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Furrow irrigation design and evaluation for enhancing indices of water usage performance and productivity of canola crop in North Nile Delta soils

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FIELD study carried out at Sakha farm in the Governorate of Kafr EL-Sheikh, Egypt during two winter seasons, aimed to optimize the furrow irrigation design and management for canola crop in soils at North Nile Delta, and to assessment its effects on the water usage performance, productivity, and profitability of the crop. The study investigated the effects of different furrow design, cut-off irrigation, alternate furrow irrigation, with irrigation discharge 4 Lps m^{-1}, and biomineral fertilization treatments on the characteristics of infiltration, intake family, and selected irrigation characters, along with post-irrigation performance. Also, conducted an economic evaluation of the treatments. The findings demonstrated that in both seasons, the infiltration rate dropped down quickly at 4 hours as time passed, and that for both alternate furrow irrigation and distinct cut-off irrigation, the applied water distribution uniformity was greater than 0.9. When the intake family shrank from 0.35 to 0.33, the application efficiency rose and was deemed suitable for a 2 lps/m furrow influx rate. There was a difference between the designed and measured irrigation time, advance time, and recession time. The designed irrigation time/advance time ratio was also greater than the observed values. Although the design was deemed acceptable on clay soil, the ratio of inflow time to advance time for the design parameters was greater than 2. The cut-off at 85% of the furrow length produced the highest ratio. The maximum irrigation application efficiency values were found when the design and measured parameters were cut off at 85% of the furrow length. In terms of the economic analysis, the interaction between I_3 and F_3 produced the highest values of net return and benefit-cost ratio. Additionally, it was discovered that I_3 and I_4 in conjunction with F_3 and F_4 produced the lowest specific cost values.

Keywords: Clay soil, Cut-off, Canola crop, Irrigation efficiency, Irrigation discharge, economic return, furrow design.

1. Introduction

Egypt faces many water challenges, such as the increasing water demand due to population growth, the limited water resources mainly from the Nile River, the climate change impacts, and the upstream developments such as the Grand Renaissance Dam of Ethiopia (GERD) (Elshamy, et al., 2020; Abbas et al. 2020, Elshafie et al., 2021, Abdalla and El-Ramady 2022). Irrigation water management is therefore crucial for achieving water security and sustainable agricultural development in Egypt, especially in the newly reclaimed lands that require more water supplies (Amer 2020; El-Gindy et al., 2020; Ramadan et al., 2023).

Egypt is among the nations with the least amount of water in the world, with an annual water deficit of around seven billion cubic meters (UNICEF, 2021) On-farm irrigation practices in Egypt are often inefficient and unsustainable, resulting in uneven water distribution, reduced crop growth, excessive or insufficient leaching, water logging, soil salinity, and lower yield and productivity of water (Aragues et al., 2011, Periera et al., 2012, El-Rawy and Abdalla 2019, AbuZeid 2020, EcoMENA 2023, Ali 2023). These problems are exacerbated by the growing shortage and demand for water, dependency on transboundary Nile River, and impacts of change in climate.

Furrow irrigation system design should aim to achieve a uniform and adequate distribution of water all over the field and to reduce the losses of water due to deep percolation and run-off. The performance of furrow irrigation depends on various factors, such as furrow length, slope, shape, spacing, in-flow rate, cutoff time, soil infiltration characteristics, surface roughness, and water crop requirement. Several studies have been conducted to optimize these factors and to develop models and methods for furrow irrigation design and management (AbuZeid 2020, Ibrahim et al. 2020, Ostad-Ali-Askari 2021, Khalifa and El-Ghannam 2021).

The performance of irrigation systems in Egypt is influenced by various factors, including the design, operation, and management of the irrigation network, as well as the on-farm irrigation practices and decisions of the farmers. These decisions involve

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ground levelling, preservation, timeliness, and irrigation events duration, as well as the ability to cope with water supply constraints and uncertainties. Finding ways to improve irrigation efficiency, water conservation, and financial sustainability is therefore crucial for sustainable irrigation. One of the key solutions is to improve the irrigation practices at the farm level, like adopting furrow irrigation level, irrigation using surface flow, and alternate furrow irrigation, which can directly affect irrigation efficiency and water productivity. Several studies have investigated the effects of these practices on saving water, crop productivity, and salinity of soil in different soil types and cropping systems in Egypt (Mahmoud and El-Bably 2017; AbuZeid 2020; Khalifa and El-Ghannam 2021; Ostad-Ali-Askari 2021). Furthermore, the waterfront moves to irrigate more cultivated regions during the subsequent cut-off irrigation event. This method is thought to be a straightforward, easy-to-use approach to conserve water (Amer, 2011; Kassab, 2012; EL-Hadidi et al., 2016; Khalifa, 2016& 2019).

The effects of a level border irrigation system with varying water output and cut-off irrigation on the infiltration process, intake family, and irrigation efficiency for wheat crop were examined by Khalifa et al. (2018). They stated that, despite certain drawbacks, the border irrigation design was comparatively efficient. An acceptable application efficiency was achieved in a cotton experiment, according to Aiad et al. (2019). This highlights the role of soil conservation service (SCS) in designing furrow irrigation systems for clayey soils in the North Nile Delta (Egypt), with an inflow rate of 2 LPS/m width and precision land levelling of 0.1%.

The effectiveness of irrigation application and uniformity of distribution for Faba beans under various cut-off irrigation and alternate furrow irrigation conditions were evaluated by Khalifa and EL-Ghannam (2021). They discovered that for both design and measured characteristics, the best outcomes were obtained with a cut-off at 85% from furrow length. For every treatment, the distribution uniformity was likewise very high, going above 0.9.

In order to attain the appropriate and cost-effective use of water, a great deal of research has been done on improving irrigation efficiency. According to studies by Abo Soliman et al. (2008), Abdel Reheem (2017), and Khalifa (2019), well-designed gated pipes with precise field levelling increase the regularity of water distribution and conserve irrigation water by roughly 12% to 19% in cotton and wheat, respectively.

On addition to providing an economic assessment, the current study intends to assess the implemented design of a furrow irrigation system with variable cut-off irrigation and alternate furrow irrigation conditions for canola crop post-planting on clay soil in the North Nile Delta region.

2. Materials and Methods

2.1 Soil characteristics of the studied area

The field trials were conducted throughout the 2020–2021 and 2021–2022 winter seasons at the Sakha Agricultural Research Station in the Kafr El-Sheikh Governorate. The station is roughly 6 meters above sea level and is situated at 31º 07-N latitude and 30º 57-E longitude. It captures the atmosphere and circumstances of the central northern Nile Delta area. Four depths of soil samples were taken prior to canola seeding: 0–15, 15–30, 30-45, and 45–60 cm. Prior to being pulverized, sieved, and air dried, the samples were prepped for physical and chemical analysis. The texture and size distribution of the soil's particles were ascertained using the pipette method. Campbell (1994) described how the core sample technique was utilised to measure the bulk density and total porosity of the soil. Before planting, before post-irrigation, and after harvesting, the infiltration rate (IR) in cm hr-1 was measured using the blocked furrow infiltrometer. The soil water constants, field capacity (FC) and permanent wilting point (PWP), were found to be 0.33 and 15 atmospheres, respectively, using the pressure cooker method as reported by Klute (1986).

According to Page et al. (1982), measurements were made of the soil response (pH) in soil water suspension (1: 2.5) and the electrical conductivity (EC) in soil paste extract. Table 1 displays the experimental fields' physical and chemical characteristics of the soil.

Table 1. The experimental field's initial soil chemical and physical characteristics prior to the canola crop being planted (mean of the two growing seasons).

Soil depth (cm)	pH	EC, dS m^{-1}	SAR	Particle size distribution %			Textural class	Basic IR. cm hr^{-1}	Bulk density mg m^{-3}	Soil moisture constants		
				Sand	Silt	Clay				FC %	PWP %	Aw %
0-15	8.11	3.66	7.92	17.8	26.94	55.26	Clayey	0.86	1.27	45.18	24.12	21.06
15-30	8.03	3.81	7.32	18.5	28.1	53.4	Clayey		1.36	44.1	23.16	20.94
30-45	8.10	4.16	7.89	18.3	29.5	52.2	Clayey		1.37	39.43	21.33	18.1
45-60	8.03	4.22	7.53	18.75	30.15	51.1	Clayey		1.39	37.2	21.1	16.1
Mean		3.96	7.67	18.34	28.68	52.99	Clayey		1.35	41.48	22.43	19.05

Abbreviations: IR: stands for infiltration rate, FC: stands for field capacity, PWP: Point of permanent wilting, AW: Available water was measured using the gravimetric technique in soil water suspension (1:2.5 for pH) and saturated soil paste extract for EC).

2.2 Agronomic practices and field trails layout

The Serw 4 variety of canola was selected as the oil seed rape (Brassica Napus L) crop. On November 24, 2021, and November 25, 2020, the seeds were planted. In both seasons, the harvesting dates are April 25, 2021, and April 19, 2022, respectively. During the two growing seasons, the area's customary agricultural techniques were followed in terms of field preparation, land levelling (0.1% ground surface slope), and agronomic practices. Ten furrows are present in each strip of canola that was sown. Each irrigation treatment covered 700 m³ (0.07 hectare) because each furrow was 100 m long and 0.7 m wide. Three duplicates of the strip block design were used. The primary plots under irrigation were treated as follows:

I_1: Complete irrigation (i.e., filling the entire furrow; check treatment)

I_2: cease watering when 90% of the furrow is reached

I_3: stop watering when the furrow is 85% of its length

I_4: Alternative furrow irrigation, or "no-cutoff irrigation," which involves fully irrigating one furrow and leaving the next one untended.

