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WATER SAVING AND MAIZE PRODUCTIVITY UNDER ALTERNATIVE FURROW IRRIGATION SYSTEM

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ABSTRACT

Field experiments were conducted along two consecutive seasons of summer (2013/2014) at private farm, Jabbars village, Itay Al-Barud, Beheira Governorate, Egypt, to demonstrate the impact of alternative furrow irrigation techniques, on maize yield, water saving percentage and crop water productivity in clay soil, using three water inflow rates of 1.14, 1.58, and 1.87 (l/s/furrow). The experiments carried out in a split plot design with three replicates at random procedure. Irrigation system treatments were used as the sub-plots namely: every furrow irrigation (CIM), alternate furrow irrigation (AFI_{7-d} irrigation intervals) and alternate furrow irrigation (AFI_{14-d} irrigation intervals). Three different water inflow rates designated as Q1, Q2, and Q3 represented the main plots. The irrigation performance was evaluated through application efficiency (AE %) and distribution uniformity (DU) parameters. Irrigation water use efficiency (WUE) was estimated, which is related to water management. Obtained results indicated that application of AFI_{7-d} lead to high significant effect between seed yields values and irrigation system treatments, (CIM, AFI_{7-d} and AFI_{14-d}). Shifting irrigation practice from conventional irrigation (CIM) to alternate furrow (AFI_{7-d}) corn grain yields were increased approximately from 8.06 to 9.23 % with an increasing water inflow rates. AFI_{14-d} and AFI_{7-d} alternate furrow irrigation treatments with inflow rate Q3, saved water by approximately about 16.25 and 8.92 %, which represented about 289.2 and 172.6 (m^3/year/fed), respectively, from total water applied as compared to conventional furrow irrigation (CIM). Both of water application efficiencies (Ea) and distribution uniformities (DU) values were improved with all irrigation system treatments as inflow rate increases. Highest values of (Ea) and (DU) were ranged between (67.15 and 73.59 %) and (0.8551 and 0.8968) were obtained with alternative furrow irrigation (AFI_{7-d}) with inflow rates Q2 and Q3, respectively, as compared to (CIM). Maize seed yields production with all irrigation system treatments had significant increases with an increasing inflow rates. The same trends were observed for water use efficiencies (WUE) and water productivities (WP).

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

INTRODUCTION

Agriculture is the main user of water for all countries of the world specially countries that use the river water for irrigation. As the frequent farmers' demand for water to irrigate crops in addition to the increase in water needs of life for other purposes with the occurrence of a water drought or scarcity of water resources in some countries, Egypt consumes about 80 % or more of the available water resources, especially from the Nile River and relied upon mainly in irrigation and production of agricultural crops, (El-Betage and Abo-Hadeed, 2008). This represents an increase in water needs resulting from population growth and the expansion is expected in the area of agricultural land challenge facing our country and to the limited amounts of incoming water from the Nile River, which will result from the process of building the Ethiopian Dam.

As a result of excessive returns farmers to irrigate their fields, especially in the conventional surface irrigation, surface irrigation efficiency value ranging from 45 to 50 % as compared to the other irrigation systems. The main reason for the low surface irrigation efficiency value is due to the loss of large amounts of applied water in the deep percolation to the detriment of the agricultural drainage and this increases the amount of water stored in the soil root zone, which does not benefit the crop throughout the growing season and become poor ventilation. So good application or optimized for surface irrigation is very important to increase the productivity of maize yield per unit of water used without any additional costs, (Swelam and Atta 2011).

Large quantities of water lost in evaporation and free drainage for agricultural land that irrigated by flood. Consequently, about or more than 45 % of the water applied for this purpose is lost in deep percolation and surface runoff, (Karrou et. al., 2012). In Egypt, maize (Zea mays L) is one of the main and important strategic crops after wheat (Triticum aestivum L.), as it represents a major source of food for the entire population, especially as they enter into the manufacture of bread. On the other hand, Egypt's production of corn was approximately about 12 million ton, (USAD, 2012). Alternate furrow irrigation technique (AFI) is considered as the most effective methods to minimize the quantity of water applied per furrow, produce a higher crop yield, one of the most effective tools to save irrigation water, improve irrigation efficiencies as compared to conventional furrow irrigation method, (Abd-El-Halim, 2013). There were no difference between both fixed and alternative furrow irrigation, irrigation performance of them decreased application of irrigated water rates by 26.2 % and 23.0 %, respectively as comparing with conventional furrow irrigation, (Rafiee and Shakarami, 2010).

The most effective technique to maintain the water available for irrigation, increasing crop yields and improving irrigation efficiencies is alternate furrow irrigation technique and it is a best way to save irrigation water. Whenever, the possibility of reducing both of water deep-percolation into the soil and surface runoff losses, resulting in increased water distribution uniformity inside the soil also it can be obtained high irrigation efficiency value. Highest irrigation efficiencies are obtained by almost filling the crop root zone after each irrigation events. The homogeneity of the water distribution into the soil with a good application for adding water with alternative furrow surface irrigation interactive mainly associated with the soil state and field condition and practices for the implementation of the process of regular irrigation, (Kashiani et al., 2011).

Kang *et al.* (2000a and b) showed that drying of part of the root zone system with alternative furrow irrigation was better than the drying of fixed part of the root zone. As a result of this partial drying of the root system with alternative furrow irrigation, led to distribution of the root system in the soil with better utilized of nutrients in the whole root zone. Using alternative surface furrows irrigation technique, result increased water productivity (WP), which reached to 58 %, as compared to traditional furrows irrigation technique (Mintesinot et al., 2004). Fixed and alternative furrow irrigation techniques have been used by many researchers, they found that both of them led to increase water use efficiency, (WUE) and reduce transpiration as compared to conventional furrow irrigation method, (Li. et al., 2007). Hiekal et.al., (2009) reported that, high significant interrelations between grain seed yield values and increases in both of application efficiency and distribution uniformity values with alternative furrow irrigation techniques as compared with conventional surface irrigation. Highest mean distribution uniformity, (DU) values were observed with highest inflow rates for two growing seasons.

