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EFFECT OF SURGE IRRIGATION AND LENGTH OF BORDER ON WATER USE EFFICIENCY AND WHEAT YIELD

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ABSTRACT

A field experiment was carried out at El Karada Water Requirement Research Station, Kafer El Sheikh Governorate, Egypt, during 1999 /2000 season to study the effect of surge irrigation and length of borders on amount of applied water, consumptive use, water use efficiency, and yield of wheat comparing with continuous flow irrigation.

Results revealed that, surge irrigation treatment had significantly effect on the seed yield, where it produced the highest seed yield. On the other hand, the length of borders treatment 40 m length irrigated by surge produced the highest seed yield that was 2151.16 kg/Fed. . The surge irrigation treatments caused water application reductions, which were 19.10, 9.19, 9.00, and 7.20 % of continuous irrigation treatments for 20, 40, 60, and 80 m borders length, respectively. Moreover, the same treatments recorded the highest water application efficiency, the highest water use efficiency.

Keywords: Irrigation, Water use efficiency, and length of border

INTRODUCTION

Wheat is the most important cereal crop in the world, since it ranks the first among major crops. However, approximately 32% of wheat (*Triticum aestivum,* L.) growing regions in development countries exposed to experience some types of drought stress during the growing seasons (Morris et al.,1991). The national wheat production does not meet the current demand for the crop. So, additional amounts have to be imported up to 50 % of the total consumption.

Water distribution uniformity and water application efficiency of long borders and / or furrows are relatively low due to the difference in soil exposion period to irrigation water along borders and furrow length from their head to their tail. Because of decreasing the infiltration rate during the irrigation, surge irrigation was suggested to control both the exposion periods and the infiltration rate of the soil in order to reduce the amount of the percolated water at borders or furrows head and to achieve better soil moisture distribution uniformity.

Stringham and Keller (1979), introduced the surge flow as a method of surface irrigation in the late of 1970 at Utah State University. Ijuno (1984) mentioned surge irrigation new terminology. The time during which water is originally flowing into the furrows is called the "on – time " . The time during which water is not flowing in the furrows is called the " off – time ". The " on – time " plus the " off – time " of a furrow is additively known as the " cycle – time ".

Cycle time = " on – time " + " of – time ".

Cycle ratio = (0n – time / cycle time).

Subsequent " on – time ", " off – time: and cycles are described by increasing numerical adjectives corresponding to the number of times the water is switched. Also, the process of irrigation may be divided into two segments. The " advanced phase " and the " post – advance phase ". The advanced phase is the period during which water has not reached the end of the field, the post – advanced phase deals with the time after water reached the end of the field. The infiltration rate reduces more quickly under intermittent application than under conventional continuous furrow irrigation. This reduced infiltration rate is the major reason where advancing of water down the furrow takes place more quickly and with less water volume than for conventional continuous irrigation.

Coolidge *et al.* (1982) carried out experiments on a silt loam soil with a 0.01 m slope and 100 meter long furrows. Using 5, 10, 20 min. " on – times " with 5, 10, 20 min. " off – times ", they reported that the 5 min. " on – times " were no better than continuous flow irrigation in advancing water to the end of the furrow, the 10 min. " on – times " showed a 49 % decrease in the volume of water required for the advance in the volume the 20 min. " on times " exhibited a 56 % reduction.

Podmore *et al.* (1983) observed 30 to 50 % less water applied to furrows to complete the advance phase using surge irrigation as opposed to continuous flow irrigation. Guirguis (1988) on clay soil with 90 meter long furrows and 0.001 m / m slope, reported that the advance time was found to be significantly shorter for surge inflows than for continuous inflow of the same time averaged inflow rate. The percent reduction in quantity of water required for surge flow treatments compared to continuous flow, generally ranged from 35.0 to 73.0 percent. Also, he found a cycle ratio one half would create the best distribution application efficiency.

Zein EL Abeden (1988) reported that the volume of water necessary to complete the advance phase could be reduced substantially using surge flow rather than using the conventional practices. Surge flow can provide a significant improvement in the efficiencies and uniform of surface irrigation.

Awady *et al.* (1988) found that the reduction in water volume required during the reason for surge irrigation wheat was 23 % less than for the continuous irrigation under the same condition.

