WATER SAVING AND MAIZE PRODUCTIVITY UNDER ALTERNATIVE FURROW IRRIGATION SYSTEM

Guirguis, A. E.

ABSTRACT

Field experiments were conducted along two consecutive seasons of summer (2013/2014) at private farm, Jabbar 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 (AFI7-d irrigation intervals) and alternate furrow irrigation (AFI14-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 AFI7-d lead to high significant effect between seed yields values and irrigation system treatments, (CIM, AFI7-d and AFI14-d). Shifting irrigation practice from conventional irrigation (CIM) to alternate furrow (AFI7-d) corn grain yields were increased approximately from 8.06 to 9.23 % with an increasing water inflow rates. AFI14-d and AFI7-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 (m³/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 (AFI7-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
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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 seasons of summer (2012/2013) and (2013/2014) at private farm, Jabbars village, north Itay Al-Barud, Beheira Governorate, Egypt, located at (Latitude 31° 03'N, Longitude 30° 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>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Particle size distribution, (%)</th>
<th>Soil texture class</th>
<th>Soil bulk density (g/cm³)</th>
<th>F.C, (%)</th>
<th>P.W.P, (%)</th>
<th>AW, (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 30</td>
<td>23.63</td>
<td>Clay</td>
<td>1.259</td>
<td>41.47</td>
<td>21.82</td>
<td>19.65</td>
</tr>
<tr>
<td>30 – 60</td>
<td>20.74</td>
<td>Clay</td>
<td>1.398</td>
<td>38.61</td>
<td>20.71</td>
<td>17.90</td>
</tr>
<tr>
<td>60 – 90</td>
<td>24.10</td>
<td>Clay loam</td>
<td>1.486</td>
<td>38.12</td>
<td>20.33</td>
<td>17.79</td>
</tr>
</tbody>
</table>

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 \( T_{\text{req}} \) to achieve the required infiltrated depth \( Z_{\text{req}} \): The design procedure requires that the intake opportunity time associated with \( Z_{\text{req}} \) be known. This time, represented by \( T_{\text{req}} \), requires a nonlinear solution as follows:

\[
T_{\text{req}} = \left( \frac{Z_{\text{req}}}{K} \right)^{1/a}
\]

(1)

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

\[
T_{\text{co}} = T_{\text{adv}} + T_{\text{req}}
\]

(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\(_7-d\)) and 3) Alternate furrow irrigation (AFI\(_{14-d}\)). With (AFI\(_7-d\)) and (AFI\(_{14-d}\)), 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 \( \times \) 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\(_7-d\) and AFI\(_{14-d}\)) 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):

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

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 \((981 \text{ cm/sec}^2)\).

**Applied irrigation water volume \((Q)\)**

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

\[
Q = q \cdot T_{\text{co}} \cdot n
\]  

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

**Water applied depth \((I)\)**

Water applied depth was estimated using the following equation:

\[
I = Q \cdot T_{\text{co}} \cdot 1000/ A
\]  

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 \((\text{applied})\) to soil, \((Vol_{\text{in}})\) according to \( T_{\text{co}} \), from the following equation:

\[
Vol_{\text{in}} = q \cdot T_{\text{co}}
\]  

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

\[
Z_{\text{inf}} = KT^a + CT
\]  

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

**Water consumptive use \((WCU)\)**

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

\[
CWU = (\theta_2 - \theta_1) \times \text{Ssd} \times \text{ERZ}
\]  

Where: \( CWU \): water consumptive use \((mm)\), or crop evapotranspiration \((ETc)\), \( \theta_2 \): soil moisture content after irrigation by 2 days, \( \theta_1 \): soil moisture content before irrigation by 2 days, \( \text{Ssd} \): specific soil density, and \( \text{ERZ} \): effective root zone, \((mm)\).

**Irrigation efficiencies**

- Water application efficiency \((Ea)\), was estimated as the ratio of the volume of water added to root zone to furrow volume of water applied to the field according to Clemmens (2007), as follows:
\[ \text{E}_d = ((Z_{\text{req}} / 1000) \cdot L \cdot F_w / F_{\text{vol}}) \cdot 100 \]  \tag{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 \((Z_{\text{inf-lq}})\) to average water infiltrated depth, \((Z_{\text{ave}})\) according to Clemmens (2007).