Subplots, on the other hand, had the following fertilisation treatments: **F_1**= administering NP at the suggested dosage (100% of RNP),.**F_2**= using 100% RP+ rhizobacterien (BioI) as a biofertilizer + 75% RN, **F3**= using biofertilizer that is 100% RN+ 65% RP+ phosphorien (Bio II).and **F_4**= using a combination of 55% RNP and BioI+BioII

2.3 Hydraulic relationships

The soil conservation service (**USDA**) developed the hydraulic relationships in 1974 and 1979, based on the infiltration concepts. Infiltration constants are necessary for the design of surface irrigation systems. Based on the ultimate intake rate, the soil was categorized into various intake families. According to EWUP Technical Report No. 35 (1983), the design furrow irrigation system's equations were given as follows:

- $$\mathbf{SO=0.0875\ QF^{0.5419}/L} \qquad \ldots \qquad (1)$$

where:
QF: L/sec flow rate
L: length of the furrow (m)
Slope (m/m) in SO

- $$\mathbf{P=0.2647\ (QFn/SO^{0.5})^{0.4247}+0.2274} \qquad \ldots \qquad (2)$$

where P is the furrow's wetted perimeter (in meters).
QF: L/sec flow rate
SO: the furrow's slope (m/m)
n: the roughness of the surface, often 0.04

- $$\boldsymbol{Tn = \left(\frac{\frac{W}{P+K}Du-c}{a}\right)^{\frac{1}{b}}} \qquad \ldots \qquad (3)$$

where: Tn= time of net infiltration (min.)
W = Furrow Interval (m)
Function parameters are a, b, and c. P= adjusted wetted perimeter (m).
C = 7.0747 + 1.7877 (family of intake)
Du: the intended infiltrated net depth (mm)

- $$\boldsymbol{Ta = \frac{PL}{60QF}(aT^{b}oa + 6.985)} \qquad \ldots \qquad (4)$$

Where:
P: modified wetted perimeter in meters
L: length of the furrow (m)
QF: rate of inflow (L/sec)
Ta: minutes of irrigation
Toa: moment of opportunity (min.)

$$\mathbf{{*}Toa=Tn+}\left(\frac{1}{\frac{c}{L}\left(\frac{dL}{Q_S^{0.5}}\right)^{2}}\left(\left(\frac{dL}{QS^{0.5}}-1\right)e^{(dl/QS^{0.5}}\right)+1\right) \qquad (5)$$

Where:
Tn: time (min.) of net infiltration
Intake family C: 7.0747+1.7877; d: 9.2493× 10-5 + 3.263×10-4 If
L: length of the furrow (m)
S: m/m furrow slope

- $$\mathbf{Tt=}\boldsymbol{\frac{L}{C}\ e^{\left(\frac{dl}{QS^{0.5}}\right)}} \qquad \ldots \qquad (6)$$

Where: Tt: time in advance (min)
C: 1.7877 + 7.0747 (IF)
d: 3.263× 10-4 + 9.2493× 10-5 IF-Q: the rate of inflow (L/sec)
S: m/m furrow slope
L: length of the furrow (m)

- $$\mathbf{Da=}\boldsymbol{\frac{60\ QF\ Ta}{WL}} \qquad \ldots \qquad (7)$$

Where:
Da: depth measured in millimetres
QF: rate of inflow (L/sec)
Ta: minimum application time
W: the furrow distance (0.7 m)
L: length of the furrow (m)

- $$\mathbf{DP= Da - Du} \qquad \ldots \qquad (8)$$

Where:
DP: millimeter-deep percolation
Da: depth applied
Du: net desired infiltrated depth (mm)

- **Deep percolation ratio**: $\boldsymbol{\frac{DP}{Da}}$ … **(9)**

Where: DP stands for deep percolation (mm).
Da: applied depth (mm)

- $$\mathbf{Ea=}\boldsymbol{\frac{Dau}{Da}} \qquad \ldots \qquad (10)$$

Where:
Ea: effectiveness of application, (%)
Dau: the intended infiltration depth (mm)

Da: applied depth (mm)

- $Er = \frac{Dau}{Du}$ … **(11)**

Where:

Er: efficiency of requirements (%)

Dau: the intended infiltration depth (mm)

Du: net desired infiltrated depth (mm)

2.4 Applied water amount

Water for irrigation was supplied via a weir with an effective head over the crest of 10 cm and a discharge rate of 4 L sec^{-1} m^{-1}. The amount of water applied was determined using the following equation:

$Q=1.84\ LH^{1.5}$, where L is the weir's length (0.5 m), H is the water column's height (in centimeters), and Q is the discharge rate, measured in m^3 min^{-1}.

Each cultivated furrow has ten stations separated by a length of 100 meters. Ten meters separate one station from the other. Starting with the start of the watering event, the advance time for reaching the water front during irrigation was noted at each station as well as at the conclusion. As a result, each station's recession time—the equivalent time to vanish—was also noted. The opportunity time for irrigation at each station is the difference between advance time and recession time.

2.5 Water consumptive usage (CU): CU was computed using **Israelson and Hansen's (1962)** equation

$$CU = \sum_{i=t}^{i=n} (\theta 2 - \theta 1)/100 * Dbi * Di\ , where$$

CU stands for "water consumptive use" (cm) in the 60-cm effective root zone.

θ2 = soil moisture percentage 48 hrs post-irrigation

Soil moisture percentage prior to the next irrigation: θ1

Dbi= The particular layer's bulk density (Mg m^{-3})

Di= depth of soil layer (15 cm)

2.6 Productivity of consumptive water (WP): According to **Ali et al. (2007),** the following equation was used to calculate it:

WP= seed yield kg fed^{-1}/ water consumptive usage (m^3 fed^{-1})

2.7 Irrigation water Productivity (PIW): In order to make clear how much kg of seed yield is produced from one cubic meter of applied water, the results were computed in kg m^{-3} for each treatment, according to Ali et al. (2007):

PIW= seed yield (kg fed^{-1}) / irrigation water applied ($m^3 fed^{-1}$)

2.8 Assessment of irrigation in furrows: Using the cut-off irrigation approach, all continuous furrows or alternative furrow irrigation was estimated using the following equation, which **James (1988)** described:

- **RZ= D (Θfc-Θ1)/100= Wa- Dp-Ro**
- **Wa= Qt/A**

where Rz is the effective root zone's water storage capacity (in mm).

Wa = total water applied in cm

Volumetric water content in percent at field capacity and before irrigation, respectively, is represented by θfc and θ1.

Q is the average stream size (m^3/min) during irrigation.

T is the irrigation time (minutes).

Deep percolation (Dp) = cm

R0= Distance travelled (in centimetres).

A= average irrigated area (m^2)

- **R0= Wa-D-,**

where D-= the calculated depth of infiltration (cm)

- **DZ= θfc-θm,**

where DZ= the needed depth (in centimetres) to fill the root zone θfc= percentage of moisture at field capacity.

θm= percentage of moisture before irrigation

- **DP=D- — Dz**

By using the modified Kostiakov's equation (e.g. Gillies and Smith, 2005) to the relationship between elapsed time (minutes) and cumulative infiltrated depth, the infiltrated depth (cm) was determined as follows:

- **Z= a T^b**, where, T= opportunity intake time (min.), Z= calculated infiltrated depth, cm, a= slope of line, and b= intercept.

According to Downy (1970), the volume of water stored in the effective root zone divided by the amount of applied irrigation water yielded the irrigation application efficiency (IAE, %).

- **IAE= (Da-(Dp+R0)/Da× 100**

where: IAE = irrigation application efficiency; Da = depth of water applied (cm); Dp = deep percolation (cm); and Ro = runoff (cm).

Efficiency of water distribution (Ewd, %) James (1988) said that it was computed as follows: Ewd= (1-y/d) ×100, where y is the average numerical departure from d, d is the average depth of soil water stored along the furrow during irrigation, and Ewd is the water distribution efficiency.

2.9 Economic assessment

In addition to calculating cash inflows and outflows for different treatments based on local market prices, some economic indicators were also assessed, including:

1. Return total and return net (L.E fed^{-1})
2. The benefit-cost ratio (BCR), which is determined by dividing the whole seasonal cost by the total seasonal return (Atiea, 1986).
3. The computation of specific cost involves dividing the overall cost (L.E fed^{-1}) by the yield of canola seeds (kg fed^{-1}).

3. Results and Discussion

3.1 Soil characteristics intake

According to Abdelhafez et al. (2020), an essential component of irrigation is the process of water moving into the soil profile, or infiltration. They stated that to design and evaluate irrigation systems, prior to runoff and/or deep percolation occur, it is critical to understand the rate, volume, and soil water-holding capacity of the soil. They also mentioned that capacity and rate of soil infiltration are needed to design or modify irrigation systems that can apply water uniformly and efficiently, especially for methods of surface irrigation, such as border irrigation or basin irrigation, where the infiltration process is thought to be one-dimensional, vertical, and shaped by the infiltration surface. In furrow irrigation, the rate of infiltration is also called intake rate. Mahmoud and El-Bably (2017) explained that most well-drained soils have a high initial infiltration rate that decreases over time and reaches a steady state, due to the reduction of capillary pressure gradient as the wetting front moves deeper into the soil. They cited Garcia (1978) as the source of this information.