The main objectives of the present study were to:

1- Improve the performance of surface irrigation through alternative furrow irrigation technique.
2- Investigate the effects of alternate furrow irrigation system on water saving, water application and distribution uniformities, and maize productivity were considered as compared to conventional irrigation method (CIM).

MATERIALS AND METHODS

Description of the study area

A field experiments were conducted along Two consecutive seasonsof summer (2012/2013) and (2013/2014) at private farm, Jabbars village, north Itay Al-Barud, Beheira Governorate, Egypt, located at (Latitude 31^{o} 03$^{"}$N, Longitude 30^{o} 28$^{"}$E and 6.7 m Altitude), for estimation the performance of alternate furrow irrigation system on the maize productivity and seeds yield of clay soil. Representative soil samples were collected for determination some physical properties according to the methods described by Klute (1986). Statistical analysis of the data was performed using a split plot design with three replicates at random procedure using Costat (version 6, 311, CoHort, USA, 1998-2004) Comparisons between plots and subplots as a mean values were carried out using the least significant difference (LSD) at 0.05 probabilities. Three different water inflow rates represented the main plots: Irrigation system treatments were used as the subplots.

Field experiments and measurements

Soil samples were collected from several different randomized locations to represent the whole experimental site. Soil samples were taken with a screw auger at planting, before and after each irrigation events by 2 days after each irrigation event, and at harvest. Samples were taken at three depths:0-30, 30-60and 60-90cm from both the ridge and bottom of the furrows to estimate some soil physical properties for experimental site(Table 1).

Table (1): Some soil physical properties for experimental site.

Soil depth (cm)	Particle size distribution, (%)			Soil texture class	Soil bulk density, (g/cm^3)	F.C, (%)	P.W.P, (%)	AW, (%)
	Sand	Silt	Clay					
0 – 30	23.63	28.23	48.14	Clay	1.259	41.47	21.82	19.65
30 – 60	20.74	29.97	49.29	Clay	1.398	38.61	20.71	17.90
60 – 90	24.10	40.15	35.75	Clay loam	1.486	38.12	20.33	17.79

F.C: Field capacity; P.W.P: Permanent welting point.

Soil water content was measured by gravimetric method (Merriam *et al.*1983) before and after irrigation events in both wet and dry furrow under AFI system and other treatments along furrow length. Double ring infiltrometer was used to determine soil infiltration parameters (a and K) values. Furrows cross-section area was determined using a profile-meter. Measurements of furrow irrigation hydraulic parameters included furrow geometry, furrow length and width, slope, water application rate, advance and recession times, cut-off time and furrow water normal depth with time through irrigation event for each inflow rate were recorded. The furrow length, width and the slope direction of water run were 70, 0.7 meter and, 0.1 (%), respectively.

- Determination of the time required (T_{req}) to achieve the required infiltrated depth (Z_{req}): 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 as follows:

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

Irrigation cutoff time was estimated according to advance time, (T_{adv}) and time required (T_{req}) to achieve the required infiltrated depth (Z_{req}). Total irrigation time or cutoff time for opened end furrows was estimated according to Walker (1989), as follows:

$$T_{co} = T_{adv} + T_{req} \qquad (2)$$

Irrigation system treatments and water management

Irrigation system treatments were: 1) conventional irrigation method (CIM), every furrow was irrigated at 14-day intervals, 2) Alternate furrow irrigation ($AFI_{7\text{-}d}$) and 3) Alternate furrow irrigation ($AFI_{14\text{-}d}$). With ($AFI_{7\text{-}d}$) and ($AFI_{14\text{-}d}$), only selective watering of every other furrow, that is, each bed receives water only on one side and alternating sides/furrow at 7-days or, 14-day intervals and odd furrows (1, 3, 5) are irrigated first followed by even furrows (2, 4, 6).

The experimental plot size was 294 m^2 (4.2 m wide × 70 m long). Each treatment included 6 furrows and 5 planting ridges (rows). The treatments were separated by non-irrigated furrows.

Inflow rate measurements

Three irrigation system treatments (CIM, $AFI_{7\text{-}d}$ and $AFI_{14\text{-}d}$) and three irrigation water inflow rates (Q1, Q2 and Q3) were considered in this study. Water was conveyed through PVC spiel pipes 80.0 cm length (63.5 mm outer diameter) installed in irrigation channel against the upper end of the furrows, which convey the water according to the required flow rate (one spiel pipe for each furrow). Average three different water inflow rates were 1.14, 1.58 and 1.87 (l/s), respectively based on the changes of water head over the center of spiels (h) and spiels diameter, which predetermined according to the technique of Merriam *et al.* (1983). The average (h) values were 2.2, 4.3 and 5.9 cm. The calibration of the spiels discharges were carried out under the operation conditions using volumes and times method. Different furrow irrigation inflow rates (q) were calculated by the following equation according to Michael, (1978).

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

Where q: irrigation water inflow rate per furrow (l/sec.), 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).

Applied irrigation water volume (Q)

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

$$Q = q \cdot T_{co} \cdot n \quad (4)$$

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

Water applied depth (I)

Water applied depth was estimated using the following equation:

$$I = Q \cdot T_{co} \cdot 1000 / A \quad (5)$$

Where I: average depth of water applied (mm); Q: water volume, (cm^3/plot) and A: plot area (m^2).

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

- Computation of water volume added per furrow (applied) to soil, (Vol_{in}) according to T_{co}, from the following equation:

$$Vol_{in} = q \ T_{CO} \quad (6)$$

- Determination of water infiltrated depth, Z_{inf} according to modified Kostiakov function using the following equation:

$$Z_{inf} = KT^a + CT \quad (7)$$

Where Z_{inf}: water infiltrated depth, (mm), T: the intake opportunity time in minutes, a: the constant exponent, K: the constant coefficient (m^3/min m of length), and C: the basic intake rate, (m^3/min m of length

Water consumptive use (WCU)

Amounts of water consumptive use (WCU) were estimated according to James (1988) using the following equation:

$$CWU = (\theta_2 - \theta_1) \times Ssd \times ERZ \quad (8)$$

Where: CWU: water consumptive use (mm), or crop evapotranspiration (ETc), Θ_2: soil moisture content after irrigation by 2 days, Θ_1: soil moisture content before irrigation by 2 days, Ssd: specific soil density, and ERZ: effective root zone, (mm).

