ABSTRACT

In Egypt, surface irrigation and irrigation till the tail end of the furrows or borders are commonly used with wheat (Triticum aestivum L.) and other crops, but they lead to poor aeration and ineffective use of water and fertilizers. Therefore, raised beds planting method and cut-off irrigation improve wheat productivity and raise water and fertilizer use efficiencies. A field experiment was carried out in two winter growing seasons (2017/18 and 2018/19) at Sakha Agricultural Research Station Farm, Kafr EL-sheikh Governorate. The objective was to evaluate the impact of raised bed and irrigation cut-off on growth and yield of wheat (Misr1 variety), some water relations and the contribution of ground water table on water consumption. A split plot design was used with three replicates. The main plots were occupied by raised bed treatments: farmer's conventional flat planting method (F1), furrow 60 cm width (F2) and furrow 120 cm width (F3). The sub plots were devoted to irrigation cut-off treatments: cut-off at 100% of strip length, C100% (control), cut-off at 90% of strip length (C90%) and cut-off at 80% of strip length (C80%). The results revealed that C90% combined with F3 achieved the lowest values of seasonal applied water and water consumptive use and the highest values of water productivity (9.69 LE m⁻³), water application efficiency (Ea) and grain and straw yields. On the other hand, C80% recorded the highest contribution value of ground water table (CGWT) of water consumption (21.4%), leading to increase of water saving. (with 34.05% increase)

Keywords: Surface irrigation, irrigation cut-off, raised beds, water relations, water productivity, grain yield, wheat and ground water table contribution.

INTRODUCTION

Limitation of water resources and the obvious increase in population forced the researcher to find how to save water without significant reduction in crop yield. The conventional irrigation method is a highly consumed water, thus saving the water is becoming decisive factor for agricultural expansion. Agricultural policies in Egypt assisted agricultural reforms to increase the farm incomes and food crop production. This study will significantly improve the lives of many Egyptians who depend on agriculture.

Hobbs and Morris (1996) compared between sowing of wheat in flat strip and raised bed technology and they stated that using of flat strip under flood irrigation reduces the binding of soil to support the plant due to wet condition around its roots. However, use of raised bed technology not only saves irrigation water, but also prevents the wet soil surface around the roots to avoid lodging especially under windy conditions. Ahmad and Mahmood (2014) concluded that bed planting was found to be useful to control lodging of wheat in comparison with the conventional flat sowing. They added that, raised bed method ensures easy drainage of excessive water from the field after irrigation which gives the plants chances to restore their stand because plants on adjacent beds are not intermingled. Also, they found that this technology is a substantial saving in irrigation water (40-50%) with increase in yield (10-25%) which improves water productivity (2.35 kg/m³). Ortega et al (2000) stated that wheat cultivation on raised bed was better than the conventional cultivation in terms of crop production and nitrogen use efficiency (NUE), which can be increased from about 30% with the traditional planting method to higher levels with best management practices.

The relationship between grain yield and irrigation water applied is economically important more than its relationship with the evapotranspiration (Farré and Faci, 2006). The higher water productivity produces either from the same yield and less water applied, or from a higher yield with the same water applied (Kjøne et al., 2003). The water productivity, WPET (kg m⁻³), which is originally referred to ‘water use efficiency’, is defined as the marketable yield from actual evapotranspiration.

Cut-off irrigation is considered as the recent developed technique in surface irrigation which is the most wide spread irrigation method in Egypt as well as worldwide. This technique is preferable in clay soils with low infiltration rate due to high horizontal lateral water movement comparing with the vertical downward movement. Such procedure could be achieved by finding the suitable irrigation run length at which irrigation should be stopped instead of watering till the tail end of cultivated field.

Mostafazadeh and Farzamnia (2000) pointed out that deep percolation and run off ratios were less in the cut-back irrigation method compared to the conventional method. Therefore, the cut-back methods have higher application efficiency in heavy textured soils as compared to light textured soils. Kassab et al (2012) reported that using irrigation cut-off at 90 % of strip length in North Nile Delta gave the same yield of berseem as obtained from irrigation cut-off at 95% of strip length, but it saved 7.9% of irrigation water and gave the highest water use efficiency (24.80 kg m⁻³) and water productivity (16.58 CE m⁻¹).
beginning of irrigation. The difference between water advance time and recession time (opportunity time) at each station was recorded. Observation wells were installed along each strip for daily recording of water table depth.

