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IMPACT OF DIFFERENT SURFACE IRRIGATION TECHNIQUES ON COTTON PRODUCTIVITY AND WATER SAVING

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ABSTRACT

Field experiments were conducted during two successive summer seasons of (2013/2014) at Al-Amrya area (Al-Nhada region) in Sanad1 village representing a new reclaimed land to assessment impacts of traditional, alternative and surge alternative furrow irrigation techniques, on cotton yield and yield components, water saving and crop water productivity in sandy clay loam soil. Application efficiency (Ea), distribution uniformity (DU) water infiltrated depth ($F_{inf.}$) as well as advance and recession times (T_{adv}. and T_{rec}.) were taken in consideration. The experiments were carried out in a randomized complete block design in three replicates. Irrigation treatments involved: conventional furrow irrigation (EFI), alternative furrow irrigation (AFI) and surge alternative furrow irrigation (SAFI) incorporated in three different cycle times and cycle ratios. Obtained results indicated that, shifting irrigation practice from conventional irrigation (EFI) to AFI and SA(10/10), decreased water consumptive use (WCU) by about 21.93 and 36.37 %, respectively. Both of water application efficiencies (Ea) and distribution uniformities (DU) values were improved under AFI and SA(10/10) treatments. Highest average values of (Ea) and (DU) were 84.95 % and 0.8532 obtained with SA(10/10), as compared to (EFI) treatment. Shifting irrigation practice from conventional furrow irrigation (EFI) to alternate furrow (AFI) increased seed cotton yield and lint yield by about 11.91 and 12.52 %, respectively, and saved irrigation water by about 15.20 % as compared to EFI treatment. Maximum seed cotton yield, seed yield and lint yield of 1746.73, 1125.82 and 610.12 (kg/fed), respectively were obtained under SA(10/10) treatment, followed by SA(10/15) by about 1041.54 and 546.92 (kg/fed), which saved irrigation water by about 25.00 and 21.57 %, respectively. Average water use efficiency (WUE) and irrigation water use efficiency (IWUE) values were significantly affected by different irrigation treatments. Maximum average WUE and IWUE values of 0.758 and 0.477 (kg/m^3) were recorded with SA(10/10) treatment. It could be concluded that, in case of lack of irrigation water, surge alternative and alternative furrow irrigation methods are mainly preferred under the conditions of the study area.

Keywords: Water saving, conventional furrow irrigation, alternative furrow irrigation, surge furrow irrigation and crop water productivity.

INTRODUCTION

Today the significance of crop irrigation and water use is highly strategic due to the two parallel crises the 1st increase of water scarcity to population as a result to decrease the available water resources for agriculture in recent years with the increased demands for irrigation and other nonagricultural water uses. And the 2nd climate change. Enhancing agricultural productivity has become essential to meet food demands for the ever growing population. Thus, available water for irrigation needs to be utilized judiciously. Viewed from the perspective of water stress, the purpose of irrigation is to keep water status at a level that maximizes yield within the constraints of irrigation supply and growing season weather. Cotton (Gossypium hirsutum L.) is the most important crop and fibers in Egypt. Furrow irrigation methods are extensively used for cotton production. The farmers use, generally, over irrigation water, which results in high losses and low irrigation efficiencies, thus in turn causes drainage and salinity problems (Khalifa 2006). In the recent past the Egyptian long staple cotton was the most important cash crop and played a significant role in the economic development of the country. The cotton crop not only met the increasing demand of domestic agro-based industries but also fetches a substantial amount of foreign exchange through exportable surplus of cotton fiber and fiber made products. Cetin and Bilgel (2002) cited that cotton provides raw material not only for the textile industry but also the feed and oil industries with its seed, rich in both oil (18-24%) and protein (20-40%). One of the critical problems in cotton production is the amount of irrigation water. Water requirements vary widely depending on growing season length, climate, cultivar, irrigation method, and production goals, but may range from 700 to 1200 mm. In regions with limited rainfall, yields increase linearly with irrigation application over the range of 600 to 900 mm, depending on the cultivar and provided the growing season is long enough to allow for complete boll and fiber development (FAO 2012). Lascano and Sojka (2007) reported that the area should be increased by more than 20 % and the irrigated crop yield should be increased by 40 % by 2025 to secure the food for 8 billion people. Despite this progressive water shortage, most farmers, especially small ones continue to use flood irrigation that results in high water loss by evaporation and drainage. Research shows that over 45 % of water applied is lost to deep soil drainage and surface runoff (Karrou *et. al*., 2012). Water resources in Egypt are limited and restrict crop production in the newly reclaimed lands because of current intensive agricultural production. Agriculture in Egypt relies heavily on irrigation. The agricultural sector consumes more than 84% of available water resources. Many efforts have been made by specialized to conserve and prevent wasteful in irrigation water by using wide spaced furrow irrigation, skipped crop rows as a means to improve water use efficiency or fixing some furrows for irrigation, while adjacent furrows were not irrigated for the whole season. Kang *et al.* (2000a and b) showed that alternative drying of part of the root system was better than the drying of fixed part of the root zone, in addition the alternate furrow irrigation drying led to an even distribution of the root system in the soil with better utilized of nutrients in the whole root zone. The results of more recent investigation (Mintesinot *et al*., 2004) showed that by using alternate furrows resulted highest water productivity values which the increase over the traditional management was 58%. Clemmens *et al*. (1999) reported that over the past decade, there has been a gradual shift in Egypt towards development of farm mechanization systems. They recommended to implementing a tail water recovery system and improving irrigation scheduling would potentially increase irrigation efficiency and reduce the over–irrigation and nitrate leaching observed for crop production system. El-Hadidi. *et al*. (2008) conducted an experiments at