Moustafa (1992) found that surge flow technique had a significant higher water distribution uniformity and higher application efficiency than the continuous irrigation.

Morcos *et al.* (1996 d) and (1996 e) carried out a series of researches to mathematically describes water behavior under surge flow. They applied for that finite difference technique. Morcos et al. (1996 a) also carried out a research to study water infiltration rates under surge technique applying different " on – time " and " of – time: periods, and they expressed the results in mathematical equations.

Since the soil moisture moves in soil profile under an unsaturated conditions, Morcos *et al.* (1996 b) mathematically described soil hydraulic conductivity " HK θ" under the unsaturated condition as a function of soil moisture content " θ ". Also, Morcos et al. (1996 c) mathematically expressed both the evaporation from soil surface, and crop roots absorption from soil layers as a function of soil moisture content " θ " and layer depth. Morcos et al. (1996 d) designed computer program, which compute water application efficiency, water distribution uniformity and water utilization efficiency under furrow surge irrigation.

Mattar (2001) studied the effect of surge furrow irrigation with continuous irrigation on water management at different ploughing methods, the results showed that, surge flow treatments requires less time completion of the advance phase than in those continuous flow treatments at different ploughing treatments.

Doorenbos and kassam (1986) found that, for obtaining high yield water requirements were 450 to 650 mm depending on climate and length of growing period. The crop coefficient (Kc) relating maximum evapotranspiration (Etm) to reference evapotranspiration (Eto) was 0.30 – 0.40 (during the initial stage), 0.70 – 0.80 (during the development stage), 1.05 – 1.20 (during the mid season stage), 0.65 – 0.70 (during the late season stage), and 0.20 – 0.25 (at harvest). They found also that the water use efficiency for wheat was about 0.80 to 1.0 kg / m^3.

So the main objective of this research was to study the effect of surge irrigation and length of border on the amount of applied water, the. consumptive use, the water use efficiency and the yield of wheat crop comparing with continuous flow irrigation.

MATERIALS AND METHODS

A field experiment was conducted at water Requirement Research Station in El Karada, Kafer El Sheikh Governorate during 1999 /2000 season under clay soil conditions.

Two irrigation systems and four borders length treatments were investigated in a split plot design at four replicates. The net area of each plot was 200, 400,600 and 800 m^2 with 3m distance between them for the borders 20,40,60, and 80 m long, respectively. All agricultural operations were practiced as usually farmers used to in Kafer El Sheikh Governorate. The application of irrigation water was according to one of the following two treatments:

i- Continuous application of irrigation water to the end of irrigation.

ii- Pulses of 5 min. on time and 5 min. off time, with 10 min cycling time each treatment of water application was applied in four borders 10 m wide and 20,40,60,and 80 m long.

The aim of irrigation was to provide the plants of each treatment plots with sufficient water to raise its soil moisture content to field capacity.

Rectangular weir was used for measuring the amount of irrigation applied using following equation:

$$Q = CLH^{3/2}$$

Where:

Q	: Discharge	(m^3 /min)
L	: Length of orifice	(m^3 /min)
H	: Pressure head	(m)
C	: Empirical coefficient	

Soil moisture was determined before and after each irrigation.
The actual consumptive use was calculated using following equation:

$$CU_a = \frac{\theta_2 - \theta_1}{100} \times Bd \times D \times A$$

Where: -

CU_a	: Actual consumptive use. (m^3)	
Θ_2	: Soil moisture content after irrigation by weight. (%)	
θ_1	:Soil moisture content before irrigation by weight. (%)	
Bd	: Bulk density.	(gm/cm^3)
D	:Depth	(m)
A	:Area	(m^2)

Table 1: Average of climatic data during 1999-2000

Month	Average temperature c°	Relative Humidity %	Wind speed, km/day
November	19.9	64.5	73.5
December	13.5	58.35	93.0
January	11.4	57.05	81.43
February	13.15	61.45	98
March	14.5	58	106
April	18.25	57.68	114.5
May	22.15	55.25	134

The determination of irrigation requirements from meteorological data (Table 1) was carried out where the modified penman equation was used to determine reference crop evapotranspiration (Doorenbos.and.Pruitt ,1977). The form of equation is: -

$$Eto = C\,[W.Rn + (1 - W)\,f(u).\,(ea - ed)\,]$$

Where

Eto	:	Reference crop evapotranspiration.	mm / day
W	:	Temperature related weighting factor.	
Rn	:	Net radiation in equivalent evaporation.	mm / day
F (u)	:	Wind related function.	
(ea-ed)	:	Difference between the saturation vapor pressure at mean air temperature and the mean actual vapor pressure of the air, both in mbar.	

