The Use of Dual and Surge Irrigation to Improve The Efficiency of Surface Irrigation

A.M.H. Aljumily* and Isam K. AL-Hadeethi

*Corresponding author's e-mail: ag.abbood.mohammed@uoanbar.edu.iq

Abstract. A field experiment was conducted in a farm (5km northwest of Ramady City) during Autumn Season in a silty clay loam sedimentary soil. The ground water table depth is 120 cm. Field has divided into 10 strips (2.40x80)m with spaces 1m between strips and 2 m between replicates each strips has divided into 3 furrows (20 cm in depth , 80 m length ,with 0.2% slope) with each others.Study factors included Continuous Irrigation (conventional), Dual Continuous irrigation, Continuous irrigation with two phases, Surge irrigation, Dual Surge irrigation Cycle ratio was 0.25 with time On-time 4 minutes and Off-time 12 minutes for both dual surge irrigation and surge irrigation with discharge of 2 liter/sec. for both advance phase while the discharge after completing advance phase was 0.8 liter/sec. The plots were planted with corn (Zea mays L) and irrigated drainage water with salinity 5.8-6.2 ds/m, and Euphrates water (1.1-1.3 ds/m). Consumptive water use was calculated by Evaporation Pan method. Twenty test has been carried out for advance and recession of flow along furrow by using eight observation stations. Apportunity time and absorbed water depth in each middle furrow was calculated at each station. Practical and Theoretical relative yield of corn were calculated. Results showed that Dual Surge Irrigation system reduced of salty water used to complete advance phase with rate of 12.41% comparing with Dual Continuous irrigation system, The efficiency of Salt-water displacement processes downward increased by 11.56% by the effect of fresh water under Dual surge irrigation system compared with Dual Continuous irrigation system, The percentage fresh water saving reached to 44.94% and 51.30% in dual surge and dual Continuous irrigation system respectively, Insert Surge Irrigation technique on Dual Continuous Irrigation system leads to reduce salt-water advance phase time, late in recession time in Dual surge Irrigation and Surge Irrigation with the other treatments during advance and post-advance phase, distribution of Dual surge Irrigation system as compared with dual Continuous irrigation system in salt- water distribution efficiency during advance phase and uniformity of total absorption depth along the furrow for all testing months during the season, the practical relative yield exceeds the theoretical relative productivity when assuming the condition of mixing between fresh water and salt water, the practical relative yield has distinction on the theoretical yield at depth of 0-90-cm in Maas 1984 equation.

1. Introduction

With the spread of water awareness in the countries of the arid and semi-arid regions, the interest in developing and rationalizing the consumption of water resources and preserving them has become part of the citizen’s culture and among the priorities of concerns of workers in the agricultural sector.

The preservation of water resources and creation of alternative resources should be given the first priority when developing a security strategy for the Arab region to overcome the current water gap between the available water resources and the actual needs for consumption. Salin water is used either alone within specific stages of the growing season, by mixing with fresh water, or by alternating use with fresh water when irrigating, but its use carries great risks that may lead to salinization of the soil unless it is studied in a scientific way. From the above, and in order to overcome the problems resulting from the irrigation methods referred to above, the dual irrigation system was proposed.
by [1], whereby the water share required to be added in a single irrigation is divided into two successive waves. The first is to add saline water to the irrigation track to complete the advance phase. Fresh water is added as a second wave immediately after the salin water recession.

The aim of this experiment is to study the effect of surge irrigation and dual irrigation on the efficiency of surface irrigation and the uses of fresh water, analysis runoff under surge and dual irrigation systems and their effect on some soil characteristics and the growth and yield of maize, development of a continuous dual irrigation system into a dual surge irrigation and evaluating the economic feasibility by calculating the actual relative production and the relative production that is predicted due to the use Dual surge irrigation technology.

2. Materials and Methods

A field experiment was conducted northwest of Ramadi city in a silty clay loam soil (ECe=4.5 dS.m-1, PH=7.46, SAR=3.82, BD = 1.38 Mgm-3).

