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Partial Wetting of Root Zone to Enhance Furrow Irrigation Indices, Yield Responses and Economic Return Of Soybean

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ABSTRACT

This study was carried out in a private farm located in Gharbiya Governorate, the Nile Delta, Egypt. The study aimed to assess how far the alternative furrow application and deficit irrigation may improve irrigation indices and water productivity of Soybean. Two techniques of alternation were applied. The first is Standing Alternate furrow Irrigation (SAI), the second is Reciprocal Alternate furrow Irrigation (RAI). The two techniques were compared with Conventional furrow Irrigation (CI), at which, all furrows are conventionally irrigated per each irrigation (Control). Results revealed that irrigation requirements under both of (SAI) and (RAI) techniques s are significantly less than that with (CI). Surface runoff increased as the level of application increased. The significant difference was found only between (RAI) with the level of 50 % Etc. and the treatment of (CI) with the level of 100% Etc. The highest value of (Ea) was achieved with (RAI) and 75% ETc irrigation level while the lowest value was found with (CI) and 100% ETc irrigation level. The lowest values of actual ET were found (RAI) and 50% ETc irrigation level. Also, results indicated that produced yield of soybean varied significantly (P<0.05) and influenced by both irrigation techniques and application levels. Yield of soybean was depressed by about 12% under (SAI) with 50% ETc, compared with the treatment of (CI) and 100% ETc. It could be concluded that, the (RAI) and 75% ETc irrigation level is efficient management for soybean production without the risk of reduced grain yield under the experiment conditions.

Keywords: Alternate Furrow Irrigation, Deficit Levels, irrigation indices Crop yield, Water Use Efficiency, Economic Return, Soybean

INTRODUCTION

Drought and rising urban water demands will put future water supplies under strain, necessitating efficient irrigation solutions to reduce agricultural water consumption. Agricultural water consumption consumes over 80% of the total water supply. Surface irrigation accounts for around 86 percent of all irrigated agriculture globally, and it is still the only viable irrigation technique in many parts of the world due to technical and budgetary constraints. (FAO 2016). However, improvement of irrigation efficiency and precise application of water in the traditional surface irrigation systems are challenging, especially in regard to water scarcity crises and agriculture production sustainability issues. Furrow irrigation, reported to be one of the most widely used techniques of surface irrigation. It involves water flow through furrows spaced regularly across the field, instead of flooding water over the whole field. Furrow irrigation is typically thought to be inefficient in terms of water use, and it can result in large amounts of runoff water, which can lead to erosion and nutrient and pesticide pollution. (Felipe *and* Jackson , 2016). Farmers are likely to be quick to accept new approaches that are practical enhancements to their current practises and result in better water use efficiency since furrow irrigation is a well-known, simple, and cost-effective irrigation technique. It should make a concerted effort to improve its management and efficiency. If these systems have been created well and also are practiced by the farmers properly, they could achieve reasonable irrigation efficiencies and fair distribution uniformities in the field without use of huge amount of energy and high costs as are with the use of the sophisticated systems such as pressurized irrigation systems. According to (Ampas and Baltas, 2009). Furrow irrigation practises, according to (Felipe and Jackson, 2016), can potentially minimise water application without impacting crop output by integrating plant physiological responses to soil water availability. (Lemma teklu kumsa 2020) found a significant amount of water (1232.9m^3/ha) was saved by alternative furrow irrigation (AFI) technique while it also maintains an acceptable tomato yield and quality. The author also added that, a furrow irrigation system that isn't conventional could be recommended as the best technology because of its high-water application efficiency both crop and irrigation water use efficiency (CWUE and FWUE), yield performance, in addition to time, labor and irrigation cost saving.

There is however, also potential in some cases for a reduction in crop yield. At full crop water requirement, alternate furrow irrigation was compared and evaluated to every furrow, fixed furrow, and farmer practise (open-ended and unstructured furrow) (Eba 2018) The researcher found that alternate furrow irrigation was substantially saved water than every furrow irrigation technique without significant yield reduction. Moreover, alternate furrow

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irrigation technique increased the benefit-cost ratio (BCR) and net return (NR) in addition to saving water.