Table (2) and Fig. (1) present the results of multiple tests conducted over the two growing seasons to determine the infiltration characteristics of Sakha soils. The soil water intake rate declines quickly with time. However, after a few hours, it stabilizes. This is when the infiltration rate reaches its steady state (Garcia, 1978).

Table (2) displays the infiltration rate and cumulative infiltration values prior to post-plant watering for the canola crop over the two growing seasons. The findings demonstrate that, for all cut-off irrigation treatments, the infiltration rate rapidly decreased after 4 hours in the first and second seasons, going from 9.84 to 0.88 cm hr-1 and from 9.36 to 0.85 cm hr-1, respectively. After four hours, the cumulative infiltration depth readings for the first and second seasons were 6.23 and 6.12 cm, respectively. Khalifa and EL-Gahnam (2021) reported about similar results.

3.2 Function of infiltration

The infiltration functions derived from the data are shown in Table (3). The infiltration depth in (cm) vs the elapsed time in (minutes) was shown. In order to determine the best fit regression coefficients for these data, a curve fitting regression was used, resulting in a power function that looked like this: $Z= a\ T^{b}$. Using the modified Kostiakov equation (e.g., Gillies and Smith, 2005) form, where Z is the accumulated depth infiltrated (cm), T is the elapsed time (minutes), and a and b are regression coefficients, we get the well-known and straightforward empirical infiltration function. Using a curve fitting regression, test data that were available for the canola crop's post-irrigation in the first and second seasons were examined. Test data for the canola crop's post-irrigation in the first and second seasons were analysed using a curve fitting regression.

Table 2. Cumulative infiltrated depth and basic infiltration rate (cm hr^{-1}) for various treatments prior to post-irrigation in the two canola crop growth seasons.

elapsed time (min.)	infiltration rate (cm hr^{-1})		cumulative infiltrated depth (cm)	
	1st season for all cut-off irrigation	2nd season for all cut-off irrigation	1st season	2nd season
5	9.84	9.36	0.82	0.78
10	6.36	6.46	1.35	1.32
20	4.02	3.84	2.02	1.96
30	2.10	2.04	2.37	2.3
45	1.88	1.92	2.84	2.78
60	2.52	2.52	3.47	3.41
90	2.0	1.04	3.97	3.93
120	1.04	0.98	4.49	4.42
180	0.88	0.85	5.37	5.27
240	0.88	0.85	6.23	6.12

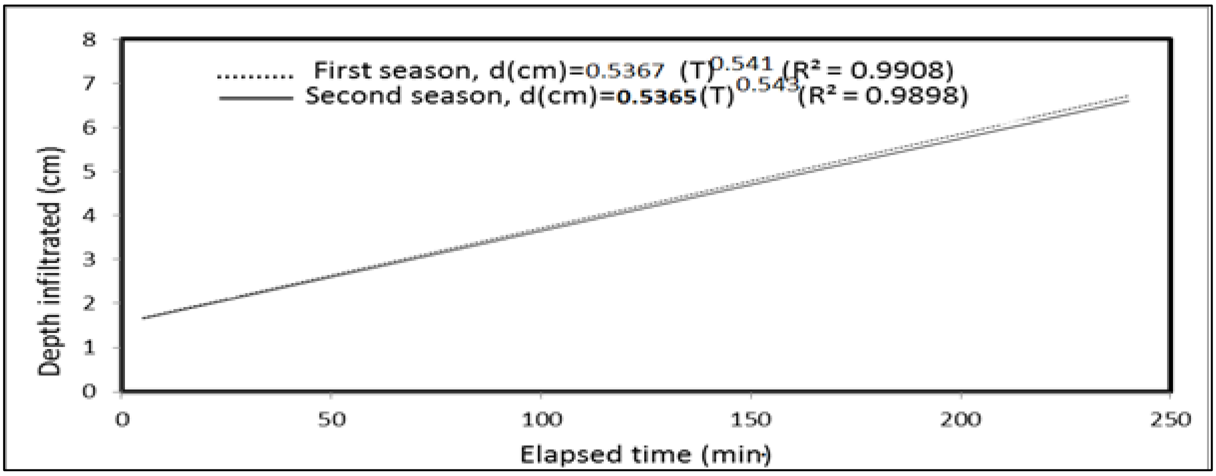

Fig. 1. Regression curves for infiltration in the first and second seasons of canola crop (post irrigation).

Table 3. Intake functions of the various post-irrigation treatments for the first and second seasons.

Crop	Infiltration function					
	1st season			2nd season		
	a	b	r^2	A	B	r^2
Canola	0.5367	0.541	0.9908	0.5365	0.543	0.9898

Table 4. Determined parameters for various intake families.

Intake family	A	b	c	F	g
0.05	0.5334	0.618	7.0	7.16	1.088×10^{-4}
0.1	0.6198	0.661	7.0	7.25	1.251×10^{-4}
0.15	0.711	0.683	7.0	7.34	1.414×10^{-4}
0.2	0.7772	0.699	7.0	7.43	1.578×10^{-4}
0.25	0.8534	0.711	7.0	7.52	1.741×10^{-4}
0.3	0.9246	0.72	7.0	7.61	1.904×10^{-4}
0.35	0.9957	0.729	7.0	7.7	2.067×10^{-4}
0.4	1.064	0.736	7.0	7.79	2.23×10^{-4}
0.45	1.13	0.742	7.0	7.88	2.393×10^{-4}
0.5	1.196	0.748	7.0	7.97	2.556×10^{-4}
0.6	1.321	0.757	7.0	8.15	2.883×10^{-4}
0.7	1.443	0.766	7.0	8.33	3.209×10^{-4}
0.8	1.56	0.773	7.0	8.5	3.535×10^{-4}
0.9	1.674	0.779	7.0	8.68	3.862×10^{-4}
1.0	1.786	0.785	7.0	8.86	4.188×10^{-4}
1.5	2.284	0.799	7.0	9.76	5.819×10^{-4}
2.0	2.753	0.808	7.0	10.65	7.451×10^{-4}

Z is equal to a $T^b + c$, where T is the intake opportunity time and Z is the intake depth (mm).

Table 5. The application uniformity (Uch) and soil conservation service (SCS) intake families for the various post-irrigation treatments given to the canola crop throughout its two growth seasons.

treatments	1st season		2nd season	
	SCS Intake family	uniformity of application	SCS Intake family	uniformity of application
Cut- off at 100%	0.35	0.94	0.33	0.94
Cut -off at 90%	0.35	0.92	0.33	0.93
Cut -off at 85%	0.35	0.92	0.33	0.93
alternative furrow irrig.	0.35	0.95	0.33	0.94

3.2. Intake families of the soil

Numerous field studies have been carried out by the US Soil Conservation Service (SCS) to ascertain and categorise soil infiltration rates. To explain the infiltration process, the SCS has utilised a modified version of the Kostiakov equation. The intake family concept has made it easier to apply this strategy. The following equation provides the governing formula for infiltration by the SCS method: $\mathbf{i = a\,(t)^{b} + c}$ where a and b are provided as a function of intake family and vary based on whether i is measured in inches or cm. Table (4) lists b for various intake families. I and t represent depth of infiltration, cm, and time of infiltration, min, respectively. The following observations are made regarding the results in Table (4) with relation to the SCS processes for level furrow (USDA, 1979) irrigation designs and the SCS methods for classifying soils into intake families.

The results for the deep-rooted canola in the first and second seasons indicate that the intake rates, which correspond to 0.35 and 0.33 intake families, are indicative of the characteristics of the soil infiltration at post-irrigation.

3.3. Uniformity coefficient of applied water

One of the criteria for evaluating irrigation methods is the uniformity of water application. This indicates how evenly the water is distributed over the field. A high uniformity value implies that the applied water depth is similar across different parts of the field (Faria et al., 2019). The data in Table (5) displays the degrees of homogeneity for various irrigation techniques. The findings indicate that when canola is grown, the homogeneity levels for both alternate furrow irrigation and cut-off irrigation are greater than 0.9.

In the first season, the uniformity coefficient was 0.94 for 100% cut-off irrigation, 0.92 for 90% and 85% cut-off irrigation, and 0.95 for alternative furrow irrigation. For the same treatments, the values were 0.94, 0.93, 0.93, and 0.94 in the second season, respectively. Alternative furrow irrigation had the highest distribution uniformity, followed by 100% cut-off irrigation. The uniformity coefficient was above 0.9 for all the designs, indicating a high level of uniformity. The intake family and uniformity of several irrigation techniques for canola crops in two seasons are shown in Table 5**.**

3.4 Designing level furrows with varying cut-off irrigation

Finding the optimal inflow rate for each furrow based on the input design requirements, the intended irrigation schedule, and the application efficiency is the aim of creating level furrows. At times, the irrigation schedule is predetermined, therefore we must strike a balance in order to minimize losses on both ends of the field.

Furrow length, furrow spacing, SCS intake family and intake function parameters, design requirement depth, and manning's n-value (typically n= 0.04 for furrow design) are the input design parameters required by the SCS level furrow design model.