The field was subdivided into 10 strips with dimensions of (2.40 x80)m after primary soil cultivation and leveling. Spaces with width 1m between strips and 2 m between replicates has left. Each strips has divided into 3 furrows (20 cm in depth, 80 m length ,with 0.2% slope) with spaces 80 cm between furrows then Yellow Corn (Zea mays L) varity (106 Bohooth) was planted in Autumn Season.

Five methodes were used:Continuous Irrigation , Dual Continuous irrigation, Continuous irrigation with two phases, Surge irrigation, Dual Surge irrigation

Cycle ratio was 0.25 with on- time 4 minutes and off- time 12 minutes for both dual surge irrigation and surge irrigation with discharge of 2 litter/sec. for both advance phase while the discharge after completing advance phase was 0.8 litter/ sec. Data Analysis in accordance with split-split plot design by using Randomized completely Block design (RCBD) . Genstate 5 statistics Analysis System has used with possibility of 0.05.

2.1. Irrigation system and irrigation scheduling.

The irrigation process was carried out with saline water (5.8 - 6.2) dSm / m during the study period, and the water of the Euphrates River (1.1 -1.3) dSm / m was used as a source of fresh water.

The irrigation process was carried out with irrigation interval according to the system of distributing fresh water between farmers (the rotation system). The amount of water consumption was calculated by using the evaporation pan method.

The amount of evaporated water was measured daily throughout the study period, and from it, the daily water consumption rate was calculated using the following equations, which were mentioned in: [2],[3]

\[ ETp = ETpan \times Kpan \]  
\[ ETcrop = ETp \times KC \]  

whereas: \( ETp \) = reference evaporation-transpiration (mm), \( ETpan \) = Evaporation from an evaporation pan (mm), \( Kpan \) = Evaporation pan Coefficient (without units), \( KC \) = yield factor (without units), \( ETcrop \) = daily crop water intake (mm).

In order to know the percentage of fresh water that was saved during the season due to the use of dual continous irrigation and dual surge irrigation system, the volume of saline water required to complete the advance phase (Vd) during the season was calculated from the following relationship, which was mentioned in [3].

\[ Vd = ad = qt \]  

whereas: a: Area (m^2), d: depth of water added (m), t: The advance time of the saline water required to complete the advance phase (minute), q: discharge (m^3 / min)

As for the volume of fresh water saved, it will be equal to the volume of drainage water used to complete the advance phase during the season for the dual continous irrigation and dual surge irrigation system, that is:

\[ Vd = Vc \]  

So the percentage of fresh water saved during the season will be equal to:
where \( VR = \frac{V_c}{V_t} \) \hspace{1cm} \text{(5)}

whereas: \( VR \) = the percentage of fresh water saved, \( V_c \): - volume of fresh water saved (m\(^3\)), \( V_t \): - the total irrigation volume m\(^3\)

2.2. Advance and recession measurements:

(Twenty) tests were performed for advance and recession of the flow and for all the experiment parameters by adopting a constant slope of the irrigation path (0.2%). To implement this, the furrow was divided into eight stations, the distance between one station and another (10) meters, and metal indication points were fixed at a height of (50) cm above the ground level. At each station to monitor the time of water advance and recession.

The advance and recession time were recorded, Opportunity time at each station was calculated from the difference between the advance time and the recession time at each station.

In order to know the variations between the dual continuous irrigation and dual surge irrigation system parameters in terms of the degree of distribution of the saline water used to complete the advance phase along the furrow, the opportunity time of the saline water at the bottom of the middle furrow was calculated for each station along the furrow within the growing season, the equation below suggested [4]. was used to calculate the efficiency of water distribution (Ed).

\[
Ed = 100 \times \left(1 - \frac{y^\text{‾}}{d^\text{‾}}\right) \hspace{1cm} \text{(6)}
\]

Where \( y^\text{‾} \) represents the average numerical deviation of the storage water depth during irrigation (cm), \( d^\text{‾} \) represents the average depth of water storage during irrigation (cm).

Practical and theoretical relative yield:

After harvesting the maize crop, the practical yield of the grain (ton / hectare) was calculated after adjusting the weight on the basis of 15.5% moisture.

