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EFFECTS OF DEFICIT IRRIGATION ON BARLEY YIELD USING SEVERAL IRRIGATION SCENARIOS

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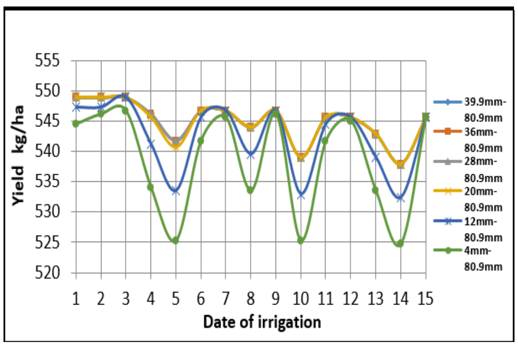
Graphical abstract



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Abstract

Deficient irrigation is a very significant study, especially with the limited water. Therefore, the current research aims to study the deficit irrigation depending on several different scenarios, by adding different amounts of water and irrigation rates (10%, 30%, 50%, 70%, 90%) of the full irrigation with changing irrigation time and studying its effect on productivity. The results showed that there is a clear effect on the productivity of barley at the level of irrigation (10%-30%) of the full irrigation and for all irrigation dates when changing the date of the first irrigation only, while the results showed when changing the second irrigation only and the first and second irrigation at the level of irrigation (10% - 30% -50%) of the full irrigation, the productivity will decrease by 13.75 - 84.7 kg/ha. It was also noticed that changing the irrigation level for the first irrigation has a very small effect on productivity compared to changing the irrigation level for the second irrigation and for all irrigation dates, and the reason for this is the difference in the stages of yield growth. While the results showed that changing the irrigation level for the first and second irrigation together will have a greater effect on productivity than the rest of the other scenarios.

Keywords: Deficient irrigation, irrigation times, productivity, irrigation levels

1.0 INTRODUCTION

Iraq is one of the arid and semi-arid regions that face great challenges due to its limited water resources with the increase in demand for it, and the lack of rainfall and its inappropriate distribution is one of the problems facing the region [1]. Therefore, the development of optimal irrigation water management is important for water productivity and food security [2]. Barley is considered one of the strategic and important crops that are grown in Iraq in general and Mosul city in particular, which requires the provision of water, which contributes to increasing productivity and raising the efficiency of water use. The barley yield in Iraq depends mainly on rain, however, the decrease in rainfall, its variation from day to day, and its inappropriate distribution, had to use supplemental irrigation, which is one of the effective tools to complete the water shortage, but the large costs resulting from this necessitated the use of the deficit irrigation method, which is considered one of the good and modern strategies in achieving the best yield with the least amount of water [3]. There are many international researches that have been conducted in different regions and for different crops, including: [4] conducted a field study in the state of São Paulo in Brazil on orange trees, the aim of which was to assess the impact of deficit irrigation and the efficiency of water consumption using the trickle irrigation method, as five irrigation scenarios were adopted in calculating productivity (100%, 75%, 50%, 25%) of the water requirement and also based on rain only. The results showed that the productivity was improved for the five years and the irrigation productivity increased by 30.8% compared to the rain production.

[5] conducted a study in China that included the effect of the deficit of different irrigation levels on corn productivity. The study for the years 2012 and 2013 included nine irrigation scenarios for different growth stages, which are (100%, 80%, and 60%) of the water requirement, crop productivity ranged for these scenarios within the limits of (9.362-6.392) tons/ha, while the irrigation water use efficiency was (58.1-32) kg/ha/1 mm. [6] conducted a field study in China that lasted four years (2013-2016) to determine the effects of timing and the intensity of water stress on the corn crop using two factors for deficit irrigation, which were applied to three stages of growth. The results showed that the vegetative growth stage was more effective in the productivity response, and that deficit irrigation can be applied in areas with severe water shortage to obtain the maximum water use efficiency, while irrigation scheduling can be used in areas with abundant water.