Irrigation efficiencies

- Water application efficiency (Ea), was estimated as the ratio of thevolume of water added to root zoon to furrow volume of water applied to the field according to Clemmens (2007).as follows:

$$E_a = ((Z_{req}/1000) \cdot L \cdot F_w / F_{vol}) \cdot 100 \quad (9)$$

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

- Water distribution uniformity (DU), was estimated as the ratio of water infiltrated depth at low quarter (Z_{inf-lq}) to average water infiltrated depth, (Z_{ave}) according to Clemmens (2007).

$$D_U = Z_{inf-lq}/Z_{ave} \quad (10)$$

Field practices and Maize yield assessment

For growing maize, best field practices of service before planting and fertilizing were conducted in accordance with the requirements and of the crop and region as recommended. Corn (Zea mays L) seed variety (White hybrid individual) was planted on 10 and 15 May, after bean in 2013 and 2014, respectively. At physiological maturity, maize yield samples (10 plants) were collected from three locations along the furrow length for each plot (at 1st, 2nd and 3rd One third denoted as 1/3 L, 2/3 L and L, respectively) with three replications, each replicate was harvested handily to determine 100-kernel weight. Then, the ears were shelled and the grains were weighed and adjusted between 14 to 15 % moisture content to obtain the grain yield (GY) in (kg/fed).

Water use efficiency (WUE)

Crop water use efficiency was determined as the ratio of grain yield (kg) and the cubic meter of water consumed by the crop (WCU) during the growing season and is expressed according to Ali et al., (2007) as follows:

$$WUE = Gy / WCU \quad (11)$$

Water productivity (WP)

Water productivity was determined by dividing grain yield by total applied irrigation water and is expressed as according Ali et al., (2007) as follows:

$$WP = Gy / Wa \quad (12)$$

Where WUE: water use efficiency, (kg/m^3), WP: water productivity, (kg/m^3), Gy: grain yield (kg/fed), WCU: water consumptive use (m^3/fed) and Wa: irrigation applied water (m^3/fed)..

RESULTS AND DISCUSSION

Applied irrigation water (Wa) and water saving

The number of irrigation events and amount of applied water (Wa) for different irrigation system treatment were: 11 irrigation events were applied with AFI_{7-d}, while 7 irrigation events were applied with AFI_{14-d}. Under lowest inflow rate Q1, the seasonal amount of water applied (Wa), was the mean of the two seasons and reached to 529.2 mm (2222.6 m^3/fed), 503.6 mm (2115.3 m^3/fed) and 477.5 mm (2005.7 m^3/fed) with CIM, AFI_{7-d} and AFI_{14-d}, respectively. While, with inflow rate (1.58 l/s), the seasonal amount of water applied (Wa), were: 513.0 mm (2154.5 m^3/fed), 473.8 mm (1989.8 m^3/fed) and 448.9 mm (1885.2 m^3/fed) with CIM, AFI_{7-d} and AFI_{14-d}, respectively.

Meanwhile, under highest inflow rate (1.87 l/s), the seasonal amount of water applied (Wa), were: 505.8 mm (2124.4 m^3/fed), 460.7 mm (1935.0 m^3/fed) and 423.6 mm (1779.2 m^3/fed) for CIM, AFI_{7-d} and AFI_{14-d}, respectively.

This demonstrated that, alternate furrow irrigation treatments (AFI_{7-d} and AFI_{14-d}) saved water by approximately about (4.83 % and 9.76 %), (7.65 % and 12.50 %) and (8.92 % and 16.25 %) with inflow rates Q1, Q2 and Q3, respectively, as compared to CIM, (Fig. 1). Alternate-furrow irrigation at 7-days intervals (AFI_{7-d}) applied more water by about (5.18 %), (5.25 %) and (8.05 %) than AFI_{14-d} with inflow rates Q1, Q2 and Q3, respectively. On the other hand, CIM applied more water by about (7.29 %), (10.07 %) and (12.58 %) than the mean of the two alternative furrow irrigation treatments with inflow rates Q1, Q2 and Q3, respectively.

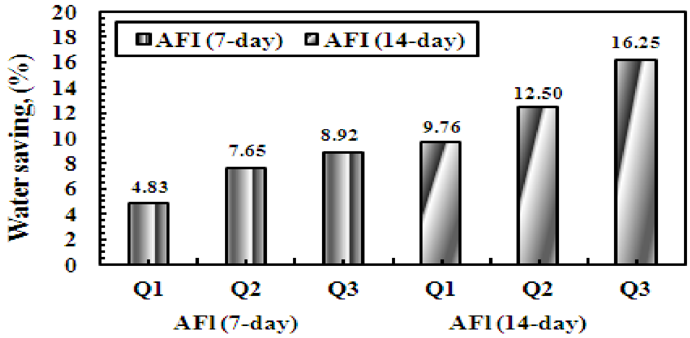

Fig. (1): Average water saving under different irrigation system treatments (AFI7-d and AFI14-d) and inflow rates.

Regarding of irrigation intervals, the lowest amount of applied water (Wa) with AFI_{14-d} treatments as compared with CIM might be due to the great reduction of wetted surface in AFI; almost half of the soil surface area is wetted in AFI as compared with CIM. This result agree with the results obtained by Hiekal *et al.* (2009), who found that AFI techniques can supply water in a way that greatly decreases the amount of wetted surface, which leads to less evapotranspiration from soil surface and less deep percolation. The amount of Wa with AFI_{7-d} was greater than AFI_{14-d}. This can be attributed to 11 irrigation events were applied with AFI_{7-d} treatment. Reduced irrigation water amounts due to alternate-furrow irrigation technique was reported by Sepaskhah and Parand (2006) and Sepaskhah and Khajehabdollahi (2005).