As a result, the actual relative grain yield(\% RY) for the treatment of continuous dual irrigation system and the treatment of dual surge irrigation was calculated according to the following relationship: [5]-

\[
\% RY = \frac{\text{practical yield for dual irrigation}}{\text{practical yield for control}} \times 100 \hspace{1cm} \text{(7)}
\]

As for the theoretical relative yield (\% RY), it was calculated by adopting the linear equation of the relative yield relationship with the degree of soil salinity prepared by[6] according to the principle of the assumption that irrigation with fresh water gives a production of 100% when the degree of soil salinity is equal to the salinity threshold of the maize crop.

\[
\% RY = 100 - B(\text{ECe} - A) \hspace{1cm} \text{(8)}
\]

whereas: \( RY \): - Theoretical relative yield (in percent), \( B \): - The slope of the relative yield line with the degree of soil salinity, \( \text{ECe} \): - Root zone salinity (dS / m), \( A \): - The threshold to salinity of the crop (dS / m)

In order to predict what is happening in the soil from the occurrence of a state of complete mixing between saline and fresh water or not, and by adopting the previous equation, the theoretical relative yield will be calculated according to the following two assumptions.: The first: Occurrence of a condition of mixing between salinity water and fresh water. Therefore, the degree of salinity of irrigation water in this case will be calculated according to the relationship contained in [7] to calculate the salinity concentration of irrigation water after mixing.

\[
\text{ECB} = \{\text{ECr} \times a \} + \{\text{ECd} \times b\} \hspace{1cm} \text{(9)}
\]

whereas: \( \text{ECB} \), \( \text{ECr} \), \( \text{ECd} \): the electrical conductivity of the mixture, river water, and drainage water (dS / m) respectively.

\( a \): - the ratio of fresh water to the total irrigation depth (mm / mm)

\( b \): - the ratio of drainage water to the total irrigation depth (mm / mm)

And since the sum of the two ratios (a, b) equals (1), so the previous relationship is written as follows:

\[
\text{ECB} = \{\text{ECr} \times a \} + \{\text{ECd} \times (1-a)\} \hspace{1cm} \text{(10)}
\]

As a result, the value of (\( \text{ECe} \)) in the previous equation (8) will change according to the change in the degree of salinity of irrigation water calculated according to the above relationship.
The second assumption that a condition of complete mixing between fresh and saline water does not occur and thus my value \((A, \text{EC}_e)\) in the previous equation (8) will be represented as follows:-

\(\text{EC}_e\): - average of the root zone salinity for the treatment of the dual irrigation system \((\text{dS} / \text{m})\). \(A\): - average root zone salinity for the control treatment \((\text{dS} / \text{m})\). \(B\): - the slope of the relative yield line with the degree of soil salinity.

3. Results and Discussion

3.1. The effect of dual irrigation (surge and continuous) on saving fresh water.

The results of Table (1) show the volumes of saline water used for the advance phase and the volumes of fresh irrigation water to supplement the irrigation water needs of the post-advancement phase for the dual surge irrigation and continuous dual irrigation treatments for all irrigation during the growing season. It is noted that the amount of saline water that was used for the treatment of dual surge irrigation during The season was less than it was in the case of continuous dual irrigation, as it decreased by \((12.41\%)\), and the opposite happened in the case of the amount of fresh water that was used after completing the advance phase of the dual irrigation treatments (surge and continuous). From this it is clear that the introduction of surge irrigation technology in the continuous dual irrigation method The constant duo had accomplished an important goal It is the completion of the advance phase with salin water, similar to the continuous dual irrigation system, but with a smaller amount of salins entering the soil body, and with a greater degree of uniformity to distribute this water along the irrigation path. Adopting the surge irrigation method during the advance of the salin water has contributed to increasing the rate of progression of the wet front and reducing the deep percolation, since after adding the first wave and giving a period of time partial drought occurs, then joining of the parts of the soil surface occurs as an expansion of it occurs when the second wave is added, the infiltration rate will be low and the water will advance faster \([8]\).

As a result of the foregoing, the percentage of fresh water that was saved in this study will depend on the volume of saline water used to complete the advance phase, as the saving rate reached \((51.30\%\) and \(44.94\%)\) for continuous dual irrigation and dual surge irrigation respectively, agree with what \([9]; [10]\). found, which saved \(50\%\) fresh water. and this percentage exceeds what he found \([11]; [12]\).