Mansuri *et al* (2018) studied the effects of conventional , fixed and alternate furrow irrigation on qualitative and quantitative yields of sugar beet. They found that, the fixed and alternate furrow irrigation reduced drainage by 44% and 50%, respectively. The root yield was obtained 79 t/ha under alternate furrow irrigation, and 16% higher compared to fixed furrow irrigation. Average water use efficiency (WUE) for sugar beet root production in conventional, fixed, and alternate furrow irrigation were achieved 7, 11, and 12 kg/m^3, respectively. Jemal and Mukerem (2017) tested the performance of alternate furrow irrigation (AFI) and convectional furrow irrigation (CFI) with three water deficit levels on crop-yield response, water use efficiency and cost benefit analysis of cabbage. Their results showed that CWUE, IWUE and EWP (Economical water productivity) were highly significantly (P<0.01) affected by both irrigation techniques and deficit levels. According to Akbar *et al.* (2015), alternative furrow irrigation treatment was a better solution for water conservation in arid and semi-arid regions, saving 50% more water than the traditional method of irrigating every furrow during each irrigation and resulting in a 6.5 percent reduction in sweet corn yield. Robel *et al* (2019) investigated the response of soybean to moisture deficit under conventional, alternate and fixed furrow irrigation technique. They found that, there were a highly significant (P<0.01) variations among treatments for grain yield, The highest grain yield was obtained from conventional furrow 100% ETc irrigating followed by conventional furrow 75% ETc and alternate furrow 100% ETc. They recommended using alternate furrow irrigation with 100% ETc and conventional furrow irrigation with 50% ETc.

The objective of this study is to assess how far the standing alternate furrow application of the irrigation water (SAI) and reciprocal alternate furrow irrigation (RAI) may save water and improve water productivity compared with conventional irrigation (CI) for soybean (*Glycine max L.*) crop.

MATERIALS AND METHODS

SITE DESCRIPTION AND EXPERIMENTAL DESIGN:

This study was carried out in a private farm located in El- Santa district, Gharbiya Governorate, middle of the Nile Delta, Egypt (30°.7028' N latitude, 31°. 0966' E altitude, 23 m a.s.l.) during 2018 season. The soil of the experimental site is characterized as a clay- loam. The experimental soil's hydro-physical characteristics were determined as outlined by Ryan *et al* (2001) and shown in Table1 :

Table 1.Hydro-physical characteristics of the experimental soil

Depth (cm)	Bulk density	Field capacity		Wilting point		Available soil water	
	(g/cm^3)	(m^{3}m^3)	(mm)	(m^{3}m^3)	(mm)	(m^{3}m^3)	(mm)
0-20	1.27	0.343	85.8	0.170	42.5	0.173	.4230
20- 40	1.51	0.333	66.56	0.165	33.0	0.168	33.56
40- 60	1.46	0.297	63.90	0.165	34.7	0.132	29.20

The main objective of the study is to test the performance of Reciprocal Alternative furrow irrigation (RAI), Standing Alternative furrow irrigation (SAI) in comparison with Conventional furrow Irrigation (CI) Three water application levels i.e., 100%, 75% and 50% of Evapotranspiration (ETc) estimated by CROPWAT 8.0 for windows - computer software program (FAO ,1998). Treatments were applied to assess their effects on some irrigation performance indices, i.e., seasonal applied water (mm), stored water (mm), storage efficiency (%), and how far this irrigation management will affect the soybean (*Glycine Max L.*) production (i.e., Crop - yield, water use efficiency.

For this purpose, soybean (*Glycine Max L.* - variety Giza-21) was planted on May-16 and harvested on September -13 of 2018 season.

The design consisted of three irrigation techniques i.e., Standing Alternate furrow Irrigation (SAI), at witch, the irrigation was fixed to one of the two adjacent furrows, Reciprocal Alternate furrow Irrigation (RAI) , at which, the furrows have odd numbers i,e.,1, 3, 5 and 7 were irrigated in an irrigation event while the furrows have even numbers i.e.,2,4,6 and 8 were irrigated in the next irrigation in reciprocal system, and Conventional furrow Irrigation (CI), at which, all furrows are conventially irrigated per each irrigation (Control). These treatments were applied with mentioned three water levels. Each of those treatments was replicated three times, that produced 27 replicates. Each treatment consisted of 8 furrows of 25 m length, spaced 0.70 m (The area of a replicate = 140 m^2 i.e,0.014 ha) which produced a net area of 3780 m^2.Treatments were distributed in split- plot - design "irrigation technique in main plot and irrigation level in sub-main plot" statistical analysis was carried out by CoStat program for windows. Main and sub plots were prepared by borders of one m width.

Techniques and field data measurements:

Irrigation performance indicators:

- **Irrigation requirements:** Climate, soil, and crop data were used as inputs in the CROPWAT 8.0 computer software application to estimate the irrigation requirements. Irrigation was implemented when 60% of total available water was depleted where root zone was re-filled up to field capacity.