Water consumptive use (WCU)

Water consumptive use (WCU) was significantly affected by the irrigation system treatments, (Table 2). Highest WCU values of 495.7, 479.3 and 473.5 mm were recorded with CIM treatments, medium WCU values of 448.8, 433.4 and 418.6 mm were observed with AFI_{7-d} treatments and lowest WCU values of 438.4, 412.7 and 388.8 mm were monitored with AFI_{14-d} treatments for Q1, Q2 and Q3, respectively. These results indicate that AFI_{7-d} and AFI_{14-d} were decreased highest WCU values by approximately 9.46 and 11.55 %, medium WCU values were decreased by approximately 9.58 and

13.89 %, and lowest WCU values were decreased by approximately 11.59 and 17.88 % for Q1, Q2 and Q3, respectively, as compared with conventional (CIM).

Table (2): Grain yield and maize-water-relationship parameters under different both of irrigation system treatments and inflow rates.

Treatments		GY	ΔGY	WCU	ΔWCU	WUE	WP
		kg/fed	%	(mm)	%	kg/m^3	kg/m^3
Q1	CIM	2207.4	-----	495.7	-----	1.060	0.993
	AF_{7-d}	2385.3	8.06	448.8	9.46	1.266	1.128
	AF_{14-d}	2117.1	-4.09	438.4	11.55	1.150	1.056
Q2	CIM	2291.5	-----	479.3	-----	1.138	1.064
	AF_{7-d}	2483.6	8.38	433.4	9.58	1.365	1.248
	AF_{14-d}	2177.7	-4.97	412.7	13.89	1.256	1.155
Q3	CIM	2348.6	-----	473.5	-----	1.181	1.106
	AF_{7-d}	2565.3	9.23	418.6	11.59	1.459	1.326
	AF_{14-d}	2223.2	-5.34	388.8	17.88	1.361	1.250
Factors		**GY**	**ΔGY**	**WCU**	**ΔWCU**	**WUE**	**WP**
		kg/fed	**%**	**(mm)**	**%**	**kg/m^3**	**kg/m^3**
Q1		2236.6a	-----	461.0a	-----	1.158b	1.051b
Q2		2317.6a	3.62	441.8b	4.16	1.253a	1.149a
Q3		2379.0a	6.37	427.0c	7.38	1.334a	1.222a
Significance		n.s		**		*	*
CIM		2282.5b	-----	482.8a	-----	1.126c	1.054c
AF_{7-d}		2478.1a	8.57	434.6b	9.98	1.363a	1.215a
AF_{14-d}		2172.7c	-4.81	413.3c	14.40	1.256b	1.153b
Significance		***		***		***	***
Interaction		n.s		*		n.s	n.s

CIM: Every-furrow irrigation; AFI_{7-d}: alternate furrow irrigation with 7-day intervals; and AFI_{14-d}: alternate furrow irrigation with 14-day intervals. 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).

The results revealed that conventional furrow irrigation treatment (CIM) not affected by water stress since the soil water content values remained around field capacity during the whole season, while, AFI_{14-d} WCU values were lower than AFI_{7-d}, which may be due to the fact that corn plants grown under AFI_{14-d} treatment conditions were subjected to water stress resulting from less frequent irrigation and lower amount of applied water. These results are agreed with Abd-El-Halim (2013).

As shown in Fig. (2), both of conventional furrow irrigation treatments (CIM) and AFI_{7-d} not affected by water stress since average soil water content values remained close to or near field capacity line during the whole two seasons. Small differences in soil water moisture content were observed between CIM and AFI_{7-d}, meanwhile, soil water content values remained near the wilting point line with destructive or bad effect for corn growth with AFI_{14-d} treatments. The high water content with AFI_{7-d} transactions reduces the ventilation of plant roots zone during the growing season. Consequently, WCU for $AFI_{7\text{-}d}$ was near WCU for CIM. These results are agreed with Abd-El-Halim (2013).

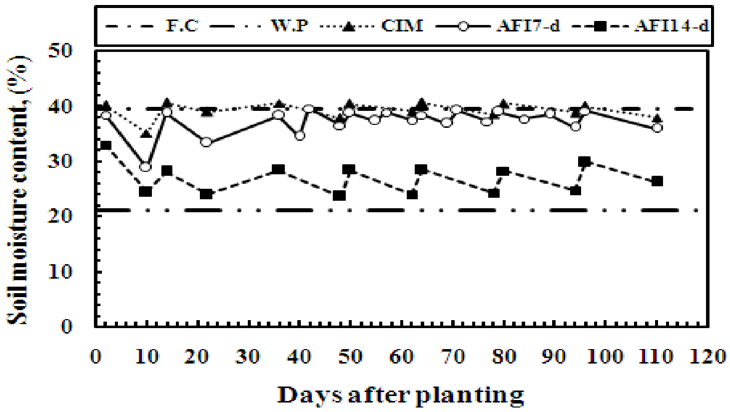

Fig. (2): Mean soil moisture content (%) under different irrigation system treatments, (CIM, AFI7-d and AFI14-d).

Maize grain yield (GY) as affected by irrigation system treatments

The effect of water quantity and irrigation system treatments on the average seed grain yield of maize crop is shown in Fig. (3). Regarding the interactions among the considered treatments, yield data showed different trends that varied due to the irrigation system treatments; there were significant differences between AFI and CIM treatments. As shown in Table (2), highest average values of maize grain yield were observed for highest inflow rate (Q3) with $AFI_{7\text{-}d}$, which may be due not affected by water stress and soil water content values remained around field capacity. While, lowest average values of maize grain yield were observed for lowest inflow rate (Q1) with $AFI_{14\text{-}d}$, which may be due affected by water stress. Average maximum values of maize grain yield were observed under all irrigation system treatments of $AFI_{7\text{-}d}$, and were increased by about 8.06, 8.38 and 9.23 % as compared with CIM under water different application rates Q1, Q2 and Q3, respectively.