**Seasonal water applied (Wa):**

Seasonal water applied (mm) was calculated according to Giriappa (1983):

\[ Wa = IW + ER + CWT \]  

(2)

Where: IW: irrigation water applied (mm), ER: the effective rainfall, mm (effective rainfall = incident rainfall × 0.7, Chavan et al., 2010) and CWT: the contribution of the ground water table to crop water use.

**Crop evapotranspiration (ETc):**

Crop evapotranspiration (ETc) or crop consumptive use (Cu) was calculated directly from the soil moisture depletion in the effective root zone.

ETc was computed by the indirect method according to Doorenbos and Pruitt (1983):

\[ ETc = ETo \times Kc \]  

(3)

Where: ETo: Crop evapotranspiration (mm), ETc: reference crop evapotranspiration (mm), and Kc: crop coefficient.

**Contribution of the ground water table to crop water use (s):**

Water movement by capillary rise from water table into the active plant root zone is recognized as an important supplementary water resource for irrigation. The contribution of ground water (%) of the consumptive use was calculated according to Ibrahim et al. (1995) and Liu and Luo (2011):

\[ CWT\% = \frac{(ETc - SMD) \times 100}{ETc} \]  

(4)

Where: ETc: crop evapotranspiration (EToxKc) and SMD: soil moisture depletion.

**The reference evapotranspiration (ETo):**

ETo was calculated by CROPWAT model v.8.0 based on the agro-meteorological data collected for the studied area (Smith, 1992).

**Fig. 1.** ETo mm day\(^{-1}\) for the region of study located at 31°07'N Latitude, 30°75'E Longitude and elevation 6 meters (mean of two years)

**Crop coefficient (Kc):**

Values of the Kc were quoted from FAO (Allen et al., 1998). The four distinct growing stages of wheat and their corresponding Kc values were 0.4, 0.8, 1.2, 0.7 for the initial growth stage (20 days), development (50 days), mid-season (45 days) and late season (30 days).

**Crop evapotranspiration:**

The crop evapotranspiration ETc was estimated as described by Allen et al. (1998):

\[ ETc = ETo \times Kc \]

Where: Kc: crop coefficient; ETc: reference evapotranspiration (mm).

**Consumptive use (Cu):**

Water consumptive use was calculated according to Hansen et al. (1979) as follow:
Groundwater to wheat crop (CGW) was affected by the interaction between planting methods and irrigation cut-off techniques in both growing seasons. The highest values of irrigation water applied (2394 and 2459 m³ fed⁻¹) during the 1st and 2nd seasons, respectively were recorded under C₀₉₀₅ x F₁ treatment. On the other hand, the lowest values of irrigation water (1560.1 and 1640.9 m³ fed⁻¹) were detected under C₀₉₀₅ x F₃ treatment during both seasons, respectively. So, the same interaction recorded the highest values of water saving during the 1st season (834 m³ fed⁻¹ with 34.8% increase) and the 2nd season (819 m³ fed⁻¹ with 33.3% increase). These results are in harmony with those obtained by EL-Hadidi et al. (2016), Kassab and Ibrahim (2007), Abd El-Fatah (2011), Beshara (2012) and Moursi et al. (2014).

**Contribution of ground water to wheat evapotranspiration (CGW %):**

The data indicated that the seasonal contribution of groundwater to wheat crop (CGW) was affected by irrigation cut-off techniques and furrow width. The CGW values were increased by increasing the irrigation cut-off rate. So, the CGW values were increased from 105.0 and 93.3 m³ fed⁻¹ with C₀₉₀₅ to 154.3 and 133.7 m³ fed⁻¹ with C₀₉₀₅ or 219.3 and 195.0 m³ fed⁻¹ with C₀₉₀₅ in the 1st and 2nd seasons, respectively. Also, CGW values were increased from 49.0 and 10.7 m³ fed⁻¹ with F₁ to 156.0 and 151.7 m³ fed⁻¹ with F₀ or 273.7 and 259.7 m³ fed⁻¹ with F₁ in the 1st and 2nd seasons, respectively. This indicated that no or less contribution under F₁ technique but it may feed the groundwater due to increasing of the applied water.