C : Adjustment factor to compensate for the effect of day and night weather conditions.

The effect of the crop characteristics on crop water requirements can be calculated using the following equation:

$$Etcrop = Kc \times Eto$$

Where

Etcrop : crop water requirements. mm / day

Kc : crop coefficient.

Crop coefficient was calculated using the following equation:

$$Kc = ETcrop / ETo$$

The efficient use of irrigation water is an obligation to use it carefully. Therefore, irrigation efficiency is a broad general term that can be applied to irrigation practices in qualitative manner.

The crop water use efficiency was calculated using following equation: -

$$WUE_{crop} = \frac{Yield\,(kg / Fed.)}{Water\,use\,(m^3 / Fed.)} = (kg / m^3)$$

Also, the field water use efficiency was calculated using following equation:

$$WUE_{field} = \frac{Yield\,(kg / Fed.)}{Water\,application\,(m^3 / Fed.)} = (kg / m^3)$$

Soil sample were collected to determine some physical characteristics of the experimental site. The average values of these measurements at different soil depths down to 60 cm are presented in Table 2.

Table 2: Some soil physical properties of the experimental site.

Depth. (Cm)	Particle Size (%)			Field Capacity by weight. (%)	Permanent Wilting Point by weight. (%)	Bulk Density (gm/cm^3)
	Sand	Silt	Clay			
0-15	18.0	17.0	65.0	45.04	25.00	1.01
15-30	20.2	21.8	58.0	39.12	21.44	1.13
30-45	22.3	26.7	51.0	35.74	19.21	1.22
45-60	19.8	33.0	47.2	33.15	18.09	1.29
Average	20.1	24.6	55.3	38.26	21.01	1.16

RESULTS AND DISCUSSION

1. Seed and straw yields :

Fig.1 shows wheat (*Triticum aestivum* L.) seed and straw yields as affected by irrigation methods i.e. surge irrigation and continuous flow irrigation, and border length i.e. 20,40,60, and 80 m.

Analysis of variance revealed that, there was a highly significant difference among irrigation treatments on the seed yield, while it has insignificant difference in the straw yield.(Tables 3 and 4)

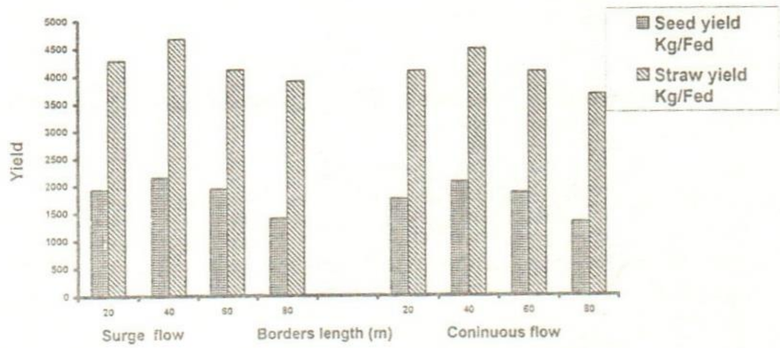

Fig. 1 Comparison between seed and straw yields of wheat as affected by surge and continuous flow irrigation

The highest seed and straw yields values (2151.16 and 4670.00 kg/Fed. respectively) were obtained from treatment which had strip length of 40 m and irrigated by surge irrigation, while the lowest seed and straw yields values (1326.14 and 3650.00 kg / Fed ,respectively) were obtained from treatment which had borders length of 80 m and irrigated by continuous flow irrigation.

The surge irrigation treatment plants were grown healthy which indicated that they did not suffer from draught at any stage of growth especially when the borders lengths were shorter. It seems evident that in surge irrigation plots, available water was sufficient for wheat plants at all stages of growth, where the total seed yields were 1930.00, 2151.16, 1945.13, 1400.75, 1750.40, 2059.23, 1860.29,and1326.14kg/Fed. and 4280.00,4670.00,4110.00,3900.00, 4080.00, 44700, 4070.00, and 3650.00 kg/Fed. for straw yields for both surge and continuous flow irrigation and 20, 40, 60, and 80 m. borders length treatments respectively. The previous result leads to conclusion that, the more water distribution in the soil the more the yield production Moreover, both continuous flow irrigation and long borders are the most critical factor, where, plants suffered from drought stress, and yield decrease.