[7] conducted a study on the potato crop in Ethiopia to calculate the water requirement and water use efficiency under different levels of irrigation. The program (CROPWAT.8) was used to estimate the water requirement of the crop and its value was 604 mm for the growing season, different percentages (55%, 70%, 85%, 100%, 115%, 130%, 145%) of the water requirement of the crop were used. The results showed that the productivity of 100% was 25.86 tons/ha, and the highest water use efficiency was at 55%, which was 6.1 kg/m^3, while the productivity and water use efficiency of 70% were 22.63 tons/ha and 5.4 kg/m^3, respectively. [8] conducted a study in Spain of semi-arid regions on the barley yield for the years (2015-2017), the aim of which was to improve water use efficiency and to demonstrate the effect of deficit irrigation on the crop. Five irrigation scenarios were used (no deficit, 100% complete irrigation, 90%, 80%, and 70%). The results showed that the highest rate of productivity obtained was 9.049 tons/ha, and the highest value of water productivity was 80% and 70%, as these percentages reduced the amount of water used by 39.1% and 46.7%, respectively.

There are many previous studies that were conducted on the barley yield using the deficit irrigation method in different regions of the world [9], [10], [11], [12], [13], [14], [15]. As for the studies conducted in Iraq, which are very rare, Hachum and Al-Talib [16] conducted a study on the cotton crop included the use of a simulation model developed to study the effect of water saving and soil salinity on productivity under the influence of deficit irrigation. Four irrigation scenarios were used (100%, 80%, 60%, 40%) of the full irrigation. The researchers found a relationship linking the relative production with the water consumption of the crop and under several levels of deficit irrigation and the salinity of the irrigation water.

[17] conducted a study on corn crop included making a computer program to study the effect of irrigation consistency under the deficient irrigation system on crop productivity in the case of sprinkler irrigation, as three cases of deficit irrigation were used, which is when the moisture depletion reaches (70%, 80%, 90%) of the total available water, and for each of these percentages, several levels were taken for the deficit irrigation. The results showed that the decrease in the relative production of the crop increases with increasing the decrease by real evapotranspiration, and the relative water use efficiency increases with the increase in moisture depletion.

AL-Talib and Mahmood Agha [18] conducted a study on corn crop using a computer model to show the effect of deficient irrigation with salty water on the accumulation of salts in the soil, and the effect of productivity due to the deficient irrigation. The results showed a decrease in the accumulation of salts in the soil when irrigated at low levels, and the relative production decreases with a decrease in the level of irrigation in the case that the effect of irrigation is greater than the effect of salinity.

[19] conducted a study in Iraq in which he demonstrated the importance of studying water use efficiency and its impact on reducing the amount of irrigation water using incomplete irrigation. The study used the (Cropwat.8) program, and in this study, eight crops (corn, cotton, alfalfa, summer vegetables, sesame, sunflower, date palm, and small grain) were adopted using incomplete irrigation (5, 10, 15, 20, 25%) The study showed that the use of under-irrigation for most crops was clear from February to September. The correlation coefficient analysis also showed that the effect of under-irrigation on the productivity of the maize crop was greater compared to the rest of the crops, while the productivity of the cotton crop gave the lowest productivity under Same conditions.

In a study conducted by AL-mansor *et al*. (2021) [20] in southern Iraq, the importance of utilizing deficit irrigation scheduling was highlighted due to the limited availability of water resources in the area. The researchers conducted a two-year field experiment to investigate the impact of deficit irrigation on crop yield and water productivity of palm trees using five different irrigation systems that provided 0%, 25%, 50%, 75%, and 100% of the crop's water needs. The findings revealed that deficit irrigation strategies resulted in significant water savings ranging from (35-9)%. The treatments that provided 0% and 75% of the water requirement for both seasons showed the highest water productivity, with values of 0.46 kg/m3 and 0.47 kg/m3, respectively. By using the (CropWat.8) program, the appropriate time and amount of perfusion will be determined to obtain the highest productivity. However, in reality, farmers with limited water resources often lack the knowledge necessary to determine the optimal timing and amount of irrigation. Therefore, the main objective of the research is to use deficit irrigation using several different scenarios, by adding different amounts of water and in the percentages (10%, 30%, 50%, 70%, 90%) of the appropriate quantities for irrigation, as well as changing the irrigation date by advancing it or delay and its impact on productivity.

2.0 METHODOLOGY

The climatic data of the Mosul station, which was obtained from the Directorate of Meteorology and Seismic Monitoring, was relied on for three consecutive years 2016, 2017, 2018, which included rainfall, maximum and minimum temperatures, average relative humidity, winds at a height of 2 meters above sea level, as well as solar radiation. One of the soils of the region with a heterogeneous texture (sandy loam soil) with a field capacity of 19.8% and wilting point of 7% was chosen on a volumetric basis. The research includes calculating the real evapotranspiration through a process of correcting the value of the crop coefficient depending on the climatic conditions and calculating the plant stress coefficient as a result of the irrigation method used and its impact on productivity.