Meanwhile, the seasonal mean CGW values of wheat were affected by the interaction between irrigation cut-off technique and furrow width. Therefore, CGW value was increased with increasing of irrigation cut-off and furrow width (C₀₉₀₅ x F₁) due to decreasing of water applied, while less or no contribution was recorded due to increase of water applied with C₀₉₀₅ x F₁ during the two growing seasons. The mean values of CGW in the two seasons were 0.3, 1.3, and 76.0

**RESULTS AND DISCUSSION**

**Seasonal water applied (Wa):**

The seasonal water applied for wheat crop consists of irrigation water (IW) + effective rainfall (ER) + contribution of ground water table (CWT) as shown in Table (1) and Figure (2). Seasonal effective rainfall was 199.6 and 214.9 m³ fed⁻¹ during the 1st and 2nd growing seasons (2017/18 and 2018/19), respectively. The obtained results reveal that the total amount of water applied under wide furrow treatments were in the following order: traditional treatment (F₁) > furrow 60 cm width (F₃) > furrow 120 cm width (F₀). So, F₁ planting method recorded the highest value of irrigation water during the 1st season (2149.7 m³ fed⁻¹) and the 2nd season (2275.7 m³ fed⁻¹), while the lowest values in both growing seasons (1729.7 and 1747.0 m³ fed⁻¹, respectively) were achieved with F₀ practice. On the other hand, irrigation water was increased with decreasing irrigation cut-off rate during both seasons of cultivation. It could be noticed that the amount of irrigation water under cut-off irrigation treatments take the following order C₀₉₀₅ > C₀₉₀₃ > C₀₉₀₁. Therefore, C₀₉₀₁ technique recorded the highest values of irrigation water in both seasons (2091.7 and 2145.0 m³ fed⁻¹, respectively), while C₀₉₀₅ technique achieved the lowest values in both growing seasons (1757.0 and 1810.7 m³ fed⁻¹, respectively).


m³/bed (0.5, 6.5, and 13%) with C100%, increased to 110.0, 152.5 and 199.0 m³/bed (6.88, 17.27 and 26.15%) with C40%, or 187.5, 266.0, and 346.5 m³/bed (15, 28.27 and 37.85%) with C80% under F1, F2, and F3, respectively. These results are in somewhat in agreement with that obtained by Khalil et al. (2005) and Khalifa (2013). The non-contribution from groundwater during both early and ripening stage periods may be attributed to the less water consumed by plants (Eid, 1994).

![Fig. 2. Irrigation water (IW), rain fall (ER) and contribution of ground water table (CWT) as a mean of the two seasons](image)

**Water consumptive use (Cus):**

The seasonal water consumptive use (Cu) or a “crop evapotranspiration ETC” is computed on the basis of moisture depletion from the effective root zone (60 cm depth). The obtained data showed that the change in the irrigation cut-off from 100 to 90 or 80% was associated with decrease of Cu values in both growing seasons as shown in Table (1). Mean values of Cu for the three irrigation cut-off techniques were 36.61, 34.69 and 32.78 cm with F1, F2 and F3, respectively. The Cu and water applied values were affected by the irrigation treatments and had the same trend in both seasons. The highest Cu values (41.75 and 42.60 cm) were recorded for with C100% x F1 followed by C80% x F3 (39.40 and 40.50 cm) while the lowest values (27.70 and 29.75 cm) were obtained under C30% x F1 in the 1st and 2nd seasons, respectively. These results indicate that C100% x F3 and C80% x F2 decreased Cu as a mean of the two seasons by approximately 27.1 and 28.8%, respectively, as compared with the conventional treatment (C100% x F1). The Cu value with C80% x F3 was lower than that with C100% x F3, may be due to the fact that wheat plants grown under C80% x F3 treatment were subjected to water stress resulting from lower amount of water applied. Also, this treatment resorted to contribution of ground water to compensate due to shortage of water applied and soil water content remained near the wilting point, while C100% x F1 treatment never had water stress since the soil water content remained above or near field capacity during the whole season. These results are in a harmony with those obtained by Kassab and Ibrahim (2007), Kassab et al. (2012), and Moursi et al. (2014).

**Grain yield (GY) and straw yield (SY) as affected by irrigation cut-off and raised beds:**

The Gy and SY values were significantly affected by irrigation cut-off techniques and they had the same trend in both growing seasons as shown Table (2).

**Grain yield (GY):**

The Gy values were significantly affected by cut-off irrigation techniques and the mean values of Gy for the two seasons were 3022.31, 3582.38 and 2759.17 kg fed⁻¹ with C100%, C60% and C30%, respectively. The increases of Gy due to C60% in relation to C100% and C80% were 15.6% and 22.9%, respectively. Concerning the effect of raised bed, the values of Gy was highly significantly affected by this planting method. The Gy means of the two seasons under F1, F2 and F3 were 3001.52 3137.26, and 3214.94 kg fed⁻¹ respectively. Thus, F3 treatment gave the highest Gy and was superior to F1 and F2 by 8.9% and 4.3%, respectively.