On the other hand, Average minimum values of maize grain yield were observed under all irrigation system treatments of $AFI_{14\text{-}d}$, and were decreased by 4.09, 4.97 and 5.34 % as compared to CIM different application rates Q1, Q2 and Q3, respectively. These increases in seed yield may be due to alternate furrow irrigation has caused good aeration of roots zoon in soil; and enhanced structure of the soil and soil moisture content. While lower yield with CIM system was attributed to irrigation water ponds at the furrow ends after irrigation event and cutoff times with CIM treatments were greater than cutoff times with $AFI_{7\text{-}d}$ and $AFI_{14\text{-}d}$ treatments, which too much water might have caused partially poor aeration of roots, and soil nutrients leaching.

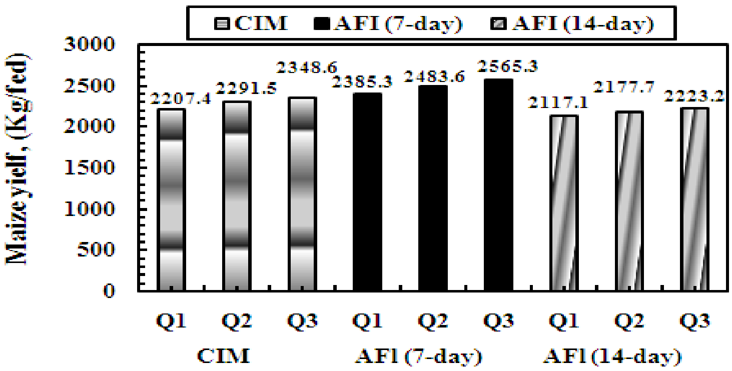

Fig. (3): Average maize seed yields under different irrigation system treatments and inflow rates.

Maize grain yield (GY) was significantly affected by the irrigation system treatments (Table 2). Highest average GY values were obtained with $AFI_{7\text{-}d}$ treatments 2385.3, 2483.6 and 2565.3 (kg/fed) with water inflow rates Q1, Q2 and Q3, respectively (Table 2), whereas $AFI_{14\text{-}d}$ showed that, lowest average GY values of 2117.1, 2177.7 and 2223.2 (kg/fed), respectively with the same inflow rates.

Maize grain yield with CIM (conventional treatment) were higher than $AFI_{14\text{-}d}$ by approximately about 90.3, 113.8 and 125.4 (kg/fed) with water inflow rates Q1, Q2 and Q3, respectively. Results showed that, if $AFI_{14\text{-}d}$ was used, acceptable GY reduction were observed and grain yield were reduced by approximately about 4.09, 4.97 and 5.34 % with lowest amount of Wa (477.5 mm), (448.9 mm) and (423.6 mm), in comparison with conventional irrigation (CIM), which have high Wa of (529.2 mm), (513.0 mm) and (505.8 mm) with water inflow rates Q1, Q2 and Q3, respectively. Practical application of transformation from conventional irrigation (CIM) to alternate furrow ($AFI_{7\text{-}d}$) increased maize grain yield by approximately about 8.06 % (177.9 kg/fed), 8.38 % (192.1 kg/fed) and 9.23 % (216.7 kg/fed) with inflow rates Q1, Q2 and Q3, respectively.

Irrigation performance

Irrigation performance parameters calculated for maize crop under different irrigation system treatments are shown in Fig. (4a and b).

Water application efficiency, (Ea)

Average values of water application efficiency (Ea) for maize crop under different irrigation system treatments are shown in (4a). Lowest average water application efficiency (Ea) value of (60.55 %) was obtained with CIM followed by $AFI_{14\text{-}d}$ (62.20 %) and $AFI_{7\text{-}d}$ (65.57 %) with lowest inflow rate Q1. On the other hand, highest average water application efficiency value of (73.59 %) obtained with $AFI_{7\text{-}d}$ followed by $AFI_{14\text{-}d}$ (63.53 %) and CIM (62.62) with highest inflow rate Q3.

As shown in Fig (4a), it is clear that about 26.41 to 39.67 % of water applied were not available to the plant and did not benefit for the crop with Q1, Q2 and Q3 water application treatments, respectively, which may be due to deep percolation loss and amounts of water applied more than necessary. AFI7-d and AFI14-d with Q1 (lowest inflow rate), it were representing an increase in (Ea) by approximately 8.30 and 2.73 % as compared to CIM at the same inflow rate. Meanwhile, (Ea) values were increased and reached to (9.48 and 17.51 %) and (3.83 and 1.45 %) with Q2 and Q3, respectively as compared to CIM.

According to these results; with low inflow rates, (Ea) values were less than that with high inflow rates, because with low water inflow rate the chance of water infiltrated into the soil to deep soil layer depths was greater than horizontally advanced water, similar trend were reported by Hiekal *et al.* (2009).

Water distribution uniformity, (DU)

Average values of water distribution uniformity (DU) for maize crop under different irrigation system treatments are shown in Fig. (4b). Lower average DU values of (0.7657) were obtained with CIM followed by $AFI_{14\text{-}d}$ (0.7882) and $AFI_{7\text{-}d}$ (0.8257) with lowest inflow rate Q1. On the other hand, higher average DU values of (0.8968) were obtained for $AFI_{7\text{-}d}$ followed by $AFI_{14\text{-}d}$ (0.8509) and CIM (0.8162) with highest inflow rate Q3.