2.1 Real Evapotranspiration of the Crop

The real evapotranspiration values are calculated by multiplying the evapotranspiration of the crop ETc by the stress coefficient using the following equation:

$$ET_{C\ adj} = ET_c * K_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Where:
$ET_{C\ adj}$: actual crop evapotranspiration (mm/day).
ET_c: evapotranspiration of the crop (mm/day).
K_s: stress coefficient.

The water stress coefficient can be calculated through equation (2) [21] value will be one when there is no effect of soil water stress.

$$K_S = \left(\frac{(TAW - Dr)}{(1-p)TAW}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(2)$$

Dr: moisture depletion.
TAW: total available water in the root zone (mm)
P: critical depletion ratio.

Through equation (3), we calculate the evapotranspiration of the crop, which results from multiplying the crop coefficient by the reference evapotranspiration [19].

$$ET_C = ET_0 * K_c \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(3)$$

whereas:
ET_o: reference Evapotranspiration (mm/day)
K_c: crop coefficient.

Table 1 represents the stages of development of the barley yield coefficient according to the growth stages (Kc initial, Kc mid, Kc late) and the rate of maximum height of the crop under standard climatic conditions (U=2 m/s, RHmin=45%).

Table 1 Crop coefficient of barley and Maximum plant height (h)

Maximum crop height(m)	Kc end	Kc mid	Kc ini	crop
1	0.25	1.15	0.3	barley

This data has been included in the Cropwat program, which uses the Penman-Monteith equation to calculate the value of Evapotranspiration, as shown in the following Equation [21]:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1+0.34u_2)} \ldots\ldots\ldots\ldots\ldots(4)$$

Where:
ET_o: reference evapotranspiration (mm/day).
Δ: slope of the saturation vapor pressure curve with temperature (kPa/°C).
R_n: net solar radiation at the plant surface (MJ/m^{2}h).
G: soil heat flux density (mJ/m2h).
γ: The psychrometric constant (kPa/°C).
T: air temperature measured at an altitude of 2 m (°C).
U_2: wind speed measured at an altitude of 2m (°C).
e_s: saturated vapor pressure (kPa).
e_a: actual vapor pressure (kPa).

2.2 Productivity

According to the International Food and Agriculture Organization [21], the percentage of shortage in production is calculated through the following equation.

$$\left(\frac{Y_m - Y_a}{Y_m}\right) = K_Y\left(\frac{ET_C - ET_{C\ adj}}{ET_C}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5)$$

Since:
Y_m: maximum crop yield (kg).
Y_a: actual crop yield (kg).
k_y: coefficient of response of yield to water.
$ET_{C\ adj}$: actual crop evapotranspiration (mm/day).
ET_c: evapotranspiration of the crop (mm/day).
* This study relied on the maximum productivity value of 550 tons/ha (Directorate of Agriculture/Nineveh/ Guidance and Research Committee).

3.3 Stages of Changing the Depth of the Root Zone during the Growth of the Crop

The International Food and Agriculture Organization (FAO) indicated that the depth of the root zone is constant during the initial stages of growth (Zr_{min}), and it begins to increase linearly at the stage of crop development until it reaches its maximum value at the middle stage of growth (Zr_{max}), as indicated by Equation (6).

$$Z_r = Zr_{min} + (Zr_{min} - Zr_{max})\frac{J - J_{start}}{J_{max} - J_{start}} \dots\dots\dots\dots\dots\dots\dots (6)$$

where:
Zr_{min}: depth of the root zone at the initial stage (mm).
Zr_{max}: the maximum root depth at the middle stage (mm).
J: the current day after planting.
J_{start}: the number of days until the beginning of the crop development stage.
J_{max}: the number of days until the ripening.

3.4 Irrigation Time

In the current study, several irrigation dates has been adopted by advancing and delaying the first and second irrigation to note the effect of this on productivity, Table 2 shows the code for the irrigation times for the first and second irrigation, and these codes has been used in presenting the results.