Sakha Agricultural Research Station, Kafr Elshiekh Governorate during two successive summer seasons (2006 and 2007) to evaluate surge, alternative and continuous flow in furrow irrigation with cotton crop. Their results indicated that the performance of the system during the evaluation was acceptable in case of surge flow at 0.75 cycle ratio with 30 min. on and 10 min. off in the two growing seasons. In case of continuous flow, the performance of the system was poor since about 48 percent of all water applied was lost from the field as runoff or deep percolation. El-Shahawy (2004) found that the irrigation of all furrows under traditional land leveling received the highest amount of irrigation water. On the other hand, alternative furrow irrigation under precision land leveling received less amount of irrigation water. Meleha (2000) reported that water requirements for cotton plants were ranged between 3500 and 3638 (m^3/fed) and many studies were carried out to improve irrigation efficiencies to achieve the proper economic use of water. Ertek and Kanber (2003), Karam *et al*. (2006) and Buttar *et al*. (2007) studied the effect of different irrigation methods and practices on lint yield. They found that the excessive irrigation of cotton can lead to increase in vegetative growth, delay maturity, reduce number of open bolls, and decrease the yield, whereas insufficient water can cause an increase in shedding, thus, a decrease in yield. Ismail and Raghab (2006) investigate that, the reduction in advance time was more pronounced in sandy clay soil and sandy clay loam soil than sandy soil. The 24 minutes cycle time was better than the 16 minutes cycle time. Horst *et. al.* (2007) assessed impacts of surge-flow irrigation on water saving and productivity of cotton. They results identified the best irrigation water productivity (0.61 kg/m^3) was achieved with surge-flow on alternate furrows, which reduced irrigation water use by 44 % (390 mm) and led to high application efficiency, near 85 %. Khalid *et. al.* (1999) observed that two varieties of cotton were grown under furrow and alternate furrow irrigation methods. In alternate furrow irrigation, 40.61 % less water was used. Water use efficiency (WUE) in both the varieties was 22 and 21 % higher with alternate furrow irrigation as compared to conventional furrow irrigation. Alternate furrow irrigation received less amount of water and produced almost the same yield as in conventional furrow irrigation method. Ebrahimian *et. al*. (2011) conducted experiments to apply surface fertigation in alternate furrow irrigation and compare it with conventional furrow irrigation in terms of yield production and water use efficiency (WUE). Total applied irrigation volume and the biomass and dry matters in the beginning, middle and end parts of the experimental field were measured for all irrigation treatments. The highest biomass and dry matters were obtained in conventional furrow irrigation 55.0 and 20.2 (ton/ha), respectively. Meanwhile, fixed alternate furrow irrigation had the lowest values for the biomass and dry matters 27.3 and 8.3 (ton/ha), respectively. WUE value was 2.82 (kg/m^3) with alternate furrow irrigation, 1.31 (kg/m^3) with fixed alternate furrow and 1.61 (kg/m^3) with conventional furrow irrigation, respectively. Alternate furrow irrigation not only decreased water and fertilizer consumptions but also significantly increased water use efficiency. Now and a long –term perspective Egypt in shortage of fresh water resources, highlights and urgent solution for innovative irrigation strategy and agricultural water management, so it was thinking about how to reduce the irrigation water used with conventional surface irrigation system by using less water than usual in the same time improving water use efficiency and increasing the homogeneity of water distribution. Therefore, the main objectives of the present study were to:

1- Assessment impacts of the different irrigation treatments (conventional, alternative and surge furrow irrigation) on cotton seed yield and yield components.
2- Determine water saving potential (WS), water use efficiencies under different surface irrigation treatments.

MATERIALS AND METHODS

Description of the study area

Two field experiments were conducted during 2013 and 2014 summer seasons at Al-Amrya area (Al-Nhada region) in Sanad 1 village representing a new reclaimed land, Alexandria Governorate, Egypt, located at (Latitude 31^{o} 06$^{"}$N, Longitude 29^{o} 59$^{"}$E and 8.0 m Altitude), to evaluate the performance of different furrow irrigation treatments (conventional, alternative and surge alternative with different cycles ratio) on seed cotton yield cotton, productivity and water saving potential and water use. The climate of the experimental site is usually dry with ineffective rainfall . Soil samples were collected at 20 cm increments to a depth of 60 cm to determine some physical properties of the experimental site according to the methods described by Klute (1986). Values of these measurements are presented in Table (1). Double ring infiltrometer was used to determine soil infiltration rate parameters with conventional and alternative irrigation. Laboratory experiments were conducted to measure the water intake rate parameters under different surge irrigation cycles. Soil roughness and furrows cross section area and furrow geometry were determined using a profile-meter. Measurements of furrow irrigation hydraulic parameters included furrow length, width, slope, water application rate, advance and recession times, cut-off time, and furrow water normal depth (Y) with time through each irrigation event were recorded.

Table (1): Some physical properties of the soil at the experimental site.

Soil depth	Particle size distribution., (%)			Soil texture	BD gcm^{-3}	F.C m^3m^{-3}	P.W.P m^3m^{-3}	AW m^3m^{-3}
	Sand	Silt	Clay					
0-20	56.8	10.8	32.4	Sandy Clay Loam	1.50	0.31	0.21	0.10
20-40	55.6	11.5	32.9		1.47	0.32	0.21	0.11
40-60	55.9	12.1	32.0		1.48	0.31	0.21	0.10
Aver	56.1	11.5	32.4		1.48	0.31	0.21	0.10

Experimental design

The experiments were laid out in randomized complete block design (RCBD) in three replicates. Each replication includes five experimental plots. Plot size consisted of six blocked end furrows each 100 m long and 0.60 m width with a total area of $360m^2$. The slope in the irrigation direction was 0.001 (m/m). Buffer zones of two wet furrows separated between replicates, and between plots to avoid the interference and to facilitate the movement between the treatments. To monitor the advance and recession time, ten monitoring points (stations) were established along the furrows. The distance between two consecutive points was 10.0 m.