Table 1. details of irrigation water volumes for the dual irrigation system (continuous and surge) during the growing season

| No. | Irrigation | Volum of fresh water to supplement the irrigation water \((V_r) / \text{m}^3 / \text{m}^2\) | Volum of saline water for advance phase \((V_d) / \text{m}^3 / \text{m}^2\) | Total \((V_t) / \text{volum m}^3 / \text{m}^2\) |
|-----|------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
|     |            | dual surge irrigation                          | continuous dual irrigation                      | dual surge irrigation                          | continuous dual irrigation                      |
| 1   | 0.023      | 0.017                                         | 0.036                                         | 0.042                                         | 0.059                                         |
| 2   | 0.065      | 0.059                                         | 0.036                                         | 0.042                                         | 0.101                                         |
| 3   | 0.055      | 0.049                                         | 0.036                                         | 0.042                                         | 0.091                                         |
| 4   | 0.056      | 0.049                                         | 0.037                                         | 0.043                                         | 0.093                                         |
| 5   | 0.059      | 0.054                                         | 0.034                                         | 0.039                                         | 0.093                                         |
| 6   | 0.057      | 0.053                                         | 0.034                                         | 0.039                                         | 0.092                                         |
| 7   | 0.053      | 0.048                                         | 0.035                                         | 0.040                                         | 0.088                                         |
| 8   | 0.032      | 0.027                                         | 0.034                                         | 0.039                                         | 0.066                                         |
| 9   | 0.026      | 0.020                                         | 0.033                                         | 0.038                                         | 0.058                                         |
| 10  | 0.020      | 0.016                                         | 0.034                                         | 0.037                                         | 0.053                                         |
| 11  | 0.022      | 0.020                                         | 0.033                                         | 0.035                                         | 0.055                                         |
| TOTAL | 0.467      | 0.413                                         | 0.381                                         | 0.435                                         | 0.848                                         |
3.2. The effect of surge irrigation technology on the dual irrigation method during the advance phase.

The results of Figure (1) show that there are no significant differences at \( P \leq 0.05 \) between the advance phase of the dual surge irrigation and surge irrigation treatments, as well as between the continuous dual irrigation and two batch continuous irrigation treatments, as it is noticed that the two curves are identical due to the similarity of the hydraulic design variables for each dual irrigation treatment and its comparison treatment. The results showed that there is a significant difference between the treatment of dual surge irrigation and surge irrigation on the one hand and between the treatment of continuous dual irrigation and continuous irrigation with two batches on the other hand, as well as with continuous (traditional) irrigation during the advance phase during the season and the occurrence of a difference in the advance curves between the parameters of the experiment, as it is noticed from the results that the shape of the water progress curve is flatter and closer to the straight line to the midpoint of the furrow, and after that it begins to bend towards the top as the distance along the furrow advances and its shape is almost similar the advance curve of water on the dry surface of the furrow initially but with less advance time, which led to the occurrence of the water progress curve for the dual surge and surge irrigation treatments below the advance curve of the first wave for the continuous dual irrigation and continuous irrigation with two waves, as well as with continuous irrigation (traditional) this is due to the change caused by the surge irrigation technology applied to the salinity water advancement phase to treat dual surge irrigation, which made the front of the water advance advancing at a high speed in the wet part within the first wave, which extends almost to the middle of the irrigation path, reducing the deep percolation, and accordingly the advance time will be shorter and this leads in turn to increase the efficiency of the uniformity of salin water along the irrigation path compared to its uniformity in the case of continuous dual irrigation, as shown in Figure (2).

As a result of the foregoing, the volume of saline water used to complete the advance phase of the dual surge irrigation treatment will decrease compared to the continuous dual irrigation, as the percentage decrease in the volume of saline water is (12.41%). These results are consistent with the findings of [8];[13];[14]; as well as the results are consistent with the findings of, [15];[16]; [17].