Table 2 Symbol for Changing the Dates of the First and Second Irrigations of the Barley Crop

Symbol	The date of the first and second irrigation	Symbol	The date of the first and second irrigation	Symbol	The date of the first and second irrigation
1	15 Nov-9 Apr	6	20 Nov-9 Apr	11	25Nov-9Apr
2	15 Nov-4 Apr	7	20Nov-4Apr	12	25Nov-4Apr
3	15 Nov-31 Mar	8	20Nov-14Apr	13	25Nov- 14Apr
4	15 Nov-14 Apr	9	20Nov-31 Apr	14	25Nov-19Apr
5	15 Nov-19 Apr	10	20Nov-19Apr	15	25Nov-31Apr

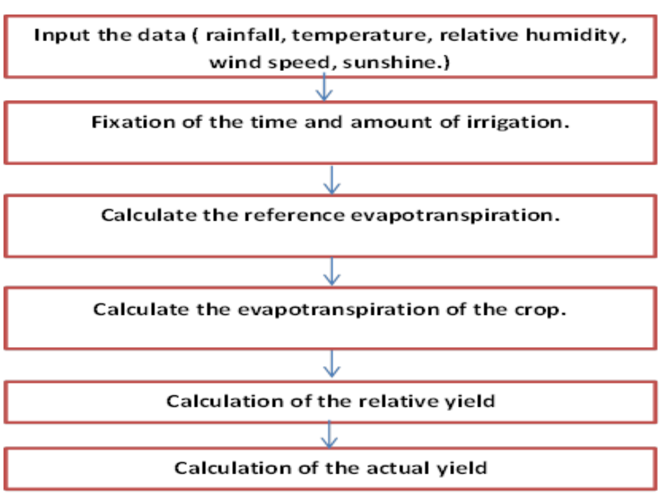

Figure 1 The general flowchart of the computational

4.0 RESULTS AND DISCUSSION

Through this study, several irrigation scenarios were applied with different irrigation depths and times. Based on the findings, the crop is only irrigated twice throughout its growth period. The initial irrigation takes place on November 15th, while the second one occurs on April 9th, with depths of 39.9 mm and 80.9 mm, respectively. Through this date and quantity, the highest productivity of the barley crop is obtained, at 549 kg / ha.

These scenarios are: The first scenario is reducing the first irrigation at different rates (10%, 30%, 50%, 70%, and 90%) of the full irrigation, while keeping the second irrigation without reduction and for different dates, which can be seen in Figure (1). As was notice through this that when reducing the percentage of irrigation water for the first irrigation by (10%, 30%, and 50%) of the full irrigation, there is no effect on productivity, as we note that the four curves correspond to each other for all irrigation times. However, there is a clear change in productivity by (70% and 90%) of the full irrigation, and the amount of decrease in productivity ranges from (1.65-24) kg per hectare, as shown in Table 1.

It was also noticed that there is no effect on productivity when changing the ratios of the amount of water at the irrigation date (25 November - 31 March), but there is a difference in productivity at the irrigation time (25 November - 19 April), and it was concluded that the delay in the second irrigation date by ten days from its actual date (9 April) affects productivity negatively for all levels of irrigation. Also, there is no significant effect on the productivity at (70% and 90%) of the full irrigation of the first irrigation at the irrigation times (15 November - 31 March), (20 November - 4 April), (20 November-31 March) (25 November - 4 April). While there is a clear difference in productivity when changing the irrigation level for the following irrigation dates: (15 November - 14 April), (20 November-14April),and(20 November - 19 April), the reason for this is due to the effect of the depths of irrigation water, which is very clear on productivity, as a result of the delay in the second irrigation by five or ten days from its scheduled date. Thus, delaying the irrigation time for the second irrigation by five or ten days with the use of deficit irrigation for the first irrigation will clearly affect the productivity. While advancing the irrigation date by five or ten days does not make an effect on productivity when using deficit irrigation.

As a result, if the deficit irrigation of the first irrigation is used in different percentages, a change will occur in the irrigation time, and thus will affect the irrigation time in the second irrigation, and when its date is delayed, the effect of irrigation rates will be clear on productivity. With regard to the second scenario, it is the change of the second irrigation only for the percentages (10%, 30%, 50%, 70%, and 90%) of the full irrigation. It was noticed from Figure 2 that there is no effect on productivity when changing the amount of irrigation water and for all irrigation times to the level of irrigation (90% and 70%) of the full irrigation. While the results show that at the irrigation level (10%, 30%, 50%) of the full irrigation, there is a decrease in productivity ranging between (13.75-18.5) kg/ha with regard to the irrigation level of 50% of the full irrigation, while for the irrigation level of 10 %, the amount of decrease in productivity in relation to total production ranges from (58.85-62.7) kg/ha, as shown in Table 2.