Irrigation treatments

The irrigation treatments are designated as EFI, AFI, SA(10/10), SA(10/15) and SA(10/20). Details descriptions of the irrigation treatments are summarized as follows:

1) **Conventional irrigation method, (EFI**): every furrow was irrigated at 20-day intervals.
2) **Alternative furrow irrigation, (AFI):** only selective watering of every other furrow, that is, each bed receives water only on one side and alternating sides/ furrow at 20-day intervals and odd furrows (1, 3, 5) are irrigated first followed by even furrows (2, 4, 6).
3) **Surge alternative furrow irrigation, (SAFI):** only selective watering of every other furrow, that is, each bed receives water only on one side and alternating sides/furrow at 20-day intervals according to on time and odd furrows (1, 3, 5) are irrigated first followed by even furrows (2, 4, 6) according to on-time.

Irrigation treatments applied for surge alternative furrow irrigation were:

SA(10/10): 10 min on-time and 10 min off-time, (cycle time 20 min and cycle ratio ½).

SA(10/15):10 min on-time and 15 min off-time, (cycle time 25 min and cycle ratio 2/5).

SA(10/20): 10 min on-time and 20 min off-time, (cycle time 30 min and cycle ratio 1/3).

Cultural practices and measurements

Cotton seed variety Giza 86 (Gossypium hirsutum L) was hand planted on 20 and 18 April after wheat in 2013 and 2014 seasons, respectively at 0.2 m apart between hills. Hand hoeing was carried out three times during the growing seasons. Before second irrigation, the plants were thinned to two plants per hill. Past management was carried out on an as-needed basis, according to local practice performed at the experimental station. The ordinary cultural practices for growing cotton were adopted as recommended, except the experimental treatments. Also, pest management was carried out according to the practice performed at the experimental site. At full maturity stage, ten plants were chosen at random from each treatment to estimate seed cotton yield/plant (g). Seed index (g 100 $seed^{-1}$) and Lint index (g lint100 $seed^{-1}$) was measured according to Zakaria *et al.* (2006) from individual plants. Total cotton yield/plot was determined by first hand-picking on September 20 and 27 with final hand-picking on October 15 and

21 in the two seasons of 2013 and 2014, respectively. Seed cotton yield/treatment in kilograms/ feddan was determined and transformed to seed cotton yield/treatment in kentars/feddan (one kentar equal to 157.5 kg).

Inflow rate measurements

Average water inflow rate was 1.075 (l/s/furrow), based on changes of water head over the center of spiels (h) and spiels diameter. The amount of water applied was estimated by a measuring water volume in a certain time. Furrow irrigation inflow rate (q) was determined using the following equation according to Michael, (1978).

$$q = 0.65 \times 10^{-3} a \times \sqrt{2gh}$$

Where q: irrigation water inflow rate per furrow (l/s.), h: water head above the center of spiels (cm), a: the spiels cross-section area (cm^2) and g: acceleration due to gravity (981 cm/sec^2).The calibration of the spiels discharges were carried out under the operation conditions using volumes and times method.

Advance and recession times (T_{adv} and T_{rec})

Advance time was recorded at each station along furrows. As water reached the end of furrows, storage time started and was recorded until the required depth of water above the surface was equal in all stations along all the furrows. As the storage phase ended, water supply was stopped and recession time began. Recession time was recorded for all stations until water in the furrow disappeared. Also, advance and recession time were measured for surge irrigation treatments, considering on-and off times. The advance distances were also measured for all treatments.

Applied irrigation water (Q)

The volume of water applied for each plot was calculated by the following relationship:

$$Q = q \cdot T_{co} \cdot n$$

Where: Q: water volume, (m^3/plot), T_{co}: total irrigation time per furrow (min), and n: number of furrows per plot.

Water applied depth (Wa)

Water applied depth for each irrigation event (I) was calculated using the following formula:

$$I = Q \cdot T_{co} \cdot 1000 / A$$

Where I is the average water applied depth (mm); Q=q · n (plot discharge, m^3/min) and A: plot area (m^2).

Water applied depth varied according to the time for each irrigation treatment. Total water applied depth or seasonal water applied (Wa) was the sum of the amounts of water added at each irrigation event during the entire growing season.

- Computation of water infiltrated depth, Z_{inf} from the following equation:

$$Z_{inf} = KT^a + CT$$

Where Z is the accumulated intake volume per unit length, (m^3/m) (per furrow or per unit width), T is the intake opportunity time in minutes, a is the constant exponent, K is the constant coefficient (m^3/min/m) of length, and C is the basic intake rate, (m^3/min/m) of length. In order to express intake as a depth of application, Z must be divided by the unit width. For furrows, the unit width is the furrow spacing, W_f. Values of K, a, b and W_f along with the volume per unit length required to refill the root zone, Z_{req}, are design input data. The design procedure requires that the intake opportunity time associated with Z_{req} be known. This time, represented by T_{req}, requires a nonlinear solution to Eq. (5):

$$T_{req} = (Z_{req}/K)^{(1/a)}$$

Water consumptive use (WCU)

The quantities of water consumptive use (WCU) were calculated using the following equation (James, 1988):

$$CWU = I + P \pm \Delta S - Rod - Dpd$$

Where: WCU: water consumptive use (mm), or so called crop evapotranspiration (ETc), I: irrigation amount (mm), P: effective precipitation (mm), ΔS: change of soil water storage (mm), Rod: surface runoff depth (mm), for closed-end furrows this value was neglected and Dpd: deep percolation depth below crop root zone (mm). Also, Gravimetric soil samples were taken at sowing, just one day before and after each irrigation event and at harvest to determine water consumptive use of cotton crop. Water consumptive use (WCU) was calculated according to the equation given by Israelson and Hansen (1962) and Abd-El-Halim (2013**)** as follows:

$$WCU = (\theta_2 - \theta_1) \times Ssd \times ERZ$$

Where: WCU: water consumptive use (mm), or so called crop evapotranspiration (ETc), Θ_2: percentage of soil moisture content after irrigation, Θ_1: percentage of soil moisture content before irrigation, Ssd: specific soil density, and ERZ: effective root zone, (mm).

