance between the amount of water applied and the system's ability to retain and use that water efficiently. This might result in the use of water more sustainably, cutting waste and maintaining or increasing output.

Future research should examine various treatments, such as improved irrigation practices, soil amendments, or scheduling strategies that take crop water requirements into account, that might enhance water storage without necessitating drastic increases in water delivery. This would contribute to the development of sustainable and more effective water usage methods in comparable situations.

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الري بالتدفق المفاجئ كتقنية غير مكلفة لترشيد استخدام المياه في دلتا النيل

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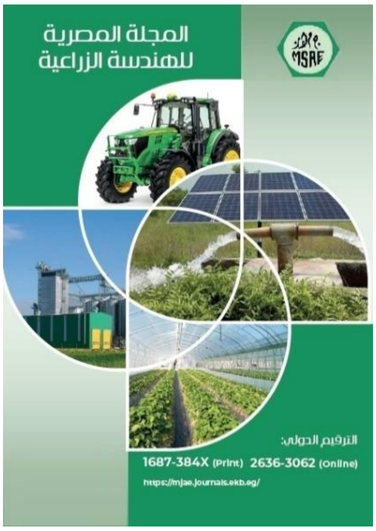

الكلمات المفتاحية:
مؤشرات الاداء لنظام الري؛ كفاءة التطبيق؛ كفاءة تخزين المياه؛ كفاءة التوزيع لمياه الري

الملخص العربى

تتناول هذه الورقة البحثية الري بالتدفق المفاجئ كاستراتيجية فعالة من حيث التكلفة لترشيد استخدام المياه في منطقة دلتا النيل. وتستكشف الدراسة فوائد هذه التقنية مقارنة بالري المستمر التقليدي، باستخدام التجارب الميدانية لتقييم فعاليتها. وقد أجريت التجربة في مزرعة خاصة تقع في مركز السنطة بمحافظة الغربية، وسط دلتا النيل، مصر، مزروعة بالذرة خلال موسم النمو ٢٠٢٣، ذات تربة طينية. في هذه الدراسة، تم اختيار اثنين من متغيرات التصميم والإدارة الرئيسية (معدل التدفق Q_0؛ ووقت القطع، t_{co} بحيث يتم قياس و/أو تقدير ومناقشة مؤشرات الأداء المقابلة) متطلبات الري الموسمية، Qreq؛ وكفاءة التطبيق، Ea؛ وكفاءة تخزين المياه، Er؛ وكفاءة استخدام المياه، Ewu وكفاءة التوزيع، DUp. تمت مقارنة ثلاث دورات للتدفق المتقطع بالتدفق المستمر إلى أخاديد طويلة مفتوحة بطول ١٢٠ مترًا بدون سدود. أوضحت النتائج الرئيسية أن المياه المطبقة أثناء الري المتقطع تقدمت بشكل أسرع مقارنة بمعاملة التدفق المستمر. وفي المتوسط، لوحظ توفير المياه بنسبة ١٨ إلى ٣٠ % في الأخاديد المروية بالطفرة تحت مستويات مختلفة من دورات التفريغ والإيقاف. مؤشرات الأداء لكل معاملة ري مثل حجم المياه الموسمي اللازم لإكمال الري، وتوحيد التوزيع، وكفاءة التطبيق، وفواقد التسرب العميق وإنتاجية الذرة، ونمط الري بالطفرة أفضل بشكل مقنع مقارنة بالري المستمر.