As for the irrigation times, the results showed that there was no significant effect on productivity when changing the irrigation times, except for the following irrigation times (15 November - 19 April, 20 November - 19 April, and 25 November - 19 April) for (10% and 50%) of the full irrigation, where we note that the decrease in productivity was (7, 10, and 11) kg/ha, respectively. The reason for this is that the effect of the irrigation time at the second irrigation is greater than the change in the amount of the added water. As for the third scenario, the change of the first and second irrigations according to the previously mentioned percentages, as noticed in Figure 3 that there is no effect on productivity when changing the irrigation time at the level of irrigation (50%, 70%, 90%) of the full irrigation, while that there is a clear effect on productivity at irrigation level (10%, 30%) of full irrigation at irrigation time (15 November - 19 April), (20 November - 19 April), (25 November -19 April).

The results show that at the irrigation level (10%, 30%, and 50%) of the full irrigation, there is a decrease in productivity of 50 and 87.7 kg/ha with regard to the irrigation level of 30% and 10% of the full irrigation, respectively, as shown in Table 3. And through the obtained results, when comparing the change in the irrigation level to the scenarios that were mentioned previously, changing the irrigation level for the first irrigation has a very small effect on productivity compared to changing the irrigation level for the second irrigation, the reason for this is the different stages of crop development, where at the beginning of crop growth the water requirement is low compared to the crop maturity stage. While that the change in the irrigation level for the first and second irrigation together will have a greater effect on productivity than the rest of the other scenarios, as shown in Figure 4 and Figure 5, which shows the amount of decrease in productivity for all the studied cases at the irrigation level of 10% and 30%, respectively.

Figure 6 shows the relationship between total irrigation and yield ratio during the growing season. In certain scenarios, deficit irrigation for both irrigations is more effective than alternating irrigation. For example, in the case of deficit irrigation, the water depth for both irrigations is 84.6 mm, yielding in a 98.5% rate of yield. When utilizing alternate irrigation with a water depth of 84.9 mm, however, the final yield rate reduces to 95.5%. Therefore, it is crucial to implement an optimal irrigation schedule that enhances productivity when utilizing deficit irrigation.

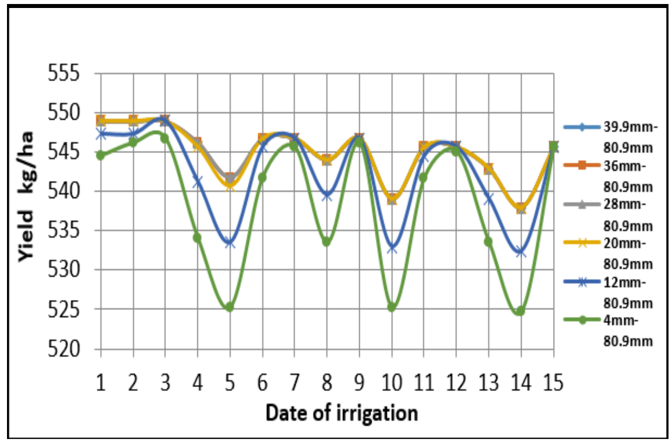

Figure 1 The relationship between productivity and irrigation times when fixing the depth of the second irrigation and changing the percentages of the depths of the first irrigation

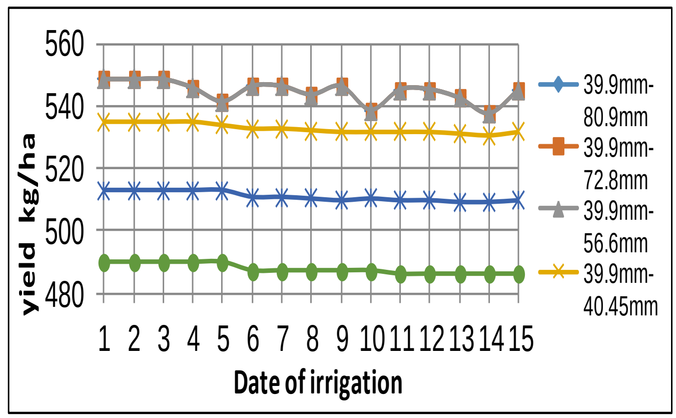

Figure 2 The relationship between productivity and irrigation times when fixing the depth of the first irrigation and changing the percentages of the depths of the second irrigation