Irrigation efficiencies

Water application efficiency (Ea)

Water application efficiency (Ea) was calculated based on required water infiltrated depth (Z_{req}) as the ratio of furrow volume (F_{vol}) of water infiltrated to furrow volume of water applied according to Clemmens (2007).as follows:

$$E_a = ((Z_{req}/1000) \cdot L \cdot S / F_{vol}) \cdot 100$$

Water distribution uniformity

To study the effect of the different irrigation treatments on water distribution uniformity along the furrow, the soil water content was measured at the beginning, middle and at the end of the furrows at 20 cm increments to a depth of 60 cm. Water distribution uniformity (DU), was calculated as the ratio of low quarter average water infiltrated depth (Z_{inf-lq}) to average water infiltrated depth, (Z_{ave}) according to Clemmens (2007).

$$D_U = Z_{inf - lq}/Z_{ave}$$

Where L: furrow length, (m) and S: furrow width, (m).

Water use efficiencies (WUE and IWUE)

Crop water use efficiency WUE and IWUE were determined according to Ali *et al.,* 2007 as follows:

$$WUE = SCy / CWU$$

$$IWUE = SCy / Wa$$

Where WUE: crop water use efficiency (kg/m^3), IWUE is the irrigation water use efficiency (kg/m^3) SCy is the seed cotton yield (kg/fed), WCU is the consumptive water use (m^3/fed) and Wa is the irrigation water applied volume (m^3/fed).

Statistical analysis

Statistical analysis of the average data over the two growing seasons was performed using a randomized complete block design with three replicates at random procedure using CoStat (version 6, 311, CoHort, USA, 1998-2004). Comparisons between treatments as a mean values were carried out using the least significant difference (LSD) at 0.05 probabilities.

RESULTS AND DISCUSSION

Advance and recession times (T_{adv} and T_{rec})

Advance and recession times behavior were different due to different irrigation treatments as shown in Fig. (1). Advance and recession times varied depending on furrow irrigation management techniques. As shown in Fig. (1a), highest average advance time values of 66.5 and 56.4 min were associated with EFI and AFI treatments as an average value for all irrigation events during growing season, respectively. Meanwhile, the lowest average advance time values were observed with SA (10/10) (36.6 min) followed by SA (10/15) (45.1 min), respectively, Fig. (1c). Faster recession times were observed with alternative furrow irrigation technique, (AFI) due to lateral infiltration in the direction of non-irrigated furrows as compared to conventional irrigation, (EFI), Fig. (1a). Also, faster recession times Fig. (1c) explained that were observed with surge alternative furrow irrigation technique, were due to less amount of water volume applied as compared to conventional irrigation (EFI).

Advance time measurements with inflow rate 1.075 (l/s) for all irrigation events during growing season showed that, advance time is faster with surge-flow at the beginning of growing season as compared with conventional irrigation, (EFI), when soil clods are yet formed. Therefore, average water volume used to complete the advance time for all irrigation events during growing season, with SA(10/10) is about 17.65 % less than with conventional treatment (EFI). Later in the growing season, the advance times are practically the same because the furrows are then smoothed and no advantages in water use are observable for surge-flow.

Water infiltrated depth (Z_{inf})

As shown in Fig. (1b), highest water infiltrated depth values were observed with EFI and AFI treatments, which, range between (151.1 mm at furrow inlet to 138.5 mm at furrow end) and (134.9 at furrow inlet to 121.8 mm at furrow end), respectively. This is may be due to using small inflow rate, the opportunity time at furrow inlet for infiltrated water, inside the soil layers in the vertical direction greater than water advance in horizontal direction.

Recession time mainly depend on the duration of intake opportunity time, (T_{opp}), average intake opportunity time values with EFI and AFI for all irrigation events during growing season, were ranged from (140.7 at furrow inlet to 117.3 min at furrow end) and (137.4 at furrow inlet to 111.6 at furrow end min), respectively. Increasing intake opportunity time at furrow inlet may be due to the rearrangement of fine partials to fill the voids between big aggregates and the formation of surface seal. On the other hand, the reduction in intake opportunity time, (T_{opp}) at furrow end was attributed to fast infiltration of water inside the soil layers in the vertical direction greater than water advance in horizontal direction.

Water infiltrated depth values were improved and decreased with surge alternative treatments, SA (10/10), SA (10/15) and SA(10/20) as shown in Fig. (1d). Average water infiltrated depth values for all irrigation events during growing season were ranged between (136.0 mm at the head of the furrow to 111.7 mm at furrow end), (144.9 mm at the head of the furrow to 115.7 mm at furrow end) and (151.0 mm at the head of the furrow to 120.4 mm at furrow end), respectively. The reduction in average water infiltrated depth values with surge alternative technique may be due to consolidation, soil particle migration and furrow smoothing results from the off times, as the furrow channels become more streamlined throughout the irrigation season.

Seasonal amount of water applied (Wa)

Average Wa values over the two growing seasons were presented in Table (2) EFI and AFI treatments had the maximum (Wa) values of 4879.0 and 4137.4 (m^3/fed), respectively. Practicing surge alternative techniques resulted in less seasonal amount of applied water (Wa), which, were: 3659.5, 3826.5 and 4022.2 (m^3/fed) with SA (10/10), SA (10/15) and SA (10/20), respectively. This indicates that, alternate furrow irrigation treatments (AFI) saved water by approximately about 15.20 %, (Fig. 2). Meanwhile, the same Figure showed that, surge alternative techniques saved water by about 25.00, 21.57 and 17.56 % with SA (10/10), SA(10/15) and SA(10/20), respectively.