Different furrow inflow rates were tried out. If the flow rate is too low, the water will take too long to reach the furrow's endpoint and the irrigation is going to be inefficient. If the flow rate is too high, the furrow will be damaged and the water will overflow the ridge (run-off). Conditions unique to a given site will typically limit the range of potential trial flow rates. Still, the performance will be better the greater the stream. Additionally, the uniformity of application correlates inversely with intake rate for a given discharge; higher uniformity corresponds with lower intake and vice versa. Therefore, large, deep, and well-made furrows are necessary for level furrow irrigation. Consequently, it is highly advised to maintain the furrow cross-section throughout the season and to tillage well (Moravejalahkami et al., 2009). The model calculates the necessary irrigation time, the expected advance time, the wetted area of the furrow, the water depth, the deep infiltration and the irrigation efficiency for each furrow flow test. Reducing deep percolation loss or improving irrigation efficiency is the goals. In order to minimise water waste and optimise irrigation effectiveness and uniformity, the ideal furrow input rate is chosen. Based on the overall flow at the field entry, the designer calculates the number of furrows that can be irrigated concurrently (Adamu, et al., 2022).

3.5 Consequences of changing design parameters

During a season of high crop water demand, an irrigation system is frequently built to accommodate those needs. These designs are usually predicated on the conditions of the design (i.e., values of the design parameters) at the time of peak use. One crucial but usually disregarded factor is the way the design parameters change over time. The effects of changing design parameters on system performance must be understood by the designer in order to produce an efficient design and offer sensible recommendations for system management. This study looked at how different furrow design parameters—such as length, depth, roughness of the soil, and flow rate—affect how effective post-planting irrigation is for canola in both the first and second seasons. The comprehensive results are shown in Tables 6–11. The data was used to create the best irrigation schemes.

The obtained results included that:

• Higher application efficiency: This occurred when the intake family decreased from 0.35 to 0.33.

• Optimal flow rate: Acceptable application efficiency was achieved at inflow rates of 2 liters per second per meter (lps/m); inflow times were excessive at lower rates.

• Decreased deep percolation: At inflow rate of 2 lps/m, the minimum deep percolation and ratio were attained.

• Optimal cutoff strategy: The maximum application efficiency was obtained by combining 2 lps/m with cut-off irrigation at 85% of the furrow length. Cut-off at 90% also performed well, while 100% cut-off with a lower inflow rate (0.5 lps) produced the lowest efficiency. These findings echo those reported by Khalifa and EL-Ghannam (2021).

According to reports in this regard (Amer, 2011, EL-Hadidi et al., 2016, Sahalou et al., 2018), the technique works best on soils with medium to low input rates and may be applied to all types of crop irrigation. Level irrigation systems should be properly designed, taking into account many parameters such as soil infiltration characteristics, water supply flow rate, and basin size and number of watered furrows.

Table 6. The effects of varying the intake rate, furrow inflow rate, roughness, design depth, and length on irrigation parameters under 100% cut-off for the first-season post-planting irrigation of canola crop (intake rate, 0.35).

Irrigation	Tested inflow stream suggestion (L/sec.)																		
parameters	0.5	0.75	1.0	1.25	1.5	1.75	2.0	2.25	2.5	2.75	3.0	3.25	3.5	3.75	4.0	4.25	4.5	4.75	5.0
Design depth applied (mm)	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
Furrow slope	0.00060	0.00075	0.00088	0.00099	0.00109	0.00118	0.00127	0.00136	0.00144	0.00151	0.00159	0.00166	0.00173	0.00179	0.00185	0.00192	0.00198	0.0020	0.00209
Wetted perimeter (m)	0.47	0.5	0.53	0.55	0.57	0.585	0.6	0.614	0.627	0.639	0.65	0.66	0.67	0.68	0.69	0.7	0.707	0.717	0.72
Net infiltration time (min.)	593.62	542.13	497.56	471.05	447.01	429.85	413.94	399.94	387.6	376.75	367.22	358.9	350.86	343.12	335.64	328.42	323.51	316.69	314.7
Opportunity time (min.)	615.5	555.24	508.19	480.23	455.5	438.08	421.59	407.44	395.04	384.44	374.92	366.26	357.58	349.95	342.38	335.07	329.82	323.65	321.62
Advance time (min.)	72.14	36.02	26.36	22.15	19.84	18.41	17.44	16.68	16.18	15.86	15.48	15.24	14.94	14.79	14.64	14.5	14.35	14.34	14.24
Application time (min.)	179.38	118.56	88.76	70.9	59.1	50.64	44.29	39.38	35.45	32.25	29.58	27.29	25.32	23.64	22.17	20.86	19.69	18.69	17.75
Depth applied (mm)	76.88	76.22	76.08	75.98	75.96	75.96	75.93	75.94	75.96	76.02	76.06	76.02	75.96	75.99	76.01	75.99	75.94	76.1	76.07
Deep percolation (mm)	1.88	1.22	1.08	0.98	0.96	0.96	0.93	0.94	0.96	1.02	1.06	1.02	0.96	0.99	1.01	0.99	0.94	1.1	1.07
Deep percolation ratio	0.02	0.016	0.014	0.013	0.013	0.0126	0.012	0.0123	0.0126	0.013	0.014	0.013	0.0126	0.013	0.0132	0.013	0.0123	0.0144	0.0141
Application efficiency %	97.55	98.4	98.58	98.74	98.7	98.74	98.78	98.76	98.74	98.66	98.61	98.66	98.74	98.7	98.67	98.7	98.76	98.56	98.59

Table 7. Effects of adjustments to the intake rate, furrow inflow rate, roughness, design depth, and length on irrigation parameters during the first season of post-planting irrigation of canola crop (intake rate, 0.35), with a 90% cut-off.

Irrigation parameters	Suggested tested inflow stream (L/sec.)																		
	0.5	0.75	1.0	1.25	1.5	1.75	2.0	2.25	2.5	2.75	3.0	3.25	3.5	3.75	4.0	4.25	4.5	4.75	5.0
Design depth applied (mm)	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
Furrow slope	0.00067	0.00083	0.00097	0.00110	0.00121	0.00132	0.00142	0.00151	0.0016	0.00168	0.00176	0.00184	0.00192	0.00199	0.002	0.0021	0.0022	0.00226	0.0023
Wetted perimeter (m)	0.46	0.5	0.52	0.54	0.56	0.58	0.59	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.68	0.69	0.7	0.704	0.71
Net infiltration time (min.)	612.6	542.13	512.73	484.01	458.64	435.4	424.4	403.8	394.2	384.84	375.9	367.2	358.9	350.9	343.11	335.6	328.4	325.6	321.44
Opportunity time (min.)	628.93	552.67	520.69	492.14	466	442.53	431.27	410.55	400.84	391.41	382.35	373.64	365.22	357.21	349.43	341.83	334.64	331.82	327.63
Advance time (min.)	50.33	27.9	21.51	18.52	16.75	15.73	15.01	14.51	14.12	13.83	13.58	13.39	13.22	13.09	13.0	12.88	12.78	12.71	12.65
Application time (min.)	160.37	106.38	79.68	63.71	53.07	45.5	39.8	35.39	31.86	28.96	26.55	24.51	22.76	19.93	18.76	18.12	17.72	16.79	15.95
Depth applied (mm)	76.37	75.99	75.89	75.85	75.81	75.83	75.81	75.84	75.86	75.85	75.86	75.86	75.87	75.92	75.93	75.92	75.95	75.95	75.95
Deep percolation (mm)	1.37	0.99	0.89	0.85	0.81	0.83	0.81	0.84	0.86	0.85	0.86	0.86	0.87	0.92	0.93	0.92	0.95	0.95	0.95
Deep percolation ratio	0.018	0.013	0.012	0.011	0.011	0.011	0.010	0.011	0.011	0.011	0.011	0.011	0.011	0.012	0.012	0.012	0.0125	0.0125	0.0125
Application efficiency %	98.21	98.7	98.83	98.84	98.93	98.91	98.93	98.89	98.87	98.84	98.87	98.87	98.85	98.79	98.78	98.79	98.75	98.75	98.75

Table 8. Impacts of modifications to the intake rate, furrow inflow rate, roughness, design depth, and length on irrigation parameters during the first season of post-planting irrigation of canola crop with cut-off at 85% (intake rate 0.35).