Table 3: Analysis of variance for seed yield of wheat as affected by irrigation methods (main plots) and borders length (sub plots)

S.V	d.f.	S.S.	M.S.	F		
				Calculated	Tabulated	
					5%	1%
Main plots	15	2358803.1	157253.5			
Replicates	3	100.16	33.39	8.18	8.81	27.34
A(irr. Method)	3	2358666.2	786222.0	192701.49**	8.81	27.34
Error (a)	9	36.74	4.08			
Sub plots	16	106404.20	6650.26			
B (Border Length)	1	91899.83	91899.83	11444.56**	2.44	61.06
AxB interaction	3	14408.07	4802.69	598.09**	8.74	27.05
Error (b)	12	96.30	8.03			
Total	31	2465207.3				

L.S.D.	5%	1%
A	1.62	2.32
B	3.09	4.33
AxB	4.37	6.12

Table 4: Analysis of variance for straw yield of wheat as affected by irrigation methods (main plots) and borders length (sub plots).

V.S	d.f.	S.S.	M.S.	F		
				Calculated	Tabulated	
					5%	1%
Main plots	15	2.5476				
Replicates	3	0.00076	0.00025	1.32	8.81.	27.34
A(irr. method)	3	2.54509	0.84836	4465.05**	8.81	27.34
Error (a)	9	.00175	0.00019			
Sub plots	16	0.28615	0.01788			
B (Border Length)	1	0.22951	0.22951	717.22**	2.44	61.06
AxB (interaction)	3	0.05277	0.01759	54.97**	8.44	27.05
Error (b)	12	0.00386	0.00032			
Total	31	2.83375				

L.S.D.	5%	1%
A	0.011	0.016
B	0.020	0.027
AxB	0.028	0.039

2- Amount of applied irrigation water

The amounts of applied water for the different irrigation treatments are listed in Table 5 and Fig. 2. These amounts were 1232.67, 1536.54,1620.94, 2051.04, 1523.70, 1692.12, 1781.29, and 2210.24 m^3/Fed. for both surge and continuous flow irrigation and 20,40,60,80 m borders length treatments, respectively.

These results show that the surge irrigation treatments under investigation saved more water comparing with continuous flow irrigation treatments as follows:19.10, 9.19, 9.00, and 7.20 % of continuous flow treatments for 20,40,60, and 80 m borders length, respectively.

From the previous discussion, it can be concluded that, the changes in the crop production under each studied treatment is mainly due to the effect of how much water to apply, when irrigate and how to irrigate, where the amounts should be sufficient to replace moisture depleted from the root zone before plants suffer from lack of moisture during the critical growth stages.

Table 5: Amount of irrigation applied, actual consumptive use and water application efficiency as affected by surge and continuous flow irrigation.

Treatment.		Amount of irrigation water applied (m^3/Fed.)	Actual consumptive Use (m^3/Fed.)	Water application efficiency (%)
Irrigation Method	Borders Length. (m)			
Surge flow	20	1232.67	876.70	71.12
	40	1536.54	1007.20	66.55
	60	1620.94	1055.29	65.10
	80	2051.04	1310.00	63.87
Continuous flow	20	1523.70	836.70	54.91
	40	1692.12	989.70	58.49
	60	1781.29	1071.50	60.15
	80	2210.24	1400.70	63.37

3- Water consumptive use

Fig.2 Comparison between amount of irrigation applied and actual consumptive in surge flow and continuous flow Water consumptive uses of wheat plants of the growing season of each irrigation treatment are shown in Table 5 and Fig 2.

The results demonstrated clearly that the water consumptive use of surge irrigation treatments were higher than the other treatments, where the consumptive use values were 876.70, 1007.20, 1055.29, 1310.00, 836.70, 989.70, 1071.50, and 1400.70 m^3/Fed. for both surge and continuous flow irrigation and 20, 40, 60, and 80 m borders length treatments ,respectively.