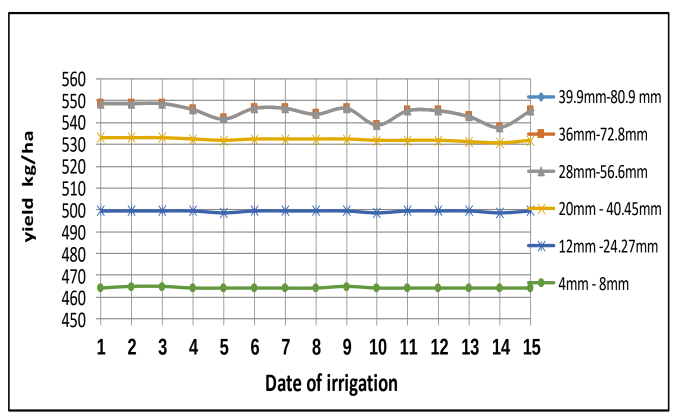

Figure 3 The relationship between productivity and irrigation times when changing the percentages of the first and second irrigation

Table 1 The amount of the decrease in productivity relative to total production (kg/ha) at the irrigation levels (30% and 10%) of the full irrigation for the first irrigation

First irrigation Date	Second irrigation Date	The amount of decrease in productivity relative to total production (kg/ha)	
		30%	10%
15 Nov	9 Apr	1.65	4.4
15 Nov	4Apr	1.65	2.75
15 Nov	31 Mar	0	2.2
15 Nov	14Apr	7.7	14.85
15 Nov	19Apr	15.4	23.65
20 Nov	9Apr	3.3	7.15
20 Nov	4Apr	2.2	3.3
20 Nov	31Mar	2.2	2.75
20 Nov	14Apr	9.35	15.4
20 Nov	19Apr	15.95	23.65
25 Nov	9Apr	4.4	7.15
25 Nov	4Apr	3.3	3.85
25 Nov	31 Mar	3.3	3.3
25 Nov	14Apr	9.9	15.4
25 Nov	19Apr	16.5	24.2

Table 2 The amount of the decrease in productivity relative to total production (kg/ha) at the irrigation levels (10%, 30%, and 50%) of the full irrigation for the second irrigation

First irrigation Date	Second irrigation Date	The amount of decrease in productivity relative to total production (Kg/ha)		
		%50	%30	%10
15 Nov	9 Apr	15.95	49.5	84.7
15 Nov	4Apr	15.95	49.5	84.15
15 Nov	31 Mar	15.95	49.5	84.15
15 Nov	14Apr	16.5	49.5	84.7
15 Nov	19Apr	17.05	50.05	84.7
20 Nov	9Apr	16.5	49.5	84.7
20 Nov	4Apr	16.5	49.5	84.7
20 Nov	31Mar	16.5	49.5	84.15
20 Nov	14Apr	16.5	49.5	84.7
20 Nov	19Apr	17.05	50.05	84.7
25 Nov	9Apr	17.05	49.5	84.7
25 Nov	4Apr	17.05	49.5	84.7
25 Nov	31 Mar	17.05	49.5	84.7
25 Nov	14Apr	17.6	49.5	84.7
25 Nov	19Apr	18.15	50.05	84.7

Table 3 The amount of decrease in productivity relative to the total production (kg/ha) at the irrigation levels (10%, 30 and 50%) of the full irrigation for the first and second irrigation

First irrigation Date	Second irrigation Date	The amount of decrease in productivity relative to total production (Kg/ha)		
		% 50	%30	%10
15 Nov	9 Apr	13.75	35.75	58.85
15 Nov	4Apr	13.75	35.75	58.85
15 Nov	31 Mar	13.75	35.75	58.85
15 Nov	14Apr	13.75	35.75	58.85
15 Nov	19Apr	14.85	35.75	58.85
20 Nov	9Apr	15.95	37.95	61.6
20 Nov	4Apr	15.95	37.95	61.6
20 Nov	31Mar	17.05	39.05	61.6
20 Nov	14Apr	16.5	38.5	61.6
20 Nov	19Apr	17.05	38.5	61.6
25 Nov	9Apr	17.05	39.05	62.7
25 Nov	4Apr	17.05	39.05	62.7
25 Nov	31 Mar	17.05	39.05	62.7
25 Nov	14Apr	17.6	39.6	62.7
25 Nov	19Apr	18.5	39.6	62.7