Soil samples were taken immediately before and two days after each watering operation to assess soil moisture content. Samples were taken in the furrows at three depths of 0-20, 20-40, and 40-60 cm from the middle furrow of each treatment on the beds and in the furrows at three depths of 0-20, 20-40, and 40-60 cm from the middle furrow of each treatment. To assess irrigation water requirements, the volumetric soil-water content in the root zone was measured using the gravimetric approach, based on the traditional oven-dry weight, and multiplied by the bulk density. Crop water requirements were calculated as:

$$dn = \Sigma (\theta f C_i - \theta_1) \Delta z$$

Where dn is the net volume of irrigation water in mm, θ f C_i is moisture content at field capacity (in volumetric percentage), and Θ_1 is soil moisture prior to each irrigation (in volumetric percentage), and Δ_z is soil depth in mm. Siphon tubes (2 inches ≈ 5.0 cm, internal diameter) were used to deliver and measure the irrigation water.

The volume of water applied was computed according to (NRCS, 2001) from the following formula:

the formula:

$$q = c_d . A . \sqrt{2gh} . t$$

Where: q = the rate of discharge (m^3/min), c_d = coefficient of discharge (≈ 0.65), A = cross-sectional area of siphon (m^2), g = acceleration due to gravity (m/min), h = effective head (m) and t = time of application (min.)

- **Surface runoff:** For each irrigation event, tail water or (surface runoff) was measured using calibrated steel V-notch with internal angle of 90° constructed at the exit of the middle furrow of each treatment. The following formula was applied according to (NRCS, 2001)

$$v = \frac{8}{15} c_d \sqrt{2g} \tan\frac{\theta}{2} H^{\frac{5}{2}}$$

Where: V= the volume of water in m^3, c_d = coefficient of discharge (≈ 0.60), g = acceleration due to gravity (m/ min), θ = the internal angle of V- notch = 90° and H = effective head (m). As (θ) = 90° and c_d = 0.6,

the volume of runoff will be:

$$V = 1.417\, H^{\frac{5}{2}} \times t$$

Where: t = time interval (min.)

- **Net applied water (I_{net}):** Net irrigation water was calculated by subtracting surface runoff (volume) from total applied water (volume) as:

I_{net} =Actual applied water (volume)-Actual surface runoff (volume)

- **Application efficiency (Ea) (%)** and **storage efficiency** were estimated by:

$$E_a = \frac{Z_{avg\ (root\ zone)}}{Z_{appl.}} \times 100$$

Where: Z_{avg} (root zone) is the soil moisture content in root zone (volume) and $Z_{appl.}$ is total applied water (volume)

- **Actual evapotranspiration (ETa)**: was calculated using the following equation according to Hansen *et al.* (1979).

$$ETa = \Sigma_{i=1}^{i=3} D_i \times D_{bi} \times \frac{\theta_1 - \theta_2}{100}$$

Where: ETa = water consumptive use in the effective root zone (0.60 m), D_i = soil layer depth (0.20 m), D_{bi} = soil bulk density, (Kg/ m) for the 0.60 m soil depth, θ_1 and θ_2 are soil moisture before and 48 hours after irrigation (%) and i = number of soil layers.

Yield response to different treatments:

Grain yield :

Grain yield was measured by harvesting the total number of plants in the net plot area (140 m^2), adjusted to 10% moisture content, weighed using electronic balance then converted to hectare (i.e.,10000m^2) basis.

Water Use Efficiency : per unit mass of soybean crop of the experiment were calculated by dividing the actual crop evapotranspiration (m^3 /ha) by the grain yield (kg /ha) **(Hoekstra, *et al.*, 2012).**

$$WUE = \frac{ETa}{Y}$$

Where: WUE is Water Use Efficiency, Et_a is seasonal actual Evapotranspiration ($m^{3/}$ ha) and Y is the grain yield in (kg / ha)

Benefit-cost ratio (BCR) and net return (NR)

Each treatment's cost and benefit were only looked at in part. To assess the advantages of different furrow irrigation systems and application levels of each treatment, yield and cost data were computed. Operating and variable costs make up the majority of overall costs. The planted area was used to calculate operating costs (labour, land preparation, seeds, fertilisers, and chemicals). Therefore, the operating costs of the applied treatments were the same as the conventional (CI) and totaled by about 6000 L.E./ha (Exchange rate: 1 L.E ≈ 0.0588 US$ as an average in 2018). Variable costs depended on the number of irrigation events and water unit price. The local irrigation farmers in the study area do not pay for water for their farms. Therefore, they only bear the costs of labor to execute the irrigation (estimated by200 L.E./fed. (476.20 L. E /ha) based on the irrigated area. Man-day labor cost of 240 L. E /ha), as well as the price of fuel to run a pump for lifting water from irrigation canals. The water unit price was estimated to be 0.50 L. E/ m^3 (Own assumption). Total water costs were calculated by multiplying the water unit price by the total amount of irrigation water required for the soybean crop. Gross revenue has been calculated by multiplying total yield in kg/ ha and soybean market price in L. E/kg. In this study, the farm-gate price for soybean grain was 9 L.E./kg. Net return (NR) and Benefit-cost ratio (BCR) due to irrigation were calculated according to *Li et al.*, (2007) as follows:

NR = Gross revenue - Total costs, BCR = NR/Total costs

RESULTS AND DISCUSSION

Irrigation performance indices:

Irrigation requirement: Data of seasonal applied water (m^3/ha) are shown in table 1 and Fig.1. This data revealed that irrigation requirements under both of (SAI) and reciprocal alternative (RAI) techniques are less than that with (CI) technique. The highest value of seasonal applied water was found with conventional technique (CI) followed by (SAI) technique, while the lowest value was found with (RAI). The differences due to irrigation technique and / or irrigation level are significant at significance level of 5%.

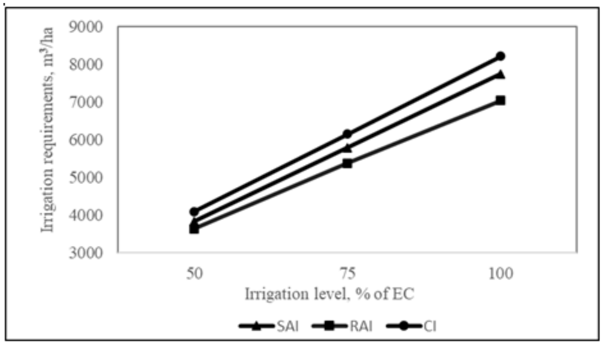

Figure 1. The effect of irrigation level on irrigation requirements

SAI :y = 79.217x - 155.92, R^2 = 0.99
RAI : y = 69.163x + 217.13, R^2 = 1
CI : y = 81.419x + 108.57, R^2 = 0.99

Correlations between irrigation technique and irrigation requirements under different irrigation levels are plotted in Fig.2. From this figure, it could be noticed that, there is a high correlation relation between irrigation application technique and irrigation requirements. The correlation coefficients (R^2) were 0.99,1.0 and 0.99 for (SAI), (RAI) and (CI) respectively. These results may interpret as: due to the amount of applied water per each irrigation was referred to ETc which represents the product of evaporation from soil and plant surfaces plus transpiration from plants, so, as the evaporation from soil decreased by partial wetting will lead to less ETc and subsequently less irrigation requirements. Irrigation requirements as a result of a combination of irrigation systems and application levels (m^3ha^{-1}). The results show that maximum amount was found with the treatment of (CI) with the level of 100% Etc. The minimum value was revealed with the treatment of (SAI) with the level of 50 % Etc. These findings are comparable to those of Akbar tagheianaghdam *et al*. (2015), who discovered that alternative furrow irrigation was a better solution for water conservation in arid and semi-arid locations, saving 50% more water than conventional furrow irrigation.

Surface runoff: Table 2 and Fig. 2 illustrate that, the surface runoff increased as the level of application increased. Concerning the irrigation level, the highest value was found to be 1207.80 m3/ha which obtained from the treatment of 100% ETc, while the lowest value was obtained from the treatment of 50%ETc level. Concerning the application technique, the highest value of surface runoff was 1909.14 m3/ha which produced from (CI) technique followed by 1418.09 m^3 /ha while the lowest value was 1176.88 m^3/ha that found with ((RAI)). The significant difference at the 5% level was found only between the treatment of (RAI) with the level of 50 % Etc. and the treatment of (CI) with the level of 100% Etc. The correlation coefficients (R^2) were 1.0,0.99 and 0.97 for (SAI), (RAI) and (CI) respectively.