$AFI_{7\text{-}d}$ and $AFI_{14\text{-}d}$ with Q1 (lowest inflow rate), it were representing an increase in (DU) value by approximately 7.83 and 2.93 % as compared to CIM. Meanwhile, (DU) values were increased and reached to (8.46 and 3.88 %) and (9.87 and 4.24 %) with Q2 and Q3, respectively as compared to CIM. According to these results; with low inflow rates, (DU) values were less than that with high inflow rates, because of with high water inflow rate, water advance in horizontal direction was faster than the chance of water infiltrated into the soil and did not reached to deep soil layer depths, these results agree with that obtained by Mintesinot *et al.* (2004). Generally, using alternative furrow irrigation leads to increased water distribution uniformity into the soil.

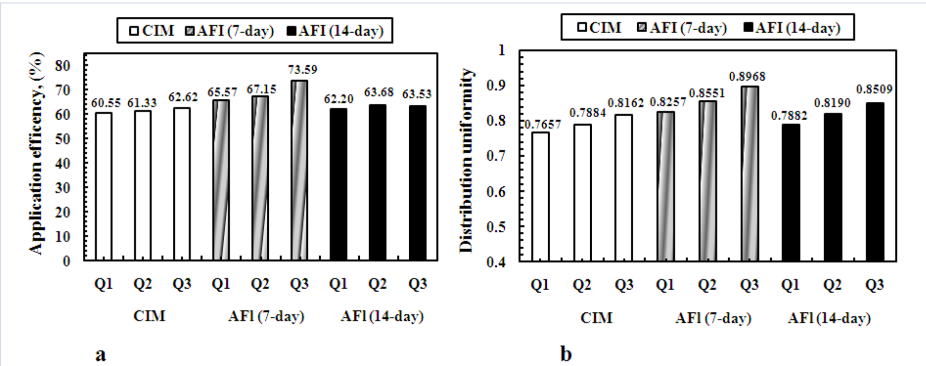

Fig. (4): Average water application efficiency and distribution uniformity under different both of irrigation system treatments and inflow rates.

Water use efficiency, (WUE, kg/m^3)

Average water use efficiency values (WUE) for alternate furrow irrigation (AFI) a significant increase as compared with conventional furrow irrigation (CIM). As shown in Fig. (5a), highest WUE values were 1.365 and 1.459 (kg/m^3) were recorded with $AFI_{7\text{-}d}$ followed by 1.256 and 1.361 (kg/m^3) for $AFI_{14\text{-}d}$ with inflow rates Q2 and Q3, respectively. Whereas, lowest WUE values were 1.138 and 1.181 (kg/m^3) were recorded with CIM treatment with inflow rates Q2 and Q3, respectively. Minimum WUE values were 1.060, 1.150 and 1.266 (Kg/m^3) were recorded with CIM followed by $AFI_{14\text{-}d}$ and $AFI_{7\text{-}d}$ with lowest inflow rate Q1, respectively.

These results revealed that both of AFI7-d and AFI14-d reached to high WUE values with inflow rates Q2 and Q3 as compared to CIM with the same inflow rates. This could be due to the high maize grain yield obtained with $AFI_{7\text{-}d}$ and lower WCU obtained with $AFI_{14\text{-}d}$ and CIM. This result confirms with results obtained by Abd-El-Halim (2013) for corn.

Water productivity, (WP, kg/m^3)

Water productivity (WP) was significantly affected by the irrigation system treatments. As shown in Fig. (5b), highest WP values were 1.248 and 1.326 (Kg/m^3) were recorded with $AFI_{7\text{-}d}$ followed by 1.155 and 1.250 (kg/m^3) with $AFI_{14\text{-}d}$ with inflow rates Q2 and Q3, respectively. Whereas, lowest WP values were 1.064 and 1.106 (kg/m^3) were recorded with CIM treatment for inflow rates Q2 and Q3, respectively. Minimum WP values were 0.993, 1.056 and 1.128 (kg/m^3) were recorded with CIM followed by $AFI_{14\text{-}d}$ and $AFI_{7\text{-}d}$ for lowest inflow rate Q1, respectively.

These results showed that both of $AFI_{7\text{-}d}$ and $AFI_{14\ \text{-}d}$ achieved high WP values with inflow rates Q2 and Q3 as compared to CIM with the same inflow rates. This could be due to the high maize grain yield obtained with $AFI_{7\text{-}d}$ and lower WCU obtained with $AFI_{14\text{-}d}$ and CIM. Also these results indicated that AFI is convenient to increase WP and WUE because they allow applying less amount of water irrigation for maize production. The high WP values for AFI could be due to the small amount of applied water with AFI as compared with the CIM treatment. Abd-El-Halim (2013) reported similar results. Cleary, WP depends on total applied water. This give a useful guide for evaluating the irrigation strategy.

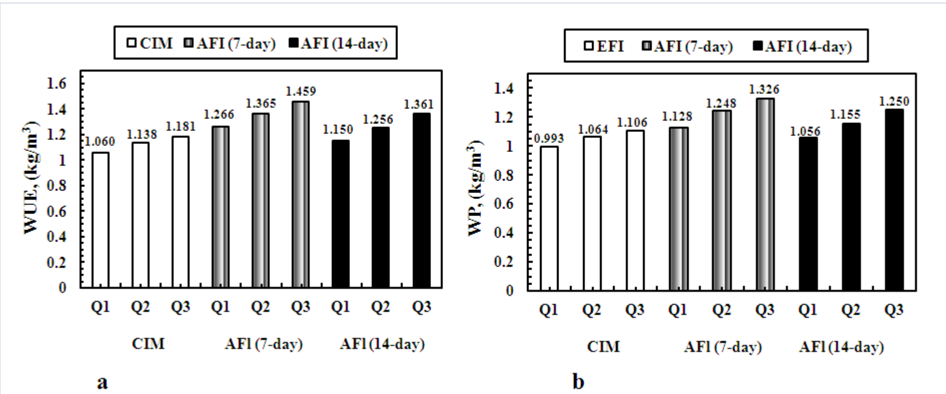

Fig. (5): Average water use efficiency and water productivity under different both of irrigation system treatments and inflow rates.