Considering irrigation intervals, lowest seasonal amount of water applied (Wa) with AFI treatments as compared to EFI might be due to the great reduction of wetted surface in AFI; almost half of the soil surface is wetted in AFI as compared to EFI. This result supports the outcome obtained by Hiekal *et al*. (2009), who found that AFI methods can supply water in a way that greatly reduces the amount of wetted surface, which leads to less evapotranspiration and less deep percolation. The amount of (Wa) with surge alternative techniques were less than EFI and AFI. This can be attributed to depths of applied water with EFI and AFI were 1.24 and 1.05 times higher than for surge alternative techniques. This is due to the fact that the inflow water volumes were reduced during the wetting phase and the cut-off time T_{co} was smaller with surge treatments.

Water consumptive use (WCU**)**

Water consumptive use (WCU) was significantly decreased under surge furrow irrigation treatments and had the same trend in both seasons (Table 2). Average highest WCU values of 3623.4 m^3/fed was recorded with EFI followed by 2828.9 m^3/fed with AFI, while lowest average values of 2305.7 m^3/fed was obtained with SA(10/10). These results indicate that AFI and SA(10/10) were decreased WCU by about 21.93 and 36.37 %, respectively, as compared to conventional EFI treatment. SA(10/10), average WCU value were lower than SA(10/15) and SA(10/20) by approximately about 9.59 and 18.71 %, respectively, as compared to conventional EFI, which may be due to the fact that cotton plants grown under SA(10/10) treatment conditions were subjected to water stress resulting from less frequent irrigation and lower amount of applied water.

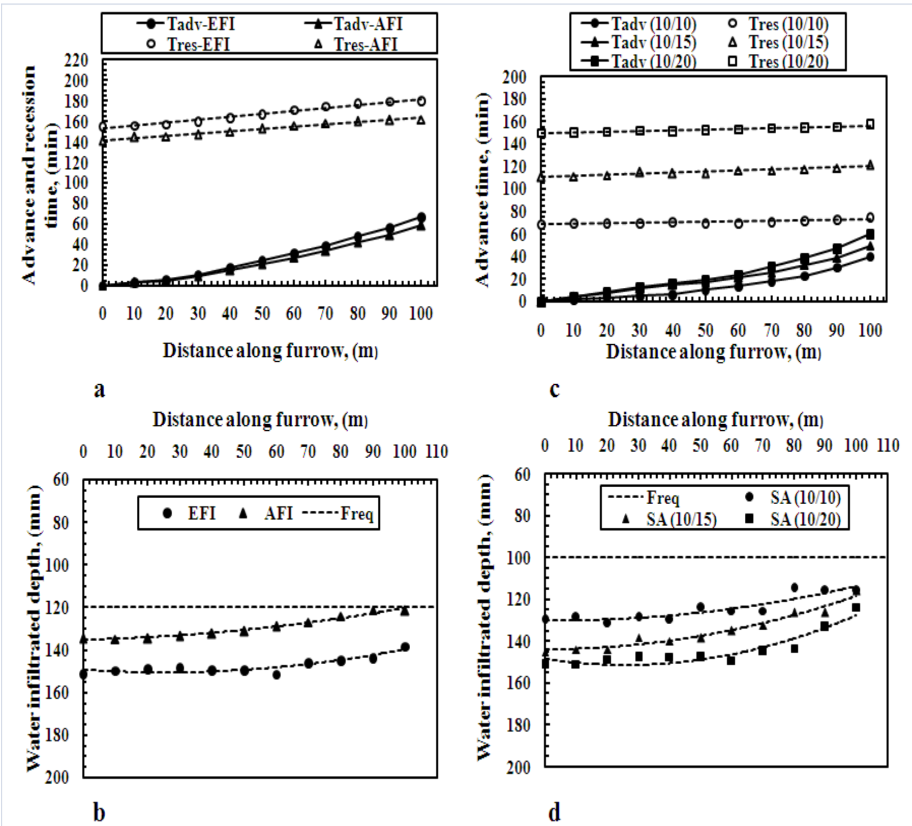

Fig. (1): Advance and recession curves a (EFI and AFI) and c (surge alternative) and water infiltrated depths, b (EFI and AFI) and d (surge alternative, SA) under different irrigation treatments.

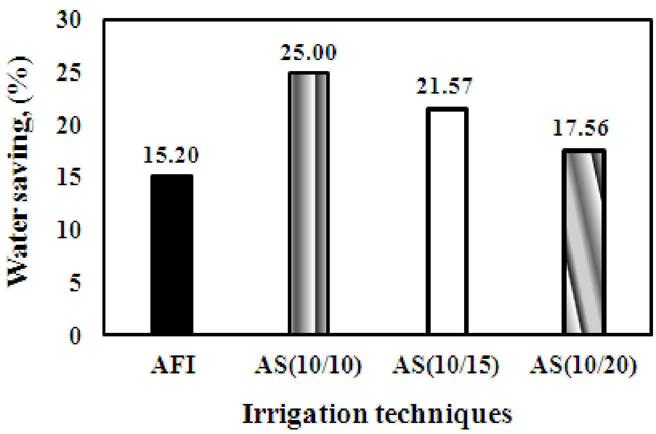

Fig. (2): Water saving under different irrigation techniques relative to EFI treatment.

Irrigation performance

Water application efficiency (Ea)

Irrigation performance parameters calculated for cotton crop under different irrigation treatments are shown in Fig. (3). As shown in Fig (3a), average values of application efficiency (Ea %), with EFI treatment for all irrigation events during growing season, showed that, approximately about 42.88 % of water applied were not available for the crop. While, with AFI, SA(10/10), SA(10/15) and SA(10/20) treatments for all irrigation events during growing season, these losses were about, 31.66, 15.05, 21.19 and 27.35 % of water applied were not available, respectively. Lowest average values of these losses were observed with SA (10/10) followed by SA (10/15). Lowest average (Ea) value of 57.12 % was obtained with EFI treatment followed by AFI treatment (68.34 %), Fig. (3a). On the other hand, highest (Ea) average values of 84.95 %, 78.81% and 72.65% were obtained with SA(10/10), followed by SA(10/15) SA(10/20), respectively.