\[ D_U = Z_{\text{inf-lq}} / Z_{\text{ave}} \]  \tag{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 \((\text{Zea mays L})\) seed variety \(\text{White hybrid individual}\) 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:

\[ \text{WUE} = \text{GY} / \text{WCU} \]  \tag{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:

\[ \text{WP} = \text{GY} / \text{Wa} \]  \tag{12}

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

**RESULTS AND DISCUSSION**

**Applied irrigation water (Wa) and water saving**

The number of irrigation events and amount of applied water \((\text{Wa})\) 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 \((\text{Wa})\), was the mean of the two seasons and reached to 529.2 mm \((2222.6 \text{ m}^3/\text{fed})\), 503.6 mm \((2115.3 \text{ m}^3/\text{fed})\) and 477.5 mm \((2005.7 \text{ m}^3/\text{fed})\) with CIM, AFI\(_{7-d}\) and AFI\(_{14-d}\), respectively. While, with inflow rate \((1.58 \text{ l/s})\), the seasonal amount of water applied \((\text{Wa})\), were: 513.0 mm \((2154.5 \text{ m}^3/\text{fed})\), 473.8 mm \((1989.8 \text{ m}^3/\text{fed})\) and 448.9 mm \((1885.2 \text{ m}^3/\text{fed})\) 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 (AFI$7$-d and AFI$14$-d) and inflow rates.](image)

Fig. (1): Average water saving under different irrigation system treatments (AFI$_{7-d}$ and AFI$_{14-d}$) 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
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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.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>GY kg/fed</th>
<th>ΔGY %</th>
<th>WCU (mm)</th>
<th>ΔWCU %</th>
<th>WUE kg/m³</th>
<th>WP kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 CIM</td>
<td>2207.4</td>
<td>-----</td>
<td>495.7</td>
<td>-----</td>
<td>1.060</td>
<td>0.993</td>
</tr>
<tr>
<td>AFI7-d</td>
<td>2385.3</td>
<td>8.06</td>
<td>448.8</td>
<td>9.46</td>
<td>1.266</td>
<td>1.128</td>
</tr>
<tr>
<td>AFI14-d</td>
<td>2171.7</td>
<td>-4.09</td>
<td>438.4</td>
<td>11.55</td>
<td>1.150</td>
<td>1.056</td>
</tr>
<tr>
<td>Q2 CIM</td>
<td>2291.5</td>
<td>-----</td>
<td>479.3</td>
<td>-----</td>
<td>1.138</td>
<td>1.064</td>
</tr>
<tr>
<td>AFI7-d</td>
<td>2483.6</td>
<td>8.38</td>
<td>433.4</td>
<td>9.58</td>
<td>1.365</td>
<td>1.248</td>
</tr>
<tr>
<td>AFI14-d</td>
<td>2177.7</td>
<td>-4.97</td>
<td>412.7</td>
<td>13.89</td>
<td>1.256</td>
<td>1.155</td>
</tr>
<tr>
<td>Q3 CIM</td>
<td>2348.6</td>
<td>-----</td>
<td>473.5</td>
<td>-----</td>
<td>1.181</td>
<td>1.106</td>
</tr>
<tr>
<td>AFI7-d</td>
<td>2565.3</td>
<td>9.23</td>
<td>418.6</td>
<td>11.59</td>
<td>1.459</td>
<td>1.326</td>
</tr>
<tr>
<td>AFI14-d</td>
<td>2223.2</td>
<td>-5.34</td>
<td>388.8</td>
<td>17.88</td>
<td>1.361</td>
<td>1.250</td>
</tr>
</tbody>
</table>

Factors

<table>
<thead>
<tr>
<th>Treatments</th>
<th>GY kg/fed</th>
<th>ΔGY %</th>
<th>WCU (mm)</th>
<th>ΔWCU %</th>
<th>WUE kg/m³</th>
<th>WP kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 CIM</td>
<td>2236.6a</td>
<td>-----</td>
<td>461.0a</td>
<td>-----</td>
<td>1.158b</td>
<td>1.051b</td>
</tr>
<tr>
<td>AFI7-d</td>
<td>2317.6</td>
<td>3.62</td>
<td>441.8b</td>
<td>4.16</td>
<td>1.253a</td>
<td>1.149a</td>
</tr>
<tr>
<td>AFI14-d</td>
<td>2379.0a</td>
<td>6.37</td>
<td>427.0c</td>
<td>7.38</td>
<td>1.334a</td>
<td>1.222a</td>
</tr>
<tr>
<td>Q2 CIM</td>
<td>2282.5b</td>
<td>-----</td>
<td>482.8a</td>
<td>-----</td>
<td>1.126c</td>
<td>1.054c</td>
</tr>
<tr>
<td>AFI7-d</td>
<td>2478.1a</td>
<td>8.57</td>
<td>434.6b</td>
<td>9.98</td>
<td>1.363a</td>
<td>1.215a</td>
</tr>
<tr>
<td>AFI14-d</td>
<td>2172.7c</td>
<td>-4.81</td>
<td>413.3c</td>
<td>14.40</td>
<td>1.256b</td>
<td>1.153b</td>
</tr>
<tr>
<td>Q3 CIM</td>
<td>2230.2a</td>
<td>-----</td>
<td>474.6c</td>
<td>-----</td>
<td>1.181</td>
<td>1.106</td>
</tr>
<tr>
<td>AFI7-d</td>
<td>2565.3a</td>
<td>9.23</td>
<td>418.6b</td>
<td>11.59</td>
<td>1.459</td>
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<td>2223.2a</td>
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<td>388.8c</td>
<td>17.88</td>
<td>1.361</td>
<td>1.250</td>
</tr>
</tbody>
</table>