Table 2.Irrigation indices as affected by applied treatments

Treatment		Irrigation indices					
Irrigation technique	Irrigation level (% of ETc)	Irrigation requirements (m^3/ha)	Surface Runoff (m^3/ha)	Net Applied Water (m^3/ha)	Ea (%)	Stored water (m^3/ha)	Storage efficiency (%)
	100	7755.40	1986.16	5769.24	74.39	4600.97	79.75
SAI	75	5798.50	1427.59	4370.91	75.38	3840.72	87.87
	50	3841.60	883.57	2958.03	77.00	2673.17	90.37
Mean		5798.50	1432.44	4366.06	75.59	3704.95	86.00
	100	7050.90	1635.10	5415.80	76.81	4341.85	80.17
RAI	75	5387.50	1186.33	4201.17	77.98	3719.72	88.54
	50	3645.90	694.18	2951.72	80.96	2700.82	91.50
Mean		5361.43	1171.87	4189.56	78.58	3634.02	86.74
	100	8225.00	2817.06	5407.94	65.75	3938.06	72.82
CI	75	6150.70	1917.17	4233.53	68.83	3432.54	81.08
	50	4096.40	1174.03	2922.37	71.34	2529.02	86.54
Mean		6157.37	1969.42	4187.95	68.64	3299.87	80.15
Mean of 100% ETc		7677.10	219.37	563.34	72.19	4293.63	77.58
Mean of 75%ETc		5778.90	139.16	430.43	76.30	3664.33	85.52
Mean of 50%ETc		3861.30	83.48	307.90	78.67	2634.33	90.52
Lsd 0.05 for main plot		9.65	6.90	--	0.07	0.08	--
Lsd 0.05 for sub- plot		9.35	3.90	--	0.05	0.12	--
Lsd 0.05 for interaction		16.20	6.75	--	0.08	0.21	--

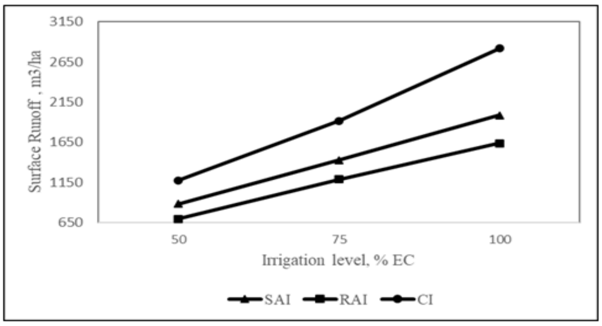

Figure 2. The effect of irrigation level on surface runoff

SAI: y = 23.707x - 359.93, R^2 = 1

RAI:: y = 18.543x - 213.81, R^2 = 0.99

CI: y = 34.753x - 697.3, R^2 = 0.97

Net applied water , application efficiency and storage efficiency:

Net applied water: means water that actually applied to the area be irrigated. It is the product of total applied water subtracted by surface runoff. It is usually measured to assess how much water was saved and stored in the root zone depth. In other words, it is an indicator for field application efficiency (Ea). Logically, as surface runoff increased, the net applied water will decrease and (Ea) will be depressed. Also, as total applied water increase, the net applied water will increase, but this increasing of total applied water may lead to higher surface runoff and less application efficiency. This discussion has been supported by data tabulated in Table 2 and plotted in Fig. 3 which illustrate that the highest value of net applied water (5633.4 m^3/ha) was found with 100 % ETc followed by (4304.3 m^3/ha) and (3079.0 m^3/ha) for 75% ETc and 50%ETc treatments respectively. Concerning the irrigation technique, net applied water was found to be highly correlated to applied treatments.

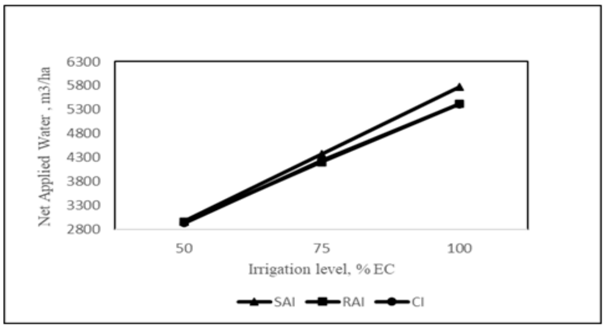

Figure 3. The effect of irrigation level on Net Applied Water

SAI : y = 55.511x + 204.01, R^2 = 0.99

RAI : y = 50.62x + 430.94, R^2 = 1

CI : : y = 46.666x + 805.87, R^2 = 0.99

Correlation coefficients(R^2) for different treatments were: 0.99, 1.0 and 0.99 for SAI, RAI and CI respectively. These results are in agreement with that found by Akbar tagheianaghdam *et al,* (2015). They found that, Alternative furrow irrigation treatment was a better solution for water saving in arid and semi-arid region with 50% saving compare to the conventional technique where every furrow was irrigated during each irrigation only with 6.5% reduction on yield of sweet corn.

Application efficiency: The highest value of (Ea) was achieved with (RAI) and 75% ETc irrigation level while the lowest value was found with (CI) and 100% ETc irrigation level. Regarding stored water, it was calculated via measuring soil moisture content 2- days after each irrigation within the root zone depth i.e., 60 cm depth under different treatments and summed for the growing season. The purpose of this measurement is to figure out how net applied water distributes through root zone profile under different treatments.