Water distribution uniformity (DU):

Average water distribution uniformity (DU) values for cotton crop under different irrigation treatments as average value for all irrigation events during growing season are presented in Fig. (3b). Lowest average (DU) values of 0.7420 were obtained with EFI treatment, followed by sa(10/20) 0.7795 and SA(10/15) 0.81515. On the other hand, highest average (DU) value of 0.8532 was obtained with SA(10/10), followed by AFI about 0.8434. AFI had an increase in (DU) by approximately 13.66 % as compared to EFI. The increment values reached to 14.97 and 9.85 % with SA (10/10) and SA(10/15) treatments, respectively as compared to EFI. These results interpreted regarding to the water inflow rate, has to be determined for each field situation according to slope, advance phase, intake opportunity time, furrow length and depth of application, Mintesinot *et al*. (2004). Generally, using alternative furrow irrigation and surge alternative furrow irrigation leads to increased homogeneity of water distribution uniformity into the soil.

Cotton productivity

Seed cotton yield and yield components (kg/fed)

Data in Table (3) illustrate the influence of the different irrigation treatments on seed cotton yield and yield components. Irrigation treatments showed highly significant effect on seed cotton yield (SCy), seed yield (SY) and lint yield (LY). There are significant differences among all treatments except SA(10/15) and SA(10//20) treatments. However, SA(10/10) occupied the maximum (SCy), (SY) and (LY) values of 1746.73 (11.09 kentar), 1125.82 and 610.12 (kg/fed), respectively, followed by SA(10/15) and SA(10//20) treatments. Meanwhile, EFI treatment had the minimum (SCy), (SY) and (LY) values of 1233.41, (7.83 kentar), 825.94 and 428.77 (kg/fed), respectively.

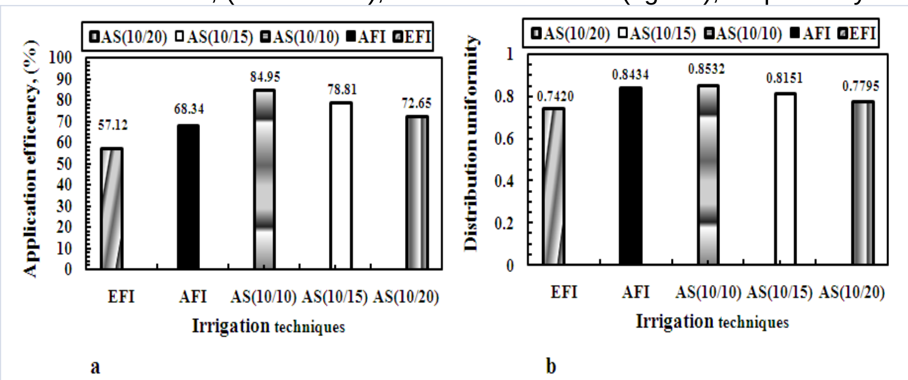

Fig. (3): Water application efficiency and distribution uniformity under different irrigation techniques.

These results demonstrated the highly effect of surge alternative irrigation treatments on (SCy), (SY) and (LY) as shown in Fig. 4(a, b and c). Practicing SA (10/10) treatments enhanced (SCy), (SY) and (LY) by about 41.62, 36.31 and 42.30 %, respectively, as compared to conventional irrigation (EFI) treatment. On the other hand, AFI treatments increased (SCy), (SY) and (LY) by about 14.55, 11.91 and 12.52 %, respectively, as compared to conventional irrigation (EFI) treatment. These increases in seed cotton yield and yield components with surge alternative irrigation treatments (SAFI) and alternative furrow irrigation treatment (AFI) may be due to surge alternate and alternate furrow irrigation have caused good aeration of roots zoon in soil; and enhanced structure of the soil and soil moisture content. While lower yield with EFI system was attributed to irrigation water ponds at the furrow ends after irrigation event, which too much water might have caused partially poor aeration of roots, and soil nutrients leaching.

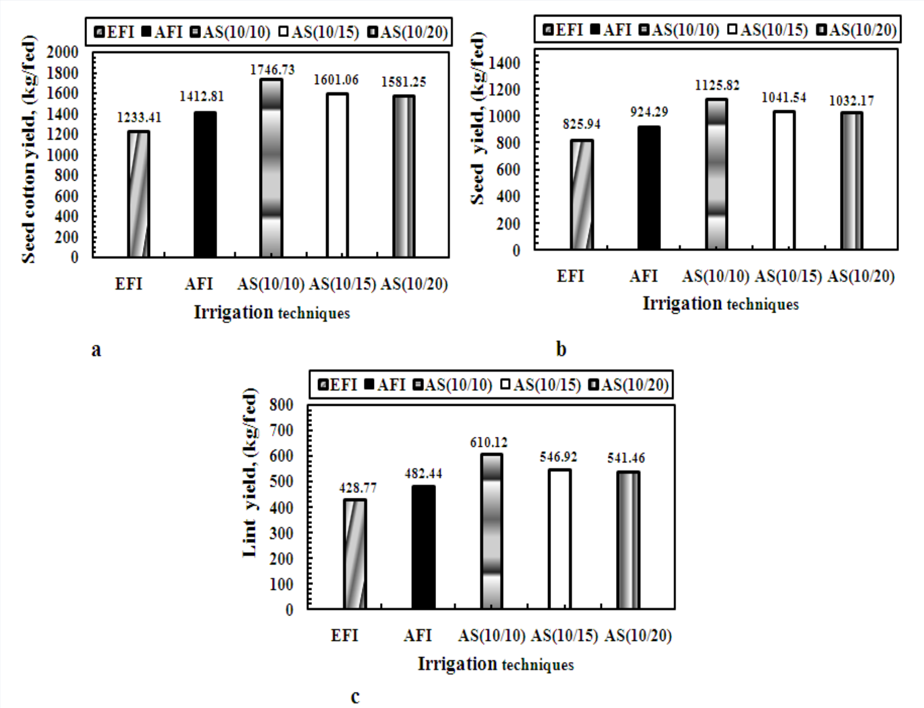

Fig. (4): Average seed cotton yield and lint cotton yield under different irrigation techniques.