Irrigation parameters	Suggested tested inflow stream (L/sec.)																		
	0.5	0.75	1.0	1.25	1.5	1.75	2.0	2.25	2.5	2.75	3.0	3.25	3.5	3.75	4.0	4.25	4.5	4.75	5.0
Design depth applied (mm)	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
Furrow slope	0.00071	0.00088	0.001	0.0012	0.0013	0.0014	0.0015	0.0016	0.0017	0.0018	0.0019	0.00195	0.002	0.0021	0.0022	0.00225	0.0023	0.0024	0.0025
Wetted perimeter (m)	0.46	0.49	0.52	0.53	0.56	0.57	0.59	0.61	0.613	0.62	0.63	0.65	0.66	0.665	0.67	0.68	0.69	0.7	0.7
Net infiltration time (min.)	612.6	558.5	511.7	497.6	458.6	448.8	424.4	403..9	400.9	394.2	384.8	367.2	358.9	354.8	350.9	343.1	335.6	328.4	328.4
Opportunity time (min.)	626.7	568	519.7	504.9	465.5	453.3	430.9	410.1	407.1	400.3	390.9	373.2	364.9	360.8	356.7	349	341.5	334.2	334.2
Advance time (min.)	42.2	24.6	19.3	16.7	15.4	14.5	13.9	13.5	13.1	12.9	12.7	12.5	12.4	12.3	12.1	12.06	12	11.91	11.85
Application time (min.)	151.1	100.3	75.2	60.1	50.1	42.9	37.6	33.4	30.1	27.3	25.1	23.1	21.5	20.1	18.8	17.7	16.7	15.8	15.04
Depth applied (mm)	76.18	75.87	75.79	75.74	75.77	75.74	75.76	75.78	75.78	75.79	75.78	75.8	75.81	75.82	75.83	75.86	75.87	75.87	75.83
Deep percolation (mm)	1.18	0.87	0.79	0.74	0.77	0.74	0.76	0.78	0.78	0.79	0.78	0.8	0.81	0.82	0.83	0.86	0.87	0.87	0.83
Deep percolation ratio	0.015	0.0115	0.010	0.0098	0.01	0.0098	0.01	0.01	0.01	0.01	0.01	0.011	0.011	0.011	0.011	0.0113	0.0115	0.0115	0.011
Application efficiency %	98.45	98.85	98.96	99.02	98.98	99.02	99.0	98.97	98.97	98.96	98.96	98.94	98.93	98.92	98.91	98.87	98.85	98.85	98.91

Table 9. Impacts of modifications to the intake rate, furrow inflow rate, roughness, design depth, and length on irrigation parameters during the second season of post-plai irrigation of canola crop (intake rate: 0.33) under 100% cut-off.

Irrigation parameters	Suggested tested inflow stream (L/sec.)																		
	0.5	0.75	1.0	1.25	1.5	1.75	2.0	2.25	2.5	2.75	3.0	3.25	3.5	3.75	4.0	4.25	4.5	4.75	5.0
Design depth applied (mm)	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
Furrow slope	0.0006	0.00075	0.00088	0.00099	0.00109	0.00118	0.00127	0.00136	0.00144	0.00151	0.00159	0.00166	0.00173	0.00179	0.00185	0.00192	0.00198	0.00204	0.00209
Wetted perimeter (m)	0.47	0.5	0.53	0.55	0.569	0.586	0.6	0.614	0.627	0.639	0.65	0.661	0.671	0.681	0.69	0.698	0.707	0.715	0.723
Net infiltration time (min.)	649.4	592.8	543.7	514.6	489.2	468.1	451.8	436.5	422.9	411.0	400.6	390.5	381.7	373.3	365.9	359.5	352.6	346.6	340.8
Opportunity time (min.)	670.2	605.6	554.1	523.8	497.8	476.3	459.8	444.1	430.5	418.4	407.8	397.7	388.9	380.4	372.9	366.5	359.4	353.5	347.6
Advance time (min.)	66.83	34.58	25.61	21.72	19.55	18.21	17.29	16.61	16.12	15.74	15.43	15.18	14.97	14.81	14.66	14.53	14.41	14.33	14.24
Application time (min.)	178.8	118.4	88.62	70.84	59.02	50.58	44.26	39.34	35.41	32.2	29.52	27.25	25.31	23.62	22.15	20.85	19.69	18.66	17.73
Depth applied (mm)	76.62	76.1	75.96	75.9	75.88	75.87	75.87	75.87	75.88	75.9	75.9	75.91	75.93	75.92	75.94	75.95	75.94	75.97	75.98
Deep percolation (mm)	1.62	1.1	0.96	0.9	0.88	0.87	0.87	0.87	0.88	0.9	0.9	0.91	0.93	0.92	0.94	0.95	0.94	0.97	0.98
Deep percolation ratio	0.021	0.014	0.013	0.012	0.0116	0.011	0.011	0.011	0.0116	0.012	0.012	0.012	0.012	0.012	0.012	0.013	0.012	0.013	0.013
Application efficiency %	97.89	98.56	98.74	98.81	98.84	98.85	98.85	98.85	98.84	98.81	98.81	98.8	98.78	98.79	98.76	98.75	98.76	98.72	98.71

Table 10. Impacts of modifications to the intake rate, furrow inflow rate, roughness, design depth, and length on irrigation parameters during the second season of post-planting irrigation of canola crop (intake rate: 0.33) under 90% cut-off.

Irrigation parameters	Suggested tested inflow stream (L/sec.)																		
	0.5	0.75	1.0	1.25	1.5	1.75	2.0	2.25	2.5	2.75	3.0	3.25	3.5	3.75	4.0	4.25	4.5	4.75	5.0
Design depth applied (mm)	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
Furrow slope	0.00067	0.00083	0.00097	0.0011	0.00121	0.00132	0.00142	0.00151	0.0016	0.00168	0.00176	0.00184	0.00192	0.00199	0.00206	0.00213	0.0022	0.00226	0.00233
Wetted perimeter (m)	0.46	0.497	0.522	0.54	0.56	0.577	0.592	0.61	0.618	0.63	0.64	0.65	0.661	0.67	0.679	0.688	0.696	0.707	0.712
Net infiltration time (min.)	670.3	598.1	556.1	528.8	501	479.1	461.03	440.8	432.2	419.9	410.04	400.6	390.5	382.6	374.9	367.5	361.1	354.9	388.8
Opportunity time (min.)	685.9	608.4	564.9	536.7	508.4	486.2	467.9	447.5	438.9	426.5	416.5	406.9	396.8	388.96	381.2	373.3	367.3	361.1	355.1
Advance time (min.)	47.2	26.95	20.98	18.13	16.59	15.59	14.92	14.44	14.07	13.79	13.56	13.37	13.21	13.09	12.97	12.88	12.79	12.72	12.66
Application time (min.)	159.98	106.2	79.6	63.6	53.02	45.45	39.77	35.36	31.82	28.94	26.52	24.49	22.74	21.23	19.9	18.73	17.7	16.77	15.93
Depth applied (mm)	76.18	75.87	75.79	75.75	75.74	75.75	75.75	75.77	75.76	75.8	75.77	75.8	75.8	75.82	75.81	75.81	75.86	75.86	75.86
Deep percolation (mm)	1.18	0.87	0.79	0.75	0.74	0.75	0.75	0.77	0.76	0.8	0.77	0.8	0.80	0.82	0.81	0.81	0.86	0.86	0.86
Deep percolation ratio	0.015	0.011	0.01	0.0099	0.0098	0.0099	0.0099	0.01	0.01	0.011	0.01	0.011	0.011	0.011	0.011	0.011	0.0113	0.0113	0.0113
Application efficiency %	98.45	98.85	98.96	99.01	99.02	99.01	99.01	98.98	98.997	98.95	98.98	98.95	98.95	98.92	98.93	98.93	98.87	98.83	98.87

Table 11. The effects of modifications to the intake rate, furrow inflow rate, roughness, design depth, and length on the irrigation parameters during the second season's post-planting irrigation of canola crop (intake rate: 0.33) under 85% cut-off.

Irrigation parameters	Suggested tested inflow stream (L/sec.)																		
	0.5	0.75	1.0	1.25	1.5	1.75	2.0	2.25	2.5	2.75	3.0	3.25	3.5	3.75	4.0	4.25	4.5	4.75	5.0
Design depth applied (mm)	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
Furrow slope	0.00071	0.00088	0.00103	0.00116	0.00128	0.00139	0.0015	0.0016	0.00169	0.00178	0.00187	0.00195	0.00203	00021	0.00218	0.00225	0.00233	0.00239	0.00246
Wetted perimeter (m)	0.462	0.493	0.518	0.539	0.557	0.573	0.588	0.601	0.61	0.625	0.636	0.646	0.656	0.665	0.674	0.683	0.69	0.699	0.706
Net infiltration time (min.)	666.04	605.25	562.53	530.3	504.99	484.1	465.73	450.71	440.77	424.96	413.93	404.3	395.02	386.96	379.16	371.61	365.89	358.75	353.35
Opportunity time (min.)	679.72	614.5	570.5	537.6	511.87	490.74	472.13	457.02	446.94	431.08	419.98	410.26	400.98	392.9	385.05	377.46	371.7	364.54	359.24
Advance time (min.)	39.91	23.73	18.85	16.54	15.24	14.41	13.81	13.41	13.09	12.85	12.65	12.49	12.36	12.25	12.15	12.02	12.0	11.94	11.9
Application time (min.)	150.82	100.19	75.08	60.05	50.04	42.89	37.53	33.36	30.03	27.3	25.03	23.11	21.46	20.03	18.78	17.68	16.7	15.82	15.04
Depth applied (mm)	76.04	75.77	75.71	75.69	75.69	75.69	75.69	75.69	75.71	75.71	75.72	75.74	75.74	75.74	75.75	75.77	75.78	75.78	75.83
Deep percolation (mm)	1.04	0.77	0.71	0.69	0.69	0.69	0.69	0.69	0.71	0.71	0.72	0.74	0.74	0.74	0.75	0.77	0.78	0.78	0.83
Deep percolation ratio	0.014	0.01	0.0094	0.0091	0.0091	0.0091	0.0091	0.0091	0.0094	0.0094	0.0095	0.0098	0.0098	0.0098	0.0099	0.01	0.01	0.01	0.011
Application efficiency %	98.63	98.98	99.06	99.09	99.09	99.09	99.09	99.09	99.06	99.06	99.05	99.02	99.02	99.02	99.01	98.98	98.97	98.97	98.91

3.6 Evaluation of the design

Tables (12 and 13) display the irrigation evaluation under different cut-off irrigation and alternate furrow irrigation conditions to confirm the designs and determine whether the design assumptions were correct. As a deeply rooted crop, canola, post-planting irrigation was used during the evaluation. It is important to note that the designs were chosen with the canola crop's intake families of 0.35 and 0.33 for the 1st and 2nd seasons, respectively.