Alternate-furrow irrigation with convenient irrigation intervals ($AFI_{7\text{-}d}$) can be used as a dynamic method for increasing corn production in arid and semi-arid areas where production depends mainly on irrigation. It could be concluded that the $AFI_{7\text{-}d}$ treatment controlled irrigation water stress without any risk of reduced grain yield. Moreover, if available water is not enough the alternate furrow irrigation with ($AFI_{7\text{-}d}$) intervals will essentially be the best technique under the conditions of the study area.

CONCLUSION

Conversion of irrigation practice from conventional irrigation (CIM) to alternate furrow ($AFI_{7\text{-}d}$), maize grain yields were increased approximately by about 8.06, 8.38 and 9.23 % with increasing water inflow rates. $AFI_{7\text{-}d}$ and $AFI_{14\text{-}d}$ alternate furrow irrigation treatments with highest inflow rate Q3, saved water approximately by about 8.92 and 16.25 %, respectively, from total water applied as compared to conventional furrow irrigation (CIM). Application efficiencies (Ea) and distribution uniformities (DU) values were improved with all irrigation system treatments as inflow rates increases. Maximum (Ea) values were 67.15 and 73.59 % obtained with ($AFI_{7\text{-}d}$) for inflow rates Q2 and Q3, respectively as compared to (CIM). Highest (DU) values were 0.8551 and 0.8968 % obtained with ($AFI_{7\text{-}d}$) for inflow rates Q2 and Q3, respectively as compared to (CIM). Maize seed yield production with all irrigation system treatments (CIM, $AFI_{7\text{-}d}$ and $AFI_{14\text{-}d}$) had significant increases with increasing inflow rates. The same trends were observed for water use efficiency (WUE) and water productivity (WP).

Alternate furrow irrigation with adequate irrigation intervals ($AFI_{7\text{-}d}$) can be used as an dynamic method for corn production in arid and semi-arid areas where production depends mainly on irrigation. It could be concluded that the $AFI_{7\text{-}d}$ treatment controlled water stress irrigation without the risk of reduced in grain yield and it increased the maize grain yield and saved irrigation water. Moreover, if available water is not enough then, the alternate furrow irrigation with ($AFI_{7\text{-}d}$) intervals will ultimately be the best technique under the conditions of the study area.

REFERENCES

Abd-El-Halim. A., (2013). Impact of alternate furrow irrigation with different irrigation intervals on yield, water use efficiency, and economic return of corn. Chilean Journal of Agricultural Research 73(2): 175-180

Ali, M. H.; M. R. Hoque, A. A. Hassan and A. Khair. (2007). Effects of deficit irrigation on yield, water productivity and economic returns of wheat. Agricultural Water Management, 92:151-161.

Clemmens, A. J., (2007). Simple approach to surface irrigation design: Spreadsheet applications Sakia.org e-publish, http://www.sakia. Org/ejlw, e-Journal of Land and Water, 2007, Vol. 1: 20-43.

Clemmens A. J.; Z. El-Haddad and T. S. Strelkoff (1999). Assessing the potential for modern surface irrigation in Egypt. Trans. of the ASAE 42 (4): 995-1008.

Costat version 6,311 CoHortSoftware. (1998- 2004) Costat 6.0 P.O. Box 1149, Berkeley, C A 94701, USA.

Dorrenbos; J. and W. O. Pruitt (1977). Crop water requirements. FAO Irrigation and Drainage Paper 24,156 pp. Rome.

El-Beltagy; A. T., and A. F. Abo-Hadeed. (2008). The main pillars of the National Program for maximizing the water-use efficiency in the old land. 30 p. The Research and Development Council. Ministry of Agriculture and Land Reclamation (MOALR), Giza, Egypt (in Arabic).

Hiekal, H. A. M.; S. A. AFiah and F. M. Al-Borahy (2009). Effect of alternate-long furrows irrigation on calcareous soils productivity. Misr J. Ag. Eng., 26(2): 818- 835

James, L. G. (1988). Principles of farm irrigation system design. Jone Willey & Sons (Ed.), New York, 543 pp.

Kang, S., P. Shi, Y. Pan, Z. Liang, X. Hu and J. Zhang (2000 a). Soil water distribution, uniformity and water-use efficiency under Alternate furrow irrigation in arid areas. Irrig. Sci. 19, 181-190.

Kang,S.;Z.Liang,Y.Pan,P. Shi and J. Zhang (2000 b).Alternate furrow irrigation for maize production in an arid area.Water Manag.45,267- 274.

Karrou M.; T. Oweis, A. E. R. Enein and M. Sherif. (2012). Yield and water productivity of maize and wheat under deficit and raised bed irrigation practices in Egypt. Afr J Agric Res. 7:1755–1760

Kashiani; P., G. Saleh, M. Osman and D. Habibi. (2011). Sweet corn yield response to alternate furrow irrigation methods under different planting densities in a semi-arid climatic condition. African Journal of Agricultural Research 6:1032-1040.

Klute; A . A. (1986). Methods of soil analysis. Part 1, 2nd Ed. Agron. Monogr. No. 9, ASA and SSSA, Madison, WI, USA.

Li, F.; J. Liang, S. Kang and J. Zhang. 2007. Benefits of alternate partial root-zone irrigation on growth, water and nitrogen use efficiencies modified by fertilization and soil water status in maize. Plant and Soil 295 (1-2):279-291.

Merriam; J. L., M. N. Shearer and C. M. Burt (1983). Evaluating irrigation systems and practices. Chapter 17: M. E. Jensen (Ed.): Design and operation of farm irrigation systems. ASAE Monograph No. 3, USA.

Michael; A. M., (1978). Irrigation theory and practice. 1st ed., New Delhi.

Mintesinot; B., H. Verplancke, E. Van Ranst and H. Mitiku (2004). Examining traditional irrigation methods, irrigation scheduling and alternate furrows irrigation on vertisols in northern Ethiopia. Agric. Water Manag. 64, 17-27.

Rafiee; M. and G. Shakarami. (2010). Water use efficiency of corn as affected by every other furrow irrigation and planting density. World Applied Science Journal 11:826-829.