3.3. The effect of using surge irrigation technology on the dual irrigation method during the recession phase.

The results of Figure (3) show that the use of dual wave irrigation has increased the recession time during the growing season. As the results of the statistical analysis showed that there are significant differences at \( P \leq 0.05 \) between the dual surge irrigation and continuous dual irrigation treatment. In addition, there are significant differences between the continuous (traditional) irrigation treatment and the rest of the other irrigation treatments this is due to the effect of surge irrigation technology in

![Figure 1. Advance phase for all treatments](image-url)
reducing the infiltration rate, reducing deep percolation, and increasing the time of water staying on the soil surface, as a clear uniformity is observed in the time of saline water residence for the dual surge irrigation with a longer residence time than it is in the case of continuous dual irrigation. In which the opportunity time of saline water is significantly low to about the middle of the furrow due to the division of the volume of saline water used to complete the advance phase of the dual surge irrigation treatment into two waves and the reason for the uniformity of the time of water stay on furrow’s surface in addition to the fact that the recession time is higher than it is in the case of Continuous dual irrigation.

Figure 2. uniformity coefficient of saline water during the advance phase

Figure 3. Recession phase for all treatments

It is also noticed through the recession curves that the recession time of the treatments in which the surge irrigation technology was used was longer than it is in the case of other irrigation treatments, whether during the recession phase of the advance phase or the post-advancement phase. These results are consistent with the findings of [13]; [15]; [17].

3.4. Uniformity of the saline water distribution during the advance phase

The results of Figure (3) show that the uniformity of the saline water distribution that was used to complete the advance phase along the anchorage of the continuous dual irrigation system was less than it was in the case of two wave irrigation for all months. This is due to the effect of the wave irrigation technology,
which was introduced to develop the continuous dual irrigation system, to reduce the depth of impregnation. This speeds up the advance of the saline water and reduces deep seepage along the moor. This led to a homogeneous distribution of the depth of infiltration of saline water, which positively affected the degree of its consistency along the marsh, and this result is consistent with what was found [12];[18];[19].

3.5. The effect of dual surge irrigation and continuous irrigation on practical and theoretical relative yield

Table (2) shows that if it is assumed that a mixture of saline water and fresh water does not occur within the soil body, the theoretical relative yield (% RY) for the two treatments of dual irrigation (continuous and surge) and calculated according to the equation (8), has decreased gradually with an increase. The depth adopted to calculate the rate of soil salinity is (0-30) (0-60) (0-90) cm and for all comparison cases for both systems dual irrigation (continuous and surge), as the percentage of decrease according to the salinity rate of depth was (0-90) cm (7.87, 9.98, 7.58 and 7.57%) for the comparison cases for the dual surge irrigation and continuous dual irrigation system respectively. In the case of adopting the value of (Ece, A) in the equation (8) represented by the rate of soil salinity for depth (0-30) cm, then a convergence is observed in the values of the theoretical relative yield (% RY) for the two treatments of dual irrigation (continuous and surge), as it reached (96.64, 96.52, 97.36, 97.60%) for all the comparison cases for both dual irrigation (continuous and surge) respectively.

The reason for this is due to the effectiveness of the second wave of fresh water after the advance phase for the continuous dual irrigation system and the third wave of fresh water for the dual surge irrigation system, which displaced the saline water entering the progression phase to the lower depths of the soil body by means of mass movement (convection) and diffusion movement [20].

This resulted in homogeneity of soil salinity values within (0-30) depth.

The results also indicate a mismatch between the theoretical relative yield calculated according to the equation (8) and the actual relative yield for both systems dual irrigation (continuous and surge) as it is noted that the theoretical relative productivity is superior to the actual relative productivity of all comparison cases for both systems dual irrigation (continuous and surge) respectively. In the case of adopting the value of Ece A in the equation (8) as an average salinity depth (0-30) cm, as the theoretical