Table (2): Water-relationship parameters under different irrigation techniques, (over two seasons).

Irrigation treatments	Wa m^3/fed.	Δ Wa %	WCU mm	WCU m^3/fed	ΔWCU %
EFI	4879.0		862.7	3623.4	
AFI	4137.4	15.2	673.6	2828.9	21.93
SA(10/10)	3659.5	25	549.0	2305.7	36.37
SA(10/15)	3826.8	21.57	607.2	2550.2	29.62
SA(10/20)	4022.2	17.57	675.3	2836.5	21.72

Seed and lint cotton indexes (g)

Seed index and lint index were significantly affected by the irrigation techniques as illustrated in Table (3) applying alternative and surge alternative furrow irrigation treatments, enhanced both of seed index and lint index. As shown in Table (3), seed index and lint index were improved and achieved their highest average values of 10.11 and 5.46 (g) with SA(10/10) treatment, respectively followed by SA (10/15), SA (10/20) and AFI treatments as compared to EFI treatment. However, the statistical analysis results showed non-significant differences among (SAFI) treatments regarding lint index.

Water use efficiency (WUE)

Average water use efficiency (WUE) values were significantly affected due to irrigation treatments. As shown in Fig. (5a), and Table (3), highest WUE values of 0.76 and 0.63 (kg/m^3) were recorded with SA(10/10) and SA(10/15) treatments, respectively. Whereas, lowest WUE values of 0.34 and 0.50 kg/m^3 were recorded with EFI and AFI treatments, respectively. These results indicate that both of SA(10/10) and SA(10/15) achieved high WUE values as compared to EFI. This could be due their higher seed cotton yield and lower WCU (2305.7 m^3/fed) and (2550.2 m^3/fed), respectively.

Table (3):Seed cotton and lint cotton yields and cotton water-relationship parameters under different irrigation techniques, (over two seasons).

Irrigation treatments	Seed Cotton yield		Seed yield kg/fed	Lint yield kg/fed	Seed index g	Lint index g	WUE kg/m^3	IWUE kg/m^3
	kg/fed	Kentar/fed						
EFI	1233.41d	7.83	825.94d	428.77d	9.08e	4.44c	0.34e	0.25d
AFI	1412.81c	8.97	924.29c	482.44c	9.55d	5.01b	0.50d	0.34c
SA(10/10)	1746.73a	11.09	1125.82a	610.12a	10.11a	5.46a	0.76a	0.48a
SA(10/15)	1601.06b	10.17	1041.54b	546.92b	9.87b	5.35a	0.63b	0.42b
SA(10/20)	1581.25b	9.00	1032.17b	541.46b	9.72c	5.29a	0.56c	0.39b
significance	***		***	***	***	***	***	***
LSD 0.05	55.73		39.78	33.68	0.070	0.25	0.037	0.033

EFI: Every-furrow irrigation; AFI: alternate furrow irrigation; and SAFI: surge alternate furrow irrigation. Means within each column followed by the same letter/s are insignificant different (P = 0.05). n.s: not significance different (P = 0.05). ∗: significance different (P = 0.05), ∗∗: significance different (P = 0.01),, ∗∗∗: significance different (P = 0.001).

Irrigation water use efficiency (IWUE)

Irrigation treatments appear highly significant effect on irrigation water use efficiency (IWUE). As shown in Fig. (5b) and Table (3) highest IWUE values of 0.48 and 0.42 (kg/m^3) were recorded with SA(10/10) and SA(10/15) treatments, respectively. Whereas, lowest average IWUE values of 0.25 and 0.34 (kg/m^3) were recorded with EFI and AFI treatments, respectively. These results showed that both of SA(10/10) and SA(10/15) achieved highest average (IWUE) values as compared to EFI. This could be due to highest seed cotton yield obtained with lower WCU (549.0 mm) and (607.2 mm), respectively (Table 2). Also, these results indicated that SA(10/10) and SA(10/15) are appropriate to increase (WUE) and (IWUE) because they allow applying less irrigation water for cotton production, 3659.5 and 3826.5 (m^3/fed), respectively while produced higher yield. This provides a useful guide to assess these irrigation strategies. So, Surge alternate-furrow irrigation with appropriate irrigation treatments AS(10/10) and AS(10/15) can be used as an efficient method for cotton production in arid areas where production depends heavily on irrigation. It could be concluded that AS(10/10) and AS(10/15) treatments controlled stress irrigation without the risk of reduced cotton yield.

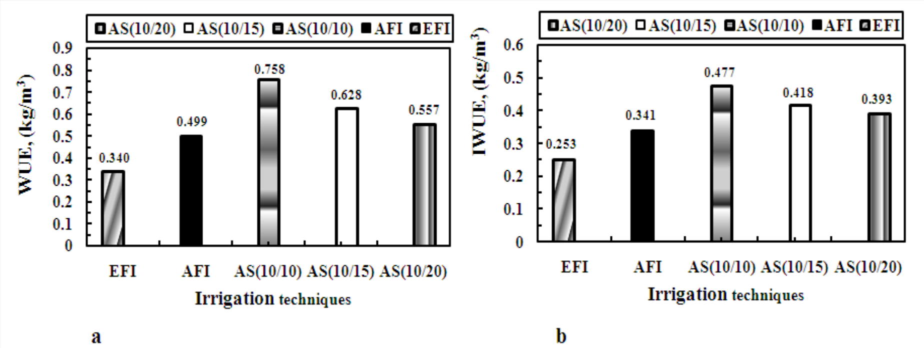

Fig. (5): Average water use efficiency, (WUE) and irrigation water use efficiency (IWUE).