Water storage efficiency: evaluates the storage of water in the root zone after the irrigation in relation to the amount of net water received. Data in Table 2 and Fig. 4 revealed that the highest value of storage efficiency was presented by (SAI) irrigation technique although the difference between this treatment and (RAI) was non- significant. The significant difference was found between (CI) and other two techniques. Considering application level, the highest value of storage efficiency was found with the level of 50% ETc. followed by 75% ETc while the lowest value was yielded from 100% Etc. These findings could be demonstrated as: after water penetrates the soil surface, it will be redistributed through the soil profile acted by many forces acting on the water per unit quantity. Forces acting on soil water are: capillary forces, and adsorptive forces. Water will move from high to low pressure or potential. In addition, water will move by gravitational forces if soil water content excessed soil field capacity. In the present research work, soil surface in both treatments of (SAI) and (RAI) was partially wetted within irrigation which results in high soil matric potential and high ability to retain most of applied water through upper depths. The same interpretation could be introduced to interpret the effect of deficit irrigation where less irrigation levels i.e., 75% ETc and 50% ETc received less water than soil field capacity, so, most of applied water is expected to be adsorbed and retained on surfaces of soil particles which result in higher storage efficiency. This visualization is in harmony with that offered by Jack *et al.* (1995) who reported that two forces primarily affect water movement through soils, gravity and capillary action. Capillary action refers to the attraction of water into soil pores - an attraction which makes water move in soil. They added that, in unsaturated soil, the primary forces causing water to move laterally are capillary. Once the soil becomes saturated, gravity is the primary force causing downward water movement.

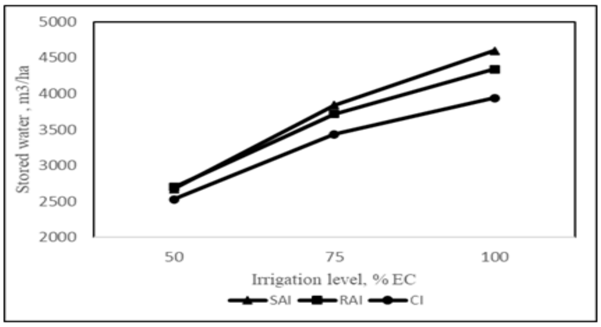

Figure 4. The effect of irrigation level on stored water
SAI : $y = 38.048x + 864.58$, $R^2 = 0.99$
RAI : $y = 58.328x - 1152.4$, $R^2 = 0.91$
CI : $y = 25.597x + 1474$, $R^2 = 0.92$

Crop yield responses:

Yield : Data plotted in Fig. 5a and 5b illustrate that the highest yield was produced from (CI) followed by (RAI) while the lowest yield was produced from (SAI). Produced yield also had been affected by irrigation level where the treatment of 50%ETc produced the lowest yield while the highest yield was produced from 100% ETc.

Results of statistical analysis indicated that produced yield of soybean varied significantly ($P<0.05$) and influenced by both irrigation techniques and application levels, but when compare conventional technique (CI) with reciprocal alternate technique (RAI), there were no significant difference between them.

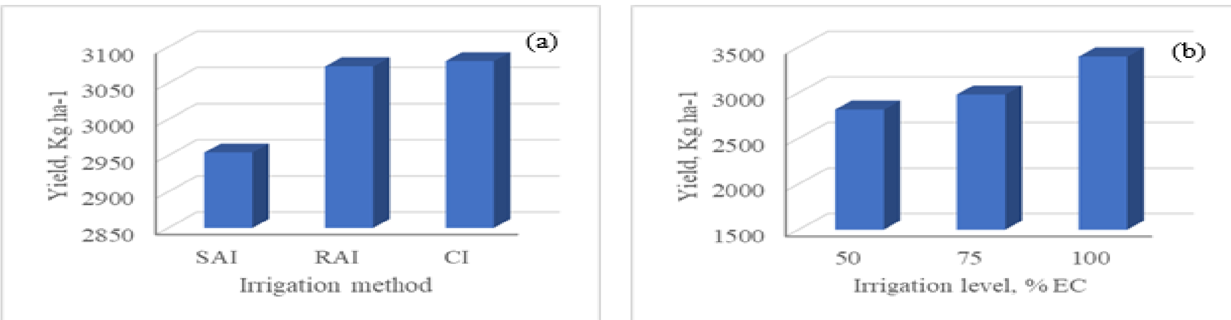

Fig. 5. Soyabean yield affected by alternation technique and irrigation level.