The design and measured conditions for canola crop under various treatments are compared in Tables (12 and 13) and Figs (2–5). With a furrow length of 100 meters, a furrow spacing of 0.7 meters, and a strip width of 7 meters, the level furrow systems were built such that each strip contained ten long furrows.

The evaluation results for the canola crop might be summed up as follows.:

- The measured rate of irrigation inflow was two times higher than the intended design value (2 lps/m).
- With the exception of alternate furrow irrigation, where the measured irrigation time was less than the planned amount while under cultivation, the measured irrigation time exceeded the designed one.
- Because of the increased input rate, the measured advance time was longer than the design.
- Recession, opportunity, irrigation, and advance times that were planned were longer than those that were measured.
- When comparing measured parameters to design parameters, the greatest values of advance ratio, irrigation depth applied, deep percolation, and deep percolation ratio were observed.

* In this instance, the design is appropriate on claysoil since the ratio of inflow time to advance time and for the set parameters is greater than 2 at 85% of the furrow length, cut-off irrigation produced the highest ratio.

For intended and measured parameters, the maximum irrigation application efficiency values were obtained with a cut-off at 85% from furrow length.

*In this case, the design is suitable for clay soil because the inflow to advance time ratio is more than two, as are the specified values. The highest ratio was obtained with cut-off irrigation at 85% of the furrow length.

Table 12. Comparison of furrow irrigation design and measurement conditions at Sakha farm during the first season of post-irrigation of canola crop.

Treatments irrigation parameters		Cut-off irrigation at 100%	90%	85%	Alternative furrow
furrow design	Length (m)	100	100	100	100
	Furrow spacing (m)	0.7	0.7	0.7	0.7
furrow inflow rate lps/m	Designed	2.0	2.0	2.0	2.0
	Measured	4.0	4.0	4.0	4.0
irrigation time (min.)	Designed	44.3	39.8	37.6	44.3
	Measured	49.0	53	57	39.0
advance time (min.)	Designed	17.4	15.01	13.9	17.4
	Measured	38	46	42.5	35
recession time(min.)	Designed	404.2	416.3	417	404.2
	Measured	231.1	230.7	231.7	200.3
opportunity time (min.)	Designed	421.6	431.3	430.9	421.6
	Measured	193.1	184.7	183.7	165.3
advance ratio	Designed	0.04	0.035	0.032	0.04
	Measured	0.197	0.249	0.231	0.212
irrigation time /advance time	Designed	2.55	2.65	2.71	2.55
	Measured	1.29	1.15	1.34	1.11
depth applied (mm)	Designed	75.93	75.81	75.76	75.93
	Measured	117.6	110.4	102.6	94.6
deep percolation (mm)	Designed	0.93	0.81	0.76	0.93
	Measured	13.1	15.4	15.3	8.6
deep percolation ratio	Designed	0.012	0.011	0.01	0.012
	Measured	0.111	0.139	0.149	0.09
application efficiency (%)	Designed	98.78	98.93	99.0	98.78
	Measured	82.56	87.32	93.86	94.72
depth required (mm)	Designed	75	75	75	75
	Measured	84	81	81	81
requirement efficiency (%)	Designed	100	100	100	100
	Measured	71.42	73.37	78.95	85.62

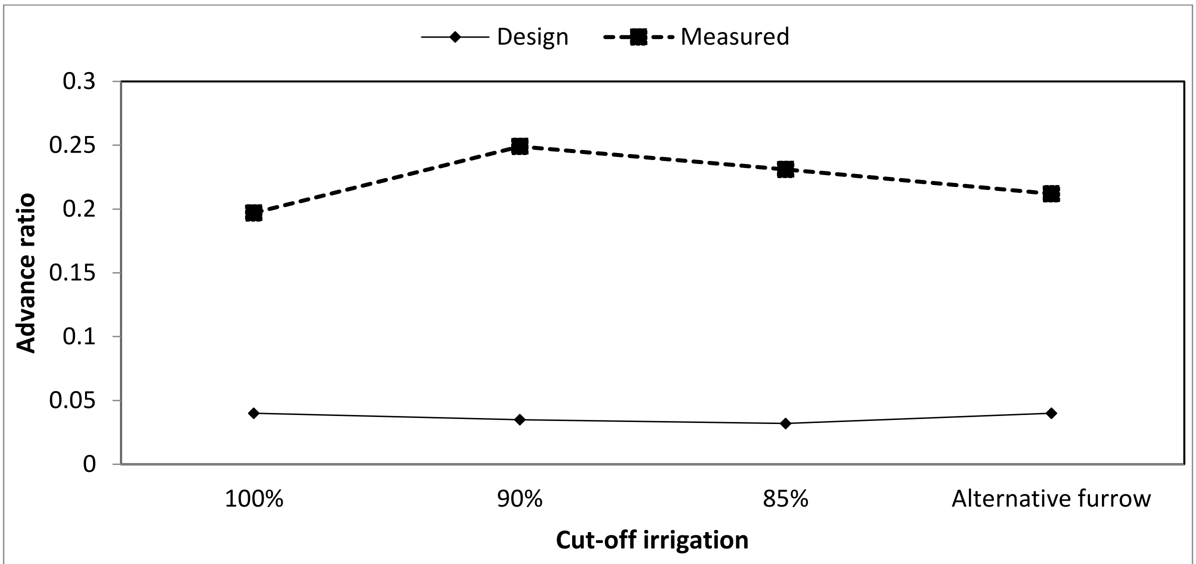

Fig (2): Relation between advance ratio with different cut-off and alternative furrow irrigation for design and measured condition under canola crop in the first season (post irrigation)

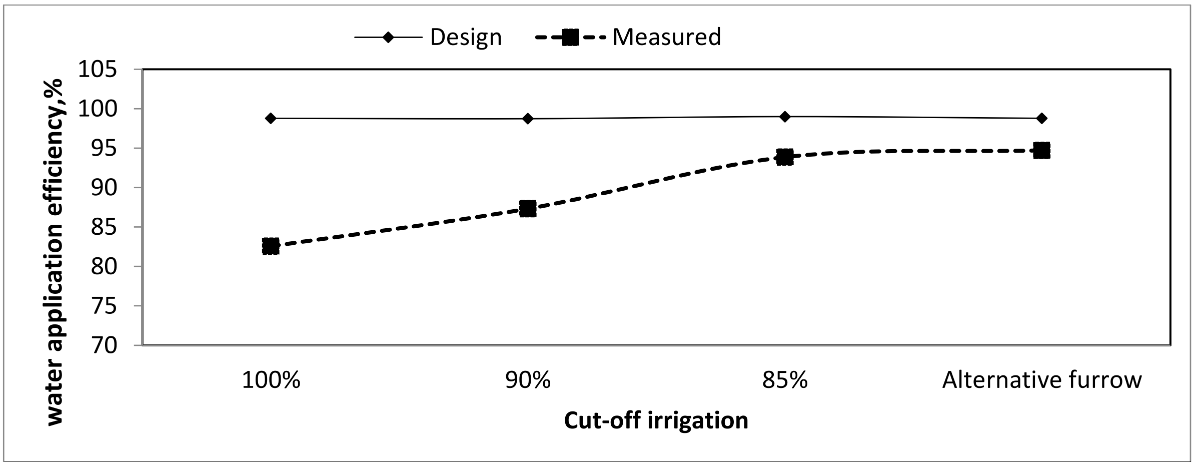

Fig. 3. Relation between application efficiency with different cut-off and alternative furrow irrigation for design and measured condition under canola crop in the first season (post irrigation).

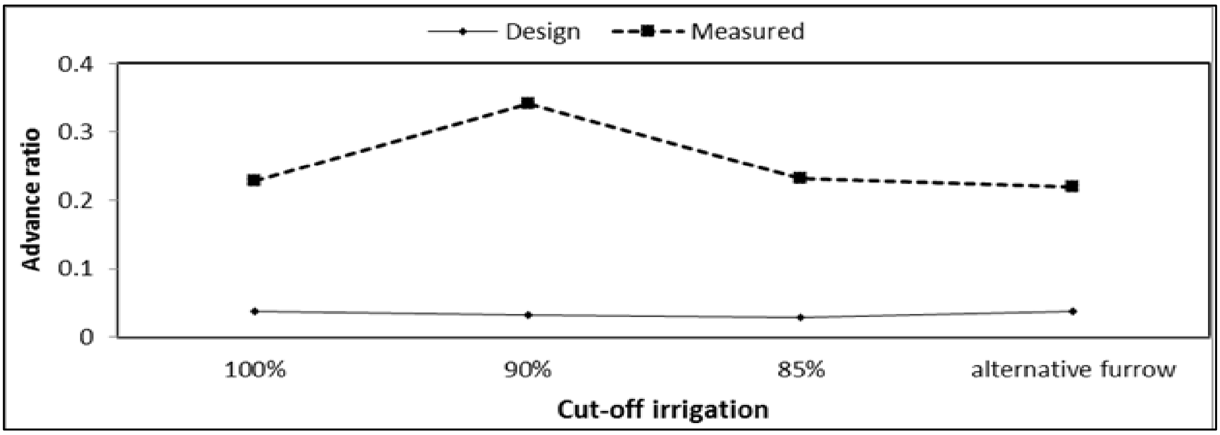

Fig. 4. Relation between advance ratio with different cut-off and alternative furrow irrigation for design and measured condition under canola crop in the second season (post irrigation).