Sepaskhah; A. R. and M. H. Khajehabdollahi. (2005). Alternate furrow irrigation with different irrigation intervals for maize (Zea mays L.) Plant Production Science 8:592-600.

Sepaskhah; A. R. and A. R. Parand. (2006). Effects of alternate furrow irrigation with supplemental every-furrow irrigation at different growth stages on the yield of maize (Zea mays L.) Plant Production Science 9:415-421.

Swelam; A. and Y. Atta. (2011). New approach of farm management under surface irrigation to improve water saving and productivity. New Horizons in Sci. Technol. 1:76–83.

USDA; (2011). Grain: World markets and trade. Foreign Agriculture Service, Circular Series FG 09-11. Foreign Agricultural Service, United States Department of Agriculture. Available at http://www. fas.usda. gov/ psdonline/ circulars/grain.pdf

Walker; W.R. (1989). Guidelines for Designing and Evaluating Surface Irrigation Systems. FAO Irrigation and Drain Paper No: 45, Rome.

توفير المياه وأنتاجية الذرة الشامية تحت نظام ري الخطوط التبادلي

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نظرا لما تواجهه بلادنا من قلة الموارد المائية وما سوف يترتب علي بناء سد النهضة الأثيوبي من تفاقم لهذه المشكلة، لذا وجب التفكير في أحد الطرق التي يمكن بها حل هذه المشكلة ومن ثم التفكير في كيفية رفع كفاءة الري السطحي بالخطوط وخاصة في مناطق الوادي ودلتا النيل والتي لا يناسبها طرق أو نظم الري الحديثة، وذلك عن طريق التقليل في كميات المياه المستخدمه مع زيادة كفاءة الري السطحي بالخطوط. لذا يهدف البحث الي تحسين أداء الري السطحي من خلال تقنية الري التبادلي للخطوط (AFI)، وتأثيره علي كل من توفير المياه، كفأءة أضافة وتجانس توزيع المياه وإنتاجية الذرة بالمقارنة بالري التقليدي للخطوط (CIM). في هذه الدراسة تم أجراء تجارب حقلية علي محصول الذرة الشامية في مزرعة خاصة بقرية جبارس، أيتاي البارود - محافظة البحيرة خلال موسمي 2014/2013 علي تربة طينية وكان تصميم التجربة هو القطع المنشقة. كانت معاملات مواعيد الري المنفذة: 1- الري السطحي لكل الخطوط كل 14 يوم (every furrow irrigation, CIM)، 2- الري السطحي التبادلي لنصف الخطوط كل 7 أيام (alternative furrow irrigation, AFI_{7-d}) و3- الري السطحي التبادلي لنصف الخطوط كل 14 يوم (alternative furrow irrigation, AFI_{14-d}). وقد شملت القياسات الحقلية كلا من طول، عرض الخطوط، الشكل الهندسي للخطوط وميل الأرض في أتجاه الري بالإضافة الي أزمنة تقدم وانحسار وغلق المياه كذلك أعماق المياه داخل الخطوط خلال الزمن الكلي للري. تمت معايرة معدلات التصرف المستعملة وكانت 1,14، 1,58 و1,87 (لتر/ث). كما تم قياس معدل تسرب الماء بالتربة وتقدير قيم معاملات معادلة التسرب. و كانت أهم النتائج المتحصل عليها:

*- تم توفبر 8,92 و16,25 ٪ من أجمالي كميات مياه الري المستخدمة ،وذلك لمعاملتي الري التبادلي للخطوط (AFI_{14-d} and AFI_{7-d})، علي الترتيب خلال موسمي نمو محصول الذرة عند أستخدام أكبر معدل تصرف (Q3) مقارنة بالري السطحي التقليدي للخطوط (CIM).

*- كفاءة أستخدام المياه (Ea) تحسنت مع جميع المعاملات وذلك بزيادة معدلات التصرف. أقصي قيم تم الحصول عليها لـ (Ea) كانت 67,15 و73,59 ٪ مع معدلي التصرف (Q2 and Q3)، علي الترتيب لمعاملة الري التبادلي للخطوط (AFI_{7-d}) مقارنة بالري السطحي التقليدي للخطوط (CIM).

*- تجانس توزيع المياه المتسربة داخل التربة (DU) تحسنت بزيادة معدلات التصرف مع جميع معاملات الري التبادلي للخطوط وذلك بزيادة معدلات التصرف. أقصي قيم تم الحصول عليها لـ (DU) كانت 0,8551 و0,8968 مع معدلي التصرف (Q2 and Q3)، علي الترتيب لمعاملة الري التبادلي للخطوط (AFI_{d-7}) مقارنة بالري السطحي التقليدي للخطوط (CIM).

*- الأنتاجية للفدان من حبوب الذرة الشامية زادت معنويا لجميع معاملات الري بزيادة معدلات التصرف وخاصة مع معاملة الري السطحي التبادلي (AFI_{7-d}). تحويل ممارسة الري من الري التقليدي (CIM) الي الري التبادلي (AFI_{7-d}) زادت أنتاجية الفدان من حبوب الذرة الشامية تقريبا من 8,06 الي 9,23٪ مع زيادة معدلات تصرف المياه.

*- تحويل ممارسة الري من الري التقليدي (CIM) الي الري التبادلي (AFI_{7-d}) كل من قيم كفاءة أستخدام المياه (WUE) وأنتاجية المياه (WP) تحسنت بزبادة معدلات التصرف حيث زادت قيم (WUE) من 1.266 الي 1.459 (كجم/م^3) بينما زادت قيم (WP) من 1.128 الي 1.326 (كجم/م^3).

*- يمكن القول أن المعاملات (AFI_{7-d}) هي من أفضل الطرق لأنتاج الذرة الشامية في المناطق الجافة والشبة الجافة كما أنها تسيطر علي أجهادات النقص في مياه الري دون التعرض لخطر الأنخفاض في محصول الحبوب.