**Table 2. Grain and straw yields (kgfed⁻¹) as affected by raised bed and irrigation cut off technique**

<table>
<thead>
<tr>
<th>Raised bed</th>
<th>Cut-off</th>
<th>1st Season</th>
<th>2nd Season</th>
<th>Mean of two seasons</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grain</td>
<td>Straw</td>
<td>Grain</td>
<td>Straw</td>
</tr>
<tr>
<td>F1</td>
<td>C100%</td>
<td>2864.23 b</td>
<td>4085.90 b</td>
<td>2950.16 b</td>
</tr>
<tr>
<td></td>
<td>C60%</td>
<td>3419.30 a</td>
<td>4773.23 a</td>
<td>3521.88 a</td>
</tr>
<tr>
<td></td>
<td>C30%</td>
<td>2617.53 c</td>
<td>3777.60 c</td>
<td>2696.06 c</td>
</tr>
<tr>
<td>Mean F1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2967.0 c</td>
<td>4212.24 c</td>
<td>3036.03 c</td>
<td>4416.29 c</td>
</tr>
<tr>
<td>F2</td>
<td>C100%</td>
<td>2991.93 b</td>
<td>4235.70 b</td>
<td>3081.69 b</td>
</tr>
<tr>
<td></td>
<td>C60%</td>
<td>3556.63 a</td>
<td>4919.80 a</td>
<td>3603.33 a</td>
</tr>
<tr>
<td></td>
<td>C30%</td>
<td>2724.10 c</td>
<td>3938.97 c</td>
<td>2805.83 c</td>
</tr>
<tr>
<td>Mean F2</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>3000.9 b</td>
<td>4364.82 b</td>
<td>3183.61 b</td>
<td>4545.20 b</td>
</tr>
<tr>
<td>F3</td>
<td>C100%</td>
<td>3076.90 b</td>
<td>4353.33 b</td>
<td>3169.21 b</td>
</tr>
<tr>
<td></td>
<td>C60%</td>
<td>3612.47 a</td>
<td>4932.00 a</td>
<td>3720.84 a</td>
</tr>
<tr>
<td></td>
<td>C30%</td>
<td>2812.97 c</td>
<td>4024.33 c</td>
<td>2897.35 c</td>
</tr>
<tr>
<td>Mean F3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3167.4 a</td>
<td>4436.56 a</td>
<td>3262.47 a</td>
<td>4647.51 a</td>
</tr>
<tr>
<td>C100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C60%</td>
<td>2977.6 b</td>
<td>4224.97 b</td>
<td>3067.01 b</td>
<td>4409.85 b</td>
</tr>
<tr>
<td>C30%</td>
<td>3529.4 a</td>
<td>4875.01 c</td>
<td>3635.35 a</td>
<td>5048.64 a</td>
</tr>
<tr>
<td>F</td>
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<td>FxC</td>
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</tbody>
</table>

In addition, the grain yield (GY) was significantly affected by the interaction between irrigation techniques and planting methods in both seasons. The mean values of Gy with F1 under C100%, C60% and C30% techniques were 2907.20, 3470.59 and 2658.80 kg fed⁻¹, respectively with increases due to C60% by 16.2 and 23.4% compared to C100% and C30%, respectively. The Gy values with F2 under C100%, C60% and C30% techniques were 3036.81, 3609.98 and 2764.97 kg fed⁻¹, respectively. So, the increases due to C90% in relation to C100% and C80% were 15.8% and 23.4% respectively. With F3, the Gy values were 3123.06, 3666.66 and 2855.16 kg fed⁻¹ for C100%, C60% and C30%, respectively; while the increases due to C60% in relation to C100% and C80% were 14.8% and 22.1% respectively. Therefore, the highest values of Gy in the 1st and 2nd seasons (3612.47 and 3720.84 kg fed⁻¹, respectively) were achieved with F1 under C100%. On the other hand, the lowest values of Gy in both
growing seasons (2617.53 and 2696.06 kg fed\(^{-1}\), respectively) were detected under F\(_1\) combined with C\(_{90\%}\). These finding are similar to that reported by Ahmad and Mahmood (2014).

**Straw yield (SY):**

The straw yield (SY) was significantly affected by the irrigation cut-off techniques in both growing seasons and the mean SY values of both seasons were 4317.41, 4961.83 and 4031.96 kg fed\(^{-1}\) under C\(_{100\%}\), C\(_{80\%}\) and C\(_{60\%}\) techniques, respectively. The increases in SY due to C\(_{60\%}\) in relation to C\(_{100\%}\) and C\(_{80\%}\) were 12.9 and 18.7\%, respectively.