Table 13. Evaluation of measured and designed furrow irrigation parameters at Sakha farm for canola crop post-irrigation in the second season

Treatments irrigation parameters		Cut-off irrigation at 100%	90%	85%	Alternative furrow
Furrow design	Length (m)	100	100	100	100
	Furrow spacing (m)	0.7	0.7	0.7	0.7
Furrow inflow rate lps/m	Designed	2.0	2.0	2.0	2.0
	Measured	4.0	4.0	4.0	4.0
Irrigation time (min.)	Designed	44.3	39.8	37.5	44.3
	Measured	50	55	59	40
Advance time (min.)	Designed	17.3	14.92	13.81	17.3
	Measured	44	46	43	36
Recession time(min.)	Designed	477..1	482.86	485.94	477.1
	Measured	236.6	236.2	235.4	199.4
Opportunity time (min.)	Designed	459.8	467.94	472.13	459.8
	Measured	192.6	190.2	185.4	163.4
Advance ratio	Designed	0.038	0.032	0.029	0.038
	Measured	0.228	0.342	0.232	0.22
Irrigation time /advance time	Designed	2.56	2.67	2.72	2.56
	Measured	1.14	1.2	1.37	1.11
Depth applied (mm)	Designed	75.87	75.75	75.69	75.87
	Measured	118.1	111.6	103.2	95
Deep percolation (mm)	Designed	0.87	0.75	0.69	0.87
	Measured	17.2	17.0	16.6	8.5
Deep percolation ratio	Designed	0.011	0.0099	0.0091	0.011
	Measured	0.146	0.152	0.161	0.089
Application efficiency (%)	Designed	98.85	99.01	99.09	98.85
	Measured	83.49	88.17	94.96	94.63
Depth required (mm)	Designed	75	75	75	75
	Measured	77.6	77.6	77.6	77.6
Requirement efficiency (%)	Designed	100	100	100	100
	Measured	68.93	72.94	78.88	85.69

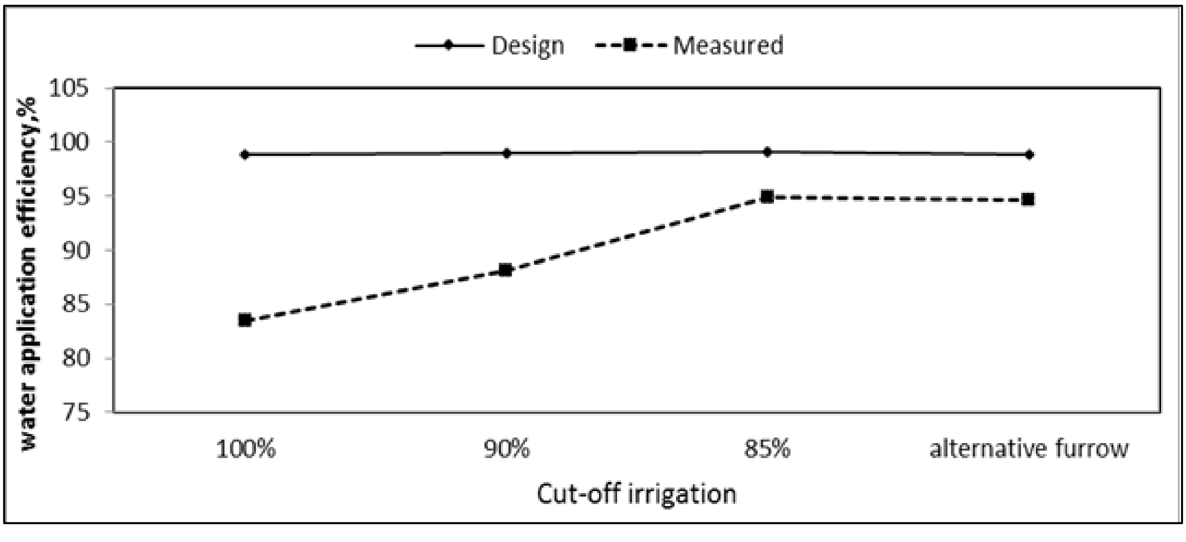

Fig. 5. Relation between application efficiency with different cut-off and alternative furrow irrigation for design and measured condition under canola in the second season (post irrigation).

3.7 Economic analysis

Special items that can be implemented during the evaluation process are needed for economic evaluation. The following items are recommended for the experimental therapies' economic evaluation:

1. Yield of canola seeds (kg fed)
2. The total yield (L.E fed^{-1})
3. Overall expense (L.E fed.$^{-1}$)
4. entire return minus entire cost equals net return.
5. The benefit-to-cost ratio, or BCR (total return / total cost).
6. Specific cost = Total cost / canola seed yield (L.E kg^{-1}).

Yield of canola seeds

Table (14) shows the effect of several cut-off irrigation systems, alternate furrow irrigation, and fertiliser treatments on canola seed output. The average value of the two study seasons is used as the economic assessment criteria. The information obtained demonstrated that the mix of turning off the irrigation at 85% of furrow length (I_3) and F_3 treatments produced the highest canola seed yield, followed by alternative furrow irrigation (I4) and (F_3), while the combination of (I_1) and (F_1) treatments produced the lowest canola seed yield.

Overall seasonal return

According to Table 14's statistics, the mean values of the total seasonal return for cut-off irrigation at 100%, 90%, 85%, and alternate furrow irrigation were, respectively, 20074.05, 20447.99, 21041.87, and 20813.12 L.E fed^{-1}. Data show that the F_3 treatment resulted in a higher overall seasonal return than the other treatments. This development may be related to higher canola seed yields and growth factors. Note that the total seasonal return was higher with cut-off irrigation at 90% (I_2), 85% (I_3), and alternate furrow irrigation (I_4) than with the I1 treatment, by 1.86, 4.82, and 3.68%, respectively. While F_2, F_3, and F_4 fertilisation treatments increased overall seasonal return by 5.1, 13.96, and 11.11%, respectively, compared to the F_1 treatment.

Seasonal net return

Table 14 data demonstrates that the net seasonal return trended in the same direction as the previously indicated metric. This tendency may be explained by the fact that the costs of production for each treatment seemed to be the same, or by the fact that the differences between them are not as great as the corresponding differences in the return values for each treatment. The lowest value (10569.98 L.E fed^{-1}) was seen under I_1 and F_1, while the maximum value (14612.5 L.E fed^{-1}) was produced through an interaction between I_3 and F_3.

Benefit-cost ratio (BCR)

According to Table 14's findings, the interaction between I3 and F3 produced the greatest BCR value (2.79). The benefit-to-cost ratio (2.28) was lowest for the I_1 therapy in combination with F_1.

Specific cost (L.E/kg)

Table (14) shows that the particular cost decreased when (I_3) and (I_4) were combined with the F_3 and F_4 treatments. The maximum value (6.58 L.E kg^{-1}) was achieved with I_1 F_1. This conclusion is based on the lowest canola seed yield.

Selecting the canola crop production's optimal profit treatment

To choose the profit treatment for canola crop production under Egyptian conditions, eight factors were considered. Canola seed yield, number of branches/plants, seed yield/plant, oil percentage in seeds, straw yield, water productivity (WP), irrigation water productivity (PIW), and specific cost were among these associated metrics, as table (15) illustrates.

A measure known as the overall relative factor of evaluation (Kt) is recommended for use. which is determined by applying the subsequent formula:

$R_1K_1\times\ R_2K_2\times\ R_3K_3\times\ R_4K_4\times\ R_5K_5\times\ R_6K_6\times\ R_7K_7\times\ R_8K_8 = K_t$

Whereas: K_1 = canola seed yield; K_2 = number of branches/plant; K_3 = seed yield/plant; K_4 = oil percentage for the tested treatment; K_5 = straw yield for the tested treatment; K_6 = water productivity for the tested treatment; K_7 = irrigation water productivity for the tested treatment; K_8 = specific cost for the tested treatment÷ all of these represent the same criteria for I_3F_3.

Selecting the optimal treatment for irrigation management may be made easier by combining several combinations of elements to find the overall relative factor of evaluation for each treatment. For the purposes of this work, the values of Ri, i = 1-8, were chosen to equal unity because the relative relevance of each parameter varies according on marketing and environmental conditions. Consequently, this method reduces the previously described formula to the following:

$$\mathbf{K_1 \times K_2 \times K_3 \times K_4 \times K_5 \times K_6 \times K_7 \times K_8 = K_t}$$

It should be noted that the value of the overall relative factor of evaluation (K_t) for each therapy was determined in this study using I_3F_3 as the basis. Therefore, the value of Kt for the base treatment should also equal unity, as should the values of K_1 through K_8 for the I_3F_3 therapy. The values of K_1 through K_8 for the several therapies that are being studied are shown in Table (16), together with the corresponding values of the overall assessment factors.