This increase in the consumptive use of water could be mainly due to the increase in the moisture content in the soil-whereas, consumptive use of water increased markedly with highest percentage of the moisture content in the soil and decreased with the lowest percentage.

4- Irrigation application efficiency

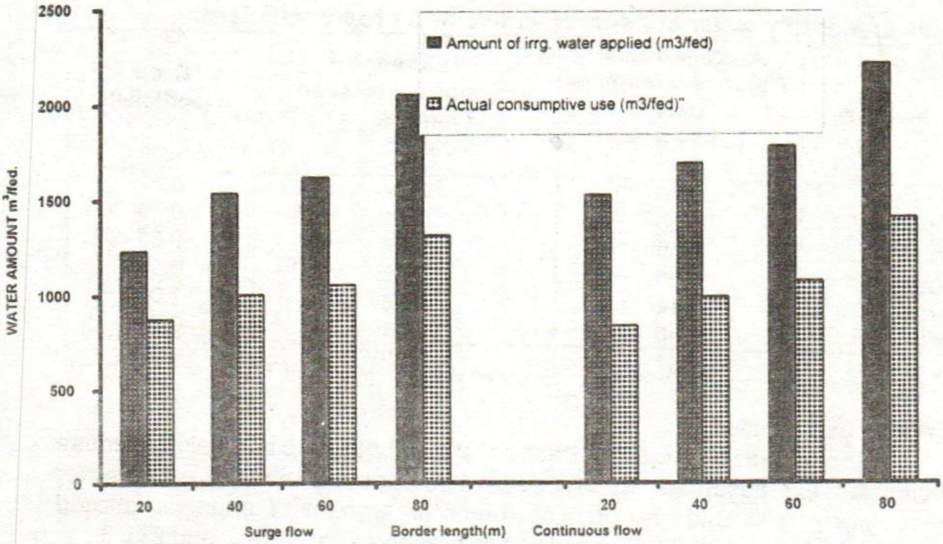

Fig.2 Comparison between amount of irrigation applied and actual consumptive in surge flow and continuous flow

Irrigation application efficiency of wheat plants for the growing season of each irrigation treatment is shown in Table 5.

The result indicated that the irrigation application efficiency of surge irrigation with 20-m border length treatment 71.12% was higher than the other treatments.

The irrigation application efficiency values were 71.12, 66.55, 65.10, 63.87, 54.91, 58.49, 60.15, and 63.37 % for both surge and continuous flow irrigation and 20, 40, 60, and 80 m borders length treatments in the growing season, respectively.

This increase in the irrigation application efficiency could be mainly due to the decrease of water losses. This indicates that surface irrigation efficiency was increased by using surge irrigation method and by decreasing the length of borders.

5- Monthly water consumptive use crop coefficient

Data of the average actual water consumptive use of all treatments (Eto) in relation to reference evapotranspiration (Eta) (Table 6) are given by the crop coefficient (Kc) using method of modified Penman as shown is low in the first month November, and increased up to March, and then declined to reach its minimum value at maturity stage in April.

It is concluded that using modified Penman equation can use the figure of

0.78 for crop coefficient to calculate the evapotranspiration of wheat plant in the North Nile Delta.

Table 6: Monthly water consumptive use and crop coefficient.

Months	Average actual Water consumptive Use. (mm / day)	Reference Evapotranspiration (mm / day)	Crop Coefficient
November	0.70	3.99	0.21
December	1.35	1.71	0.79
January	1.55	1.87	0.83
February	2.55	2.57	0.99
March	4.14	3.98	1.04
April	3.60	4.41	0.82
Average.	2.32	2.99	0.78

6- Water use efficiency

The effect of irrigation treatments on both crop and field water use efficiencies expressed as kg dry seed yield per cubic meter of actual water consumptive use and per cubic meter of amount of irrigation applied respectively during 1999/2000 season are presented in Table 7 and Fig. 3.

The values of both crop and field water uses efficiencies varied from 0.95 to 2.20 and from 0.60 to 1.57 kg dry seed yield /m^3, respectively.

Table 7: The water uses efficiency as affected by surge and continuous flow irrigation.