Concerning the effect of planting on raised beds, the mean SY values of both two seasons were 4314.27, 4455.01 and 4542.04 kg fed\(^{-1}\) under F\(_1\), F\(_2\) and F\(_3\), respectively. Thus, the increase of SY by F\(_1\) was 7.0 and 3.2\% over that with F\(_2\) and F\(_3\), respectively.

Meanwhile, the SY value was significantly affected by the interaction between irrigation cut-off techniques and planting methods in both growing seasons. The SY values with F\(_1\) were 4168.64, 4864.72 and 3909.19 kg fed\(^{-1}\) under C\(_{100\%}\), C\(_{80\%}\) and C\(_{60\%}\), respectively; with increases of 14.3 and 19.6\% due to C\(_{60\%}\) in relation to C\(_{100\%}\) and C\(_{80\%}\), respectively. Also, with F\(_3\) the SY values were 4335.32, 4983.40 and 4046.32 kg fed\(^{-1}\) under C\(_{100\%}\), C\(_{80\%}\) and C\(_{60\%}\) techniques, respectively with the increases of 13.0 and 18.8\% due to C\(_{60\%}\) in relation to C\(_{100\%}\) and C\(_{80\%}\), respectively. Finally, the SY values with F\(_3\) were 4448.35, 5037.37 and 4140.38 kg fed\(^{-1}\) under C\(_{100\%}\), C\(_{80\%}\) and C\(_{60\%}\) techniques, respectively; with the increases of 11.7 and 17.7\% with C\(_{60\%}\) over that with C\(_{100\%}\) and C\(_{80\%}\), respectively.

Therefore, the highest values of SY (4932.00 and 5142.73 kg fed\(^{-1}\)) were recorded under C\(_{60\%}\) technique combined with F\(_3\) method during the 1\(^{st}\) and 2\(^{nd}\) seasons, respectively, while the lowest values (3777.60 and 4040.77 kg fed\(^{-1}\)) were detected under C\(_{90\%}\) technique with F\(_1\) treatment during both seasons, respectively. These finding are similar to that given by Ahmad and Mahmood (2014).

**Water productivity (WP):**

The mean of WP values of the two growing seasons are illustrated in Table (3). The mean of WP were clearly affected by irrigation cut-off and the mean values of WP with C\(_{100\%}\), C\(_{80\%}\) and C\(_{60\%}\) were 6.67, 8.56 and 7.26 L.E.m\(^{-3}\), respectively. Concerning the effect of raised beds, the data showed that the greatest WP value was achieved with F\(_3\) followed by F\(_2\) then F\(_1\). The mean values for WP of the two growing seasons due to F\(_1\), F\(_2\) and F\(_3\) were 7.7, 9.5 and 10.8 L.E.m\(^{-3}\), respectively. So, the increases in WP given by F\(_3\) over that obtain by F\(_1\) and F\(_2\) were 27.7 and 12.0%, respectively.

Regarding the effect of the interaction of furrow width with irrigation cut off during the two growing seasons. The values of WP with F\(_1\) under C\(_{100\%}\), C\(_{80\%}\) and C\(_{60\%}\) were 5.53, 7.16 and 6.20 L.E.m\(^{-3}\) respectively and the increases due to C\(_{60\%}\) in relation to C\(_{100\%}\) and C\(_{80\%}\) were 22.7 and 13.4\%, respectively. The WP values with F\(_3\) were 6.85, 8.83 and 7.31 L.E.m\(^{-3}\) for C\(_{100\%}\), C\(_{80\%}\) and C\(_{60\%}\) respectively with the increases of 22.4 and 17.2\% due to C\(_{60\%}\) in relation to C\(_{100\%}\) and C\(_{80\%}\), respectively. With F\(_2\), the values of WP were 7.63, 9.69 and 8.26 L.E.m\(^{-3}\) for C\(_{100\%}\), C\(_{80\%}\) and C\(_{60\%}\) respectively with increases of 21.2 and 14.7% due to C\(_{60\%}\) in combined with C\(_{100\%}\) and C\(_{80\%}\), respectively. So, the highest WP value (9.69 L.E) was achieved by F\(_3\) combined with C\(_{60\%}\), while the lowest value (5.53 L.E.m\(^{-3}\)) was occurred with F\(_1\) in combined with C\(_{100\%}\) technique. These results are agreed with Kassab et al (2012) and Kassab and Ibrahim (2007).
Ahmad R. N. and N. Mahmood (2014). Impact of raised bed technology on water productivity and lodging of wheat. See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/256542862.


Moench) to deficit irrigation in a Mediterranean