It is clear that the therapies being studied have an impact on the overall evaluation factor (Kt) value.

Thus, the various canola production treatments that were investigated revealed the following decreasing order:

$I_3F_3 > I_4F_3 > I_4F_4 > I_3F_4 > I_2F_3 > I_2F_4 > I_1F_3 > I_1F_4 > I_4F_2 > I_3F_2 > I_2F_2 > I_1F_2 > I_3F_1 > I_4F_1 > I_2F_1 > I_1F_1$.

As a result, the study suggested that the optimum treatments to achieve the intended outcomes would be to stop off irrigation at 85% of the furrow length (I_3) combined with F_3 treatment, followed by the alternative furrow irrigation I_4 combined with F_3.

Table 14. Total return, Total cost, net return and some economic criteria for canola production (average two seasons).

Treatments		Canola seed yield kg/fed.(a)	overall seasonal yield L.E/fed.(b)	Total seasonal cost L.E/fed.(c)	Net return L.E/fed. (b-c)	Benefit-cost ratio (b/c)	Specific cost L.E/kg (c/a)
Cut-off irrigation	**Fertilizer treatments**						
I_1	**F_1**	1254.67	18819.98	8250	10569.98	2.28	6.58
	F_2	1307	19605	8152.5	11452.5	2.4	6.24
	F_3	1407.09	21106.28	8195	12911.28	2.58	5.82
	F_4	1384.33	20764.95	7953.75	12811.2	2.61	5.75
Mean		**1338.27**	**20074.05**	**8137.8**	**11936.3**	**2.47**	**6.10**
I_2	**F_1**	1282.67	19239.98	8230	11009.98	2.34	6.42
	F_2	1328.67	19927.5	8132.5	11795.0	2.45	6.12
	F_3	1433.75	21506.18	8175	13331.18	2.63	5.7
	F_4	1407.89	21118.28	7933.75	13184.53	2.66	5.64
Mean		**1363.20**	**20447.99**	**8117.81**	**12330.17**	**2.52**	**5.97**
I_3	**F_1**	1283.67	19254.98	8220	11034.98	2.34	6.4
	F_2	1370	20550	8122.5	12427.5	2.53	5.93
	F_3	1518.5	22777.5	8165	14612.5	2.79	5.38
	F_4	1439	21585	7923.75	13661.25	2.72	5.51
Mean		**1402.79**	**21041.87**	**8107.81**	**12934.06**	**2.6**	**5.81**
I_4	**F_1**	1285.67	19284.98	8200	11084.98	2.35	6.4
	F_2	1361.83	20427.45	8102.5	12324.95	2.52	5.95
	F_3	1460	21900	8145	13755	2.69	5.58
	F_4	1442.67	21640.05	7903.75	13736.3	2.74	5.48
Mean		**1387.54**	**20813.12**	**8095.31**	**12717.81**	**2.57**	**5.85**

I1: watering the entire length of the furrow (verify treatment) I2: cease watering when 90% of the furrow is reached I3: stop watering when the furrow is 85% of its length I4: No-cutoff irrigation, often known as alternative furrow irrigation. F1= administering NP at the suggested dosage (100% of RNP). Application of 75% RN+ 100% RP+ rhizobacterien (BioI) is F2.F3= using 65% of RP+ and 100% of RN+ phosphorien (Bio II) F4= using a combination of 55% RNP and BioI+BioII.

Table 15. Values of several characteristics used to choose the canola crop's lucrative treatments (average over two seasons).

Treatments		Canola seed yield kg/fed	No. of branches/ plant	Seed yield /plant (g)	Oil% in seed	Straw yield kg/fed	WP kg/m^{3}WCU	PIW kg/m^3 WA	Specific cost, L.E/kg
Cut-off irrigation	Fertilizer treatments								
I_1	F_1	1254.67	6.78	25.08	44.73	828.53	0.82	0.58	6.58
	F_2	1307	8.63	26.14	45.02	950	0.84	0.60	6.24
	F_3	1407.09	8.82	28.14	45.59	1125	0.90	0.64	5.82
	F_4	1384.33	8.55	27.69	46.53	1029.32	0.88	0.64	5.75
I_2	F_1	1282.67	7.27	25.92	44.9	846.67	0.85	0.60	6.42
	F_2	1328.5	8.04	26.57	45.32	960	0.88	0.64	6.12
	F_3	1433.75	8.57	28.68	45.81	1008.34	0.94	0.64	5.7
	F_4	1407.89	9.0	28.16	46.6	1059.99	0.92	0.71	5.64
I_3	F_1	1283.67	7.57	25.68	44.73	903.34	0.87	0.66	6.4
	F_2	1370	8.2	27.4	45.37	949.67	0.93	0.7	5.93
	F_3	1518.5	8.72	30.38	45.86	1023.67	1.02	0.78	5.38
	F_4	1439	8.75	28.79	46.66	1096.67	0.96	0.74	5.51
I_4	F_1	1285.67	7.54	25.72	45.11	912.84	0.94	0.74	6.4
	F_2	1361.83	7.97	27.25	45.52	1005.5	0.98	0.78	5.95
	F_3	1460	8.27	29.2	46.13	1074.17	1.06	0.84	5.58
	F_4	1442.67	8.64	28.86	46.69	1156.67	1.03	0.83	5.48

I_1: watering the entire length of the furrow (verify treatment) I_2: cease watering when 90% of the furrow is reached I_3: stop watering when the furrow is 85% of its length I_4: No-cutoff irrigation, often known as alternative furrow irrigation. F_1= administering NP at the suggested dosage (100% of RNP). Application of 75% RN+ 100% RP+ rhizobacterien (BioI) is F_2.,F_3= using 65% of RP+ and 100% of RN+ phosphorien (Bio II) F_4= using a combination of 55% RNP and BioI+BioII.

Table 16. The criterion for choosing the most advantageous treatment for the development of canola crops.

Treatments		Canola seed yield kg/fed.(K_1)	No. of branches / plant (K_2)	Seed yield /plant (g) (K_3)	Oil% in seed (K_4)	Straw yield kg/fed(K_5)	WP kg/m^{3}W CU (K_6)	PIW kg/m^3 WA(K_7)	Specific cost, L.E/kg(K_8)	Overall factor (Kt)
Cut-off irrigation	Fertilizer treatments									
I_1	F_1	0.83	0.78	0.83	0.98	0.81	0.8	0.74	1.2	0.3
	F_2	0.86	0.99	0.86	0.98	0.93	0.82	0.77	1.16	0.49
	F_3	0.93	1.01	0.93	0.99	1.1	0.88	0.82	1.08	0.74
	F_4	0.91	0.98	0.91	1.01	1.01	0.86	0.82	1.07	0.62
I_2	F_1	0.84	0.83	0.85	0.98	0.83	0.83	0.77	1.19	0.37
	F_2	0.87	0.92	0.87	0.99	0.94	0.86	0.82	1.14	0.52
	F_3	0.94	0.98	0.94	1.0	0.99	0.92	0.82	1.06	0.69
	F_4	0.93	1.03	0.93	1.02	1.04	0.9	0.91	1.05	0.81
I_3	F_1	0.85	0.87	0.85	0.98	0.88	0.85	0.85	1.19	0.47
	F_2	0.9	0.94	0.90	0.99	0.93	0.91	0.9	1.1	0.63
	F_3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	F_4	0.95	1.0	0.95	1.02	1.07	0.94	0.95	1.02	0.90
I_4	F_1	0.85	0.86	0.85	0.98	0.89	0.92	0.95	1.19	0.56
	F_2	0.9	0.91	0.9	0.99	0.98	0.96	1.0	1.11	0.76
	F_3	0.96	0.95	0.96	1.01	1.05	1.04	1.08	1.04	1.08
	F_4	0.95	0.99	0.95	1.02	1.13	1.01	1.06	1.02	1.12

I_1: watering the entire length of the furrow (verify treatment) I_2: cease watering when 90% of the furrow is reached I_3: stop watering when the furrow is 85% of its length I_4: No-cutoff irrigation, often known as alternative furrow irrigation. F_1= administering NP at the suggested dosage (100% of RNP). Application of 75% RN+ 100% RP+ rhizobacterien (BioI) is F_2.,F_3= using 65% of RP+ and 100% of RN+ phosphorien (Bio II) F_4= using a combination of 55% RNP and BioI+BioII.

4. Conclusion

Furrow inflow rate, furrow roughness, and design depth for canola crops were all included in the level furrow irrigation design study. The findings demonstrated that application efficiency increased when the intake family shrank from 0.35 to 0.33 and reached a suitable level at a 2 lps/m input rate. The optimal application efficiency was achieved at 85% and 2 lps/m with cut-off irrigation. Due of the higher inflow rate, the measured irrigation and advance times were longer than the planned times. Using measured parameters instead of intended parameters, the maximum values of the advance ratio, applied irrigation depth, deep percolation, and deep infiltration ratio were discovered. In clay soil, the furrow's design allowed for an inflow rate of two litres per metre and an irrigation cutoff point of 85%. Also, the maximum net return and benefit cost ratio were obtained with cut-off at 85% or alternate furrow watering with F_3 treatment.

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