Significance

| CIM: Every-furrow irrigation; AFI7-d: alternate furrow irrigation with 7-day intervals; and AFI14-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 = 0.01), ***: 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, AFI14-d WCU values were lower than AFI7-d, which may be due to the fact that corn plants grown under AFI14-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 AFI7-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 AFI7-d, meanwhile, soil water content values remained near the wilting point line with destructive or bad effect for corn growth with AFI14-d treatments. The high water content with AFI7-d transactions reduces the
ventilation of plant roots zone during the growing season. Consequently, WCU for AFI<sub>7-d</sub> 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).](image)

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<sub>7-d</sub>, 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<sub>14-d</sub>, which may be due affected by water stress. Average maximum values of maize grain yield were observed under all irrigation system treatments of AFI<sub>7-d</sub>, 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<sub>14-d</sub>, 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<sub>7-d</sub> and AFI<sub>14-d</sub> treatments, which too much water might have caused partially poor aeration of roots, and soil nutrients leaching.
Guirgis, A. E.

Maize grain yield (GY) was significantly affected by the irrigation system treatments (Table 2). Highest average GY values were obtained with AFI14-d treatments 2385.3, 2483.6 and 2565.3 (kg/fed) with water inflow rates Q1, Q2 and Q3, respectively (Table 2), whereas AFI14-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 AFI14-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 AFI14-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 (AFI7-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 AFI14-d (62.20 %) and AFI7-d (65.57 %) with lowest inflow rate Q1. On the other hand, highest average water application efficiency value of (73.59 %) obtained with AFI7-d followed by AFI14-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. AF17-d and AF114-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 AF114-d (0.7882) and AF17-d (0.8257) with lowest inflow rate Q1. On the other hand, higher average DU values of (0.8968) were obtained for AF17-d followed by AF114-d (0.8509) and CIM (0.8162) with highest inflow rate Q3.

AF17-d and AF114-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.

![Diagram](image)

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

**Water use efficiency, (WUE, kg/m³)**

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$_{7-d}$ followed by 1.256 and 1.361 (kg/m$^3$) for AFI$_{14-d}$ 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$_{14-d}$ and AFI$_{7-d}$ with lowest inflow rate Q1, respectively.

These results revealed that both of AFI$_{7-d}$ and AFI$_{14-d}$ 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$_{7-d}$ and lower WCU obtained with AFI$_{14-d}$ 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$_{7-d}$ followed by 1.155 and 1.250 (kg/m$^3$) with AFI$_{14-d}$ 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$_{14-d}$ and AFI$_{7-d}$ for lowest inflow rate Q1, respectively.

These results showed that both of AFI$_{7-d}$ and AFI$_{14-d}$ 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$_{7-d}$ and lower WCU obtained with AFI$_{14-d}$ 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\textsubscript{7-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\textsubscript{7-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\textsubscript{7-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\textsubscript{7-d}), maize grain yields were increased approximately by about 8.06, 8.38 and 9.23 % with increasing water inflow rates. AFI\textsubscript{7-d} and AFI\textsubscript{14-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 (E\textsubscript{a}) and distribution uniformities (DU) values were improved with all irrigation system treatments as inflow rates increases. Maximum (E\textsubscript{a}) values were 67.15 and 73.59 % obtained with (AFI\textsubscript{7-d}) for inflow rates Q2 and Q3, respectively as compared to (CIM). Highest (DU) values were 0.8551 and 0.8968 % obtained with (AFI\textsubscript{7-d}) for inflow rates Q2 and Q3, respectively as compared to (CIM). Maize seed yield production with all irrigation system treatments (CIM, AFI\textsubscript{7-d} and AFI\textsubscript{14-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\textsubscript{7-d}) can be used as a dynamic method for corn production in arid and semi-arid areas where production depends mainly on irrigation. It could be concluded that the AFI\textsubscript{7-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\textsubscript{7-d}) intervals will ultimately be the best technique under the conditions of the study area.

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توفر المياه والانتاجية الذرة الشامية تحت نظام ري الخطي التبادلي

هذه المقالة تناقش النماذج التي تم استخدامها في تقييم Optional Treatment (Q3) (AFI) في نظام ري الخطي التبادلي (AFI) والجذر التبادلي (AFI) مع نظام ري الخطي التبادلي (AFI)...

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