CONCLUSIONS

* Cotton yield data showed different trends that varied due to different irrigation treatments; there were significant differences between alternative, surge alternative and conventional irrigation treatments.
* Shifting irrigation practice from conventional irrigation (EFI) to alternate furrow (AFI), increased seed cotton yield and lint yield by about 11.91 and 12.52 %, respectively, and saved water by about 15.20 % as compared to EFI.
* Maximum seed cotton yield and lint yield were observed with SA(10/10) 1125.82 and 610.12 (kg/fed) followed by SA(10/15) 1041.54 and 546.92 (kg/fed),which saved water by about 25.00 and 21.57 %, respectively.
* Application efficiencies (Ea) and distribution uniformities (DU) values were improved with alternative and surge alternative furrow irrigation, as compared to EFI.
* Maximum (Ea) values were 84.95 and 78.81 % obtained with SA(10/10) and SA(10/15), respectively as compared to (EFI). Highest (DU) values were 0.8532 and 0.8434 % obtained with SA(10/10) and (AFI), respectively as compared to (EFI).
* Average water use efficiency (WUE) and irrigation water use efficiency (IWUE) values were significantly increased under alternative and surge alternative furrow irrigation treatments, as compared to covenantal furrow irrigation (EFI).

From above mentioned results it can be concluded that, alternative and surge alternative furrow irrigation treatments can be used for cotton production in case of lack of irrigation water and in arid and semi-arid areas where production depends heavily on irrigation.

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تأثير تقنيات الري السطحي المختلفة علي إنتاجية القطن وتوفير المياه

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يهدف البحث الي دراسة تأثير تقنيات الري السطحي المختلفة علي الأنتاجية و كفاءة استخدام المياة لمحصول القطن فضلا عن مساهمة هذه التقنيات في ترشيد و توفير مياه الري. و لتحقيق أهداف هذه الدراسة تـم أجـراء تجـارب حقليـة علـي محصـول القطـن (جيـزه 86) لموسـمي الصـيف المتتـاليين (2014/2013) بآلعامرية (منطقة آلنهضة) في قرية سند1 علي تربة رملية طينية طمبية حيث تمثل هذه المنطقة الأرض حديثة الاستصلاح. تم تصميم التجربة إحصائياً بإستخدام القطع كاملة العشوائية (RCBD) في ثلاث مكررات لمتغير واحد وهو طريقة الري. وكانت المعاملات تحت الدراسة:

الري السطحي لكل الخطوط كل 20 يوم (EFI)، 2- الري السطحي التبادلي لنصف الخطوط كل 20 يـوم (AFI)، 3- وكانـت معـاملات الـري السـطحي النبضـي التبـادلي كالتـالي: (10/10)، (15/10) و(20/10). وقد شملت القياسات الحقلية أزمنة تقدم وانحسار وغلق المياه كذلك أعماق المياه داخل الخطوط خلال الزمن الكلي للري. كما تم قياس معدلات تسرب الماء للتربة بالاضافة الي تقدير كميات المياه المضافة واللاستهلاك المائي للمحصول كذلك فقد تم تجميع البيانات الخاصة بالمحصول عند تمام النضج وتقدير المحصول الكلي و كفاءة استخدام المياه و كانت أهم النتائج المتحصل عليها:

- أدي تطبيق الـري التبـادلي (AFI) والـري التبـادلي بالتـدفق المـوجي (SA(10/10 الـي إنخفـاض القيم المتوسطة للإستهلاك المائي للنبات (WCU) الي حوالي21.93 و36.37٪ وعلى الترتيب.
- تحسنت قيم كلاٌ من كفاءة أضافة المياه (EA) وتجانس توزيع المياه بالتربـه (DU) للمعاملتين AFI و(SA 10/10) على الترتيب. حيث بلغ أعلى متوسط لقيم (Ea) و(DU) 84.95 ٪ و 0,8532 للمعاملة (SA 10/10)، 68.34 ٪ و0.8434 لمعاملة AFI على الترتيب مقارنة بمعاملة الري التقليدي (EFI).
- أدي تحويل ممارسة الري من الري بـالخطوط التقليدي (EFI) الي الري بالخطوط التبادلي (AFI) الي زيـادة متوسط أنتاجيـة للقطـن الـي 14.55٪ مـن البـذور وشـعر القطـن بنحـو 11.91 و 12.52٪ علـى الترتيب مقارنة بالري التقليدي (EFI)، وتوفير كمية مياه الري المستخدمة بنسبة 15.20 ٪ مقارنـة بـالري التقليدي (EFI).
- حققـت المعاملـة (10/10) SA أقصـى متوسـط لأنتاجيـة محصـول القطـن وبـذور وشـعر القطـن 1746، 1125.82 و610.12 (كج/فـدان) علـي الترتيـب يليهـا المعاملـة (10/15) SA وكانـت 1601، 1041.54 و546.92 (كج/فدان) علي الترتيب وتوفير كمية من مياه الري المستخدمة بنسبة 25.000 و21.57 ٪ على الترتيب مقارنةً بمعاملة الري التقليدي (EFI).
- بلـغ أقصـي قيمـه لكفـاءة أسـتخدام الميـاه (WUE) وكفـاءة أسـتخدام ميـاه الـري (IWUE) مـع المعاملـة SA(10/10) بقيم وقدرها 0.76 و0.48 (كج/متر^3) على الترتيب مقارنةً بمعاملة الري التقليدي (EFI).

*هذا و لقد خلص البحث الي أن:

- تقنية الري السطحي التبادلي والري التبادلي بالتدفق الموجي (AFI) وSAFI) من الطرق المفضلة لأنتاج القطن وتوفير مياه الري في المناطق الجافة والشبة جافة وكذلك الأماكن التي تعاني من عدم وفرة المياه حيث انها تقلل من فرص تعرض النبات للإجهاد المائي دون التعرض لمخاطر الإنخفاض في إنتاجية المحصول من البذور أو شعر القطن.