When the amount or depth of irrigation was increased, the yield of soybeans increased dramatically. On the basis of the combined influence of irrigation systems and application amounts on soybean production, it can be concluded that the maximum yield (3080.48 kg/ha) was obtained by (CI) with 100 % ETc and no water stress, whereas the minimum yield (2954.16 kg/ha) was obtained by (SAI) with 50 % ETc. This stress was reflected in low yield by about 12% compared with the treatment of (CI) and 100% ETc. which had no stress. These results are similar to that found by Akbar *et al.* (2015) and Jemal and Seid (2017) and Robel *et al*. (2019) who found that analysis of soybean grain yield shows a highly significant difference ($P<0.01$) on the use of different furrow system as well as on different deficit levels of irrigation. Their results revealed that conventional furrow technique with 100% ETc gave the highest grain yield (1901.8 Kg /ha) followed by conventional furrow 75% ETc (1769.9 Kg /ha) and alternate furrow 100% ETc (1722.3 Kg /ha). They added that the minimum grain yield was obtained from fixed furrow technique and 50% ETc (1323.1 Kg /ha) followed by alternate furrow 50% ETc (1445.0 Kg /ha).

Water Use Efficiency: Water-use efficiency of productivity (also called integrated water-use efficiency), which is typically defined as the ratio of biomass produced to the rate of transpiration. It is usually measured by harvesting plants, determining dry weight of the vegetative portion or grain, and dividing that by the rainfall or irrigation plus rainfall. (Kirkham ,2005).

In the present research work, water use efficiency was measured for different treatments of irrigation techniques and irrigation levels. Data plotted in Fig. 6a and 6b clear out that. Irrigation strategies and application levels both have an impact on WUE. The highest value of (WUE) (0.77) was achieved with the treatment of (RAI) followed by (SAI) (0.74) while the lowest value (0.70) was achieved with the treatment of (CI). Considering irrigation level treatments, the highest value of (0.92) was found with the treatment of 50%ETc followed by treatment of 75% ETc (0.69) while the lowest value (0.61) was recorded with the treatment of 100% ETc.

When comparing the outcomes of various irrigation systems, it was discovered that there were no significant changes in (WUE) values, whereas application levels revealed that (WUE) increased dramatically when irrigation volume or depth decreased. Similarly, the results for application levels demonstrate that a level of 50 percent ETc yielded the highest value of crop water use efficiency, followed by 75 percent ETc, and finally 100 percent ETc. It's also clear that the WUE increased as the water application volume was reduced for each irrigation technique. This conclusion implies that WUE is inversely proportional to the amount of water delivered, as previously indicated.

Fig. 6. Water use efficiency as affected by irrigation techniques and irrigation level.

Cost- Benefit Analysis and Net Return:

To compare the advantages of different furrow irrigation systems and application levels of each treatment, the cost and benefit of each treatment were partially analysed, and the produced yield and total costs were determined.

Data of the Benefit-Cost Ratio (BCR) and Net Return (NR) are presented in Table 3. These data illustrate that maximum BCR was 4.63 which obtained from conventional irrigation technique while the minimum value of BCR (3.55) was found with standing alternate furrow irrigation technique (SAI). Concerning irrigation levels, maximum BCR (4.12) was gained from the treatment of 75%ETc level whereas, minimum BCR (3.79) was found with the treatment of 50% ETc. Maximum NR was (22154.67 LE /ha), it was found with (RAI) followed by (CI) technique which has a value of NR of (21750LE /ha) while the minimum value of NR (20837.15 LE/ ha) was resulted (SAI).

Table 3 . Benefit- Cost Ratio (BCR) and Net Return (NR) associated with the adopted irrigation treatments

Irrigation technique	SAI			RAI			CI		
Irrigation level, % EC	100	75	50	100	75	50	100	75	50
Number of irrigations	9	11	13	9	10	12	9	11	12
Cost of applied water (LE)*	3891.15	2876.22	1910.72	3566.36	2702.85	1837.29	4134.88	3088.15	2099.42
Labor cost (LE)*	1800	2200	2600	1800	2000	2400	1800	2200	2400
Fuel cost (LE)*	630	770	910	630	700	840	630	770	840
Total Costs (LE)**	6321.15	5846.22	5420.72	5996.36	5402.85	5077.29	6564.88	6058.15	5339.42
Grain yield price (LE)*	30201.21	26674.74	23223.60	31110.21	26290.71	25539.39	36548.61	33677.16	30987.87
NR ha^{-1} (LE)*	23880.06	20828.52	17802.88	25113.85	20887.86	20462.10	29983.73	27619.01	25648.45
BCR	3.78	3.56	3.28	4.19	3.87	4.03	4.57	4.56	4.80

***LE = 0.064 of US $ according to average exchange rate of the season of (2021) , ** Total costs include operating and variable costs. Operating costs (labor, land preparation, seeds, fertilizers, and chemicals) were based on the planted area and processed for hectare. It were the same of the applied treatments as (CI) and totalled by about 6000 L. E/ha**

Due to irrigation levels effect, maximum NR (25917.51 LE /ha) was found with 75% ETc level followed by100 % ETc which has NR value of (24315.28 LE/ ha) whereas minimum value of NR (20018.85 LE/ ha) was resulted from 50%ETc level.