Treatment		Crop water use Efficiency (Kg/m^3)	Field water use Efficiency (Kg/m^3)
Irrigation Method	Border Length (m)		
Surge flow	20	2.20	1.57
	40	2.14	1.40
	60	1.84	1.20
	80	1.07	0.68
Continuous flow	20	2.09	1.15
	40	2.08	1.22
	60	1.74	1.04
	80	0.95	0.60

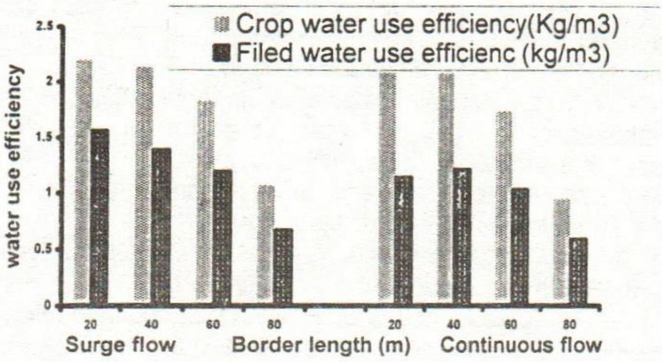

Fig 3 Comparison between surge flow and continuous flow irrigation

Crop and field water use efficiency values of surge irrigation and 20 m border length treatment (2.20 and 1.57 kg/m^3 respectively) were higher than that of the other irrigation treatments. Whereas, the greatest values of them were obtained from the surge irrigation and 20 m border length treatment and the lowest values were recorded with continuous flow irrigation and 80 m border length treatment.

It can be concluded that wheat seed and straw yields were increased in the clay soil with using the surge irrigation and short borders to be only 20, 40, and 60 instead of 80-m border length. Where, using surge irrigation with 20, 40 and 60 m borders length caused the maximum production of seed and straw yields. Data of amount of irrigation water applied for the surge treatments showed that it was much lower than the continuous flow irrigation under all the lengths of borders, where it caused water application reduction. On the other hand, water consumptive use was higher in the continuous flow irrigation under all lengths of borders.

Water application efficiency and water use efficiency were also increased due to using surge irrigation especially with shorter borders to be 60 m instead of 80 m and by using surge irrigation instead of continuous flow irrigation.

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تأثير الرى النبضى وطول الشريحة على كفاءة استخدام مياه الرى وإنتاجية محصول القمح

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أجريت هذه الدراسة بمحطة تجارب المقننات المائية بالقرضا – محافظة كفر الشيخ خلال الموسم الزراعى شتوى (١٩٩٩/٢٠٠٠) لدراسة تأثير طرق الرى الحقلى (رى متقطع "نبضى" ورى مستمر) وطول الشريحة على كفاءة أستخدم مياه الرى وعلى إنتاجية محصول القمح. وقد تمت زراعة القمح واستخدام تصميم القطاعات المنشقة فى أربعة مكررات. وقد نفذت فى ثمانية معاملات رى كالآتى : معاملات رئيسية وهى رى مستمر ورى متقطع أو نبضى (فتح ٥ دقائق وغلق ٥ دقائق) زمن الدورة ١٠ دقائق، بينما كانت المعاملات الشقية هى طول الشريحة والتى كانت ٢٠،٤٠،٦٠،٨٠ متر.

أظهرت النتائج أن هناك تأثير معنوي لمعاملات الري على إنتاجية محصول الحبوب فى حين كان التأثير غير معنوي على إنتاجية القش.

وقد سجلت معاملة الري النبضي للشرائح طول ٤٠ متر أعلى إنتاجية من الحبوب والقش ٢١٥١,١٦ ، ٤٦٧٠,٠٠ كجم/فدان على الترتيب.

كما أظهرت النتائج أن الري النبضي أدى إلى تقليل كميات مياه الرى المضافة بنسب ١٩,١٠ ، ٩,٢٠ ، ٩,٠٠ ، ٧,٢٠ % تحت أطوال الشرائح ٢٠ ، ٤٠ ، ٦٠ ، ٨٠ متر على الترتيب فى حين أدت إلى زيادة الاستهلاك المائي الفعلي.

كما أظهرت النتائج أيضا أن قيمة كفاءة إضافة مياه الري كانت أعلى فى معاملات الري النبضي عن معاملات الري المستمر وفى الشرائح القصيرة عن الشرائح الطويلة وكذلك كفاءة استخدام المياه.