Table 2. The practical and theoretical relative yield assuming that no mixing condition occurs between saline water and fresh water

| practical relative yield (%) | Relative yield | %RY=100-B(Ece-A) Salinity/ds/m) | (cm)/Depth | Treatmenstes and its comparison |
|-----------------------------|----------------|---------------------------------|------------|-------------------------------|
| %RY                        | ECe            | A                              |            |                               |
| 95.56                      | 97.60          | 3.66                           | 3.46       | 0-30 Dual surge irrigation    |
|                            | 94.00          | 4.48                           | 3.98       | 0-60 continuous irrigation    |
|                            | 89.92          | 5.31                           | 4.47       | 0-90                          |
|                            | 97.36          | 3.66                           | 3.44       | 0-30 Dual surge irrigation    |
|                            | 91.72          | 4.48                           | 3.79       | 0-60 continuous irrigation    |
|                            | 87.64          | 5.31                           | 4.28       | 0-90                          |
| 93.10                      | 96.52          | 3.75                           | 3.46       | 0-30 continuous dual irrigation |
|                            | 91.60          | 4.68                           | 3.98       | 0-60 continuous irrigation    |
|                            | 89.20          | 5.37                           | 4.47       | 0-90                          |
|                            | 96.64          | 3.75                           | 3.47       | 0-30 continuous dual irrigation |
|                            | 91.48          | 4.68                           | 3.97       | 0-60 continuous irrigation    |
|                            | 89.32          | 5.37                           | 4.48       | 0-90                          |

continuous irrig. with two waves
and actual relative productivity reached (97.60%, 95.56%), (97.36%, 93.10%), (96.52%, 93.45%), (96.64%, 92.47%) for all comparison cases for both systems dual irrigation (continuous and surge) respectively for the same previous reason.

While it is noted that the actual relative yield exceeds the theoretical relative yield in the case of adopting the value of \((E_{ce}, A)\) as a rate of soil salinity for the depth \((0-90)\ cm\), as the percentage increase is \((3.41, 4.55, 5.86, 5.90\%)\) and the reason for that is due To increase the degree of salinity adopted in the equation \((8)\) to calculate the theoretical relative production \((\%\ RY)\) originally resulting from the process of displacing the batch of saline water used to \([12];[13]\). In the event that a mixing condition between saline drainage water and fresh water is assumed, the results of table (3) indicate the superiority of the practical relative yield of the dual surge irrigation treatment over the theoretical relative yield as the percentage increase was \((23.23\%, 21.20\%)\) for the two comparison cases with the irrigation system Continuous and surge irrigation respectively, and treatmentes of continuous dual irrigation followed the same behavior, as the percentage increase was \((26.12\%, 25.34\%)\) for the two cases of comparison with the continuous irrigation system and continuous irrigation with two waves respectively. These results are consistent with what was found \([9];[19]\).that the yield of yellow corn decreased by\((31\%)\, (13.8\%),\) respectively.

Table 3. The practical and theoretical relative yield assuming that mixing condition occurs between saline water and fresh water

| Continuous dual irrigation x continuous irrigation with two waves | Continuous dual irrigation x continuous irrigation | Dual surge irrigation x surge irrigation | Dual surge irrigation x continuous irrigation | Yield       |
|---------------------------------------------------------------|-----------------------------------------------|-----------------------------------------|-------------------------------------------|-------------|
| 92.47                                                        | 93.45                                         | 93.10                                   | 95.56                                     | Practical % RY |
| 69.04                                                        |                                               | 73.36                                   |                                           | Theoretical % RY |

4. Conclusion

Results showed that Dual Surge Irrigation system reduced of salty water used to complete advance phase with rate of 12.41% comparing with Dual Continuous irrigation system, The efficiency of Salt- water displacement process decreased by 11.56% by the effect of fresh water under Dual surge irrigation system compared with Dual Continuous Irrigation system, The percentage fresh water saving reached to 44.94% and 51.30% in dual surge and dual Continuous irrigation system respectively, Insert Surge Irrigation technique on Dual Continuous Irrigation system leads to reduce salt- water advance phase time, late in recession time in Dual surge Irrigation and Surge Irrigation with the other treatments during advance and post- advance phase, distribution of Dual surge Irrigation system as compared with dual Continuous irrigation system in salt- water distribution efficiency during advance phase and uniformity of total absorption depth along the furrow for all testing months during the season, theoretical relative yield \((\%\ RY)\) has decreased gradually with increasing in depended depth for calculating the average soil salinity \((E_{ce})\)

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