These results indicate that, from the economic point of view, (RAI) and 75% ETc irrigation level is the highly efficient management for soybean irrigation under the experiment conditions either on the bases of BCR or NR. So, if water is available with no high cost and excess water delivery to the field does not require any additional expense, (RAI) and 75%ETc level treatment is essentially the best choice under the conditions of the study area.

CONCLUSIONS

From the results conducted from the present study it could be concluded that, alternate-furrow irrigation with appropriate irrigation levels (75% ETc) can be used as an efficient management for soybean production without the risk of reduced grain yield in arid areas where production depends mainly on irrigation. Moreover, this management increased the benefit-cost ratio (BCR), net return (NR), and saved irrigation water

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الترطيب الجزئى لمنطقة الجذور لتحسين مؤشرات الرى بالخطوط واستجابة المحصول والعائد الاقتصادي لفول الصويا

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يعتير الري بالخطوط أحد أكثر تقنيات الري السطحي استخدامًا. وغالبًا ما يعتبر ذات كفاءة منخفضة في استخدام المياه. يمثل تحسين كفاءة الري والتطبيق الدقيق للمياه في أنظمة الري بالخطوط تحدياً في ظل نقص المياه. أجريت التجربة بمزرعة خاصة تابعة لمركز السنطة – محافظة الغربية في وسط دلتا نهر النيل – مصر (30°.7028' N latitude, 31°. 0966' E altitude, 23 m a.s.l.) خلال موسم 2018. هدفت الدراسة الحالية إلى تقييم إلى أي مدى يمكن أن يؤدي استخدام الخط البديل والري الناقص إلى تحسين مؤشرات الري وإنتاجية المياه لفول الصويا (Glycine max L.). تم تطبيق طريقتين لتناوب الري. الأول هو الري البديل الدائم (SAI) ، حيث تم تثبيت الري على أحد الخطوط المتجاورة. والثاني هو الري المتبادل البديل (RAI) حيث تكون الخطوط ذات الأرقام الفردية ، أي 1 و 3 و 5 و 7 يتم ريها في احدى الريات بينما الخطوط التي لها أعداد زوجية ، أي 2،4،6 و 8 تروى في الريه التالية بنظام متبادل. تمت مقارنة الطريقتين مع الري التقليدي (CI) حيث يتم ري جميع الخطوط بشكل تقليدي في كل ريه . أظهرت النتائج أن متطلبات الري تحت كل من (SAI) و (RAI) أقل بكثير من (CI). زاد الجريان السطحي مع زيادة مستوى الإضافة. وجد ان هناك على فرق معنوي فقط بين معاملة (RAI) بمستوى 50٪ إلخ ومعاملة (CI) بمستوى 100٪ إلخ. تم تحقيق أعلى قيمة لكفاءة الإضافة (Ea) مع البديل المتبادل طريقة (RAI) ومستوى ري 75٪ ETc بينما كانت على أقل قيمة باستخدام لطريقة التقليدية (CI) ومستوى الري 100٪ ETc. بينما كانت أعلى قيمة لكفاءة التخزين بواسطة طريقة الري (SAI) على الرغم من أن الفرق بين هذه المعاملة و (RAI) كان غير معنوي. بينما وجد أدنى القيم الفعلية لـ ET باستخدام طريقة الري البديلة المتبادلة (RAI) ومستوى الري بنسبة 50٪ من ETc. أشارت النتائج إلى أن إنتاج فول الصويا يتباين معنوياً (P <0.05) ويتأثر بكل من طرق الري ومستويات الإضافة. انخفض محصول فول الصويا بحوالي 12٪ تحت الري بالخط البديل (SAI) مع 50٪ ETc ، مقارنة مع معاملة (CI) و 100٪ ETc.. يمكن الاستنتاج أن الري المتبادل و البديل (RAI) ومستوى الري 75٪ ETc هو إدارة فعالة لإنتاج فول الصويا دون التعرض لخطر انخفاض محصول الحبوب في ظل ظروف التجربة.