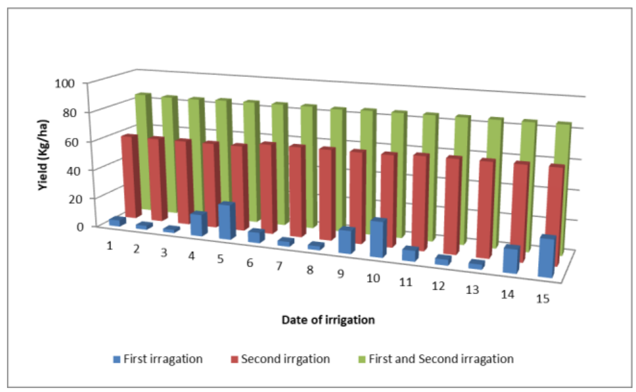

Figure 4 The amount of decrease in productivity at the irrigation level 10% for the studied scenarios

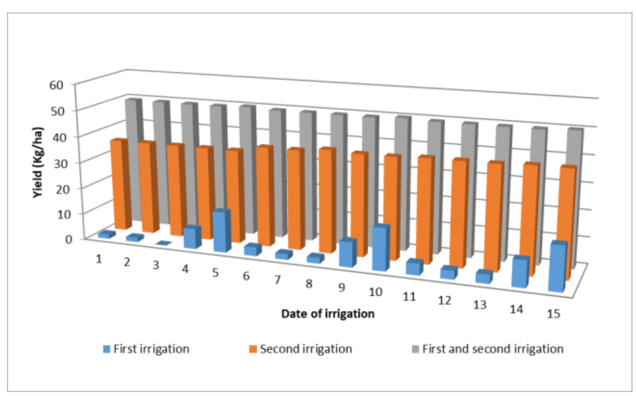

Figure 5 The amount of decrease in productivity at the irrigation level 30% for the studied scenarios

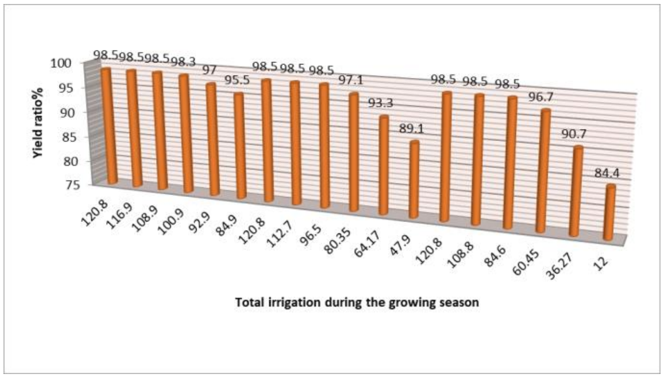

Figure 6 the relationship between total irrigation and yield ratio during the growing season

5.0 CONCLUSIONS

In this research, the effect of deficit irrigation on the productivity of barley was studied, depending on several irrigation scenarios by reducing the first irrigation only, or the two irrigations together, or the second irrigation only, with changing the irrigation time for all cases. Through the obtained results, conclude that when the irrigation level changes for the first irrigation, the effect on barley productivity will be very small compared to when changing the irrigation level for the second irrigation, the reason for this is the different stages of crop development, where at the beginning of crop growth the water requirement is low compared to the crop maturity stage. It was also noted that the delay of the second irrigation by five or ten days, with the use of deficit irrigation of the first irrigation, will affect the productivity of the crop in a clear and large way, but when advancing its date by five or ten days, there will be no effect on productivity. The reason for this is that the use of deficit irrigation for the first irrigation in different percentages will affect the irrigation time in the second irrigation, and therefore when its date is delayed, the effect of irrigation percentages will be clear on productivity. But when changing the irrigation date for the second irrigation with the following dates (15 November - 19 April, 20 November - 19 April, 25 November - 19 April) with regard to the irrigation level (10% and 50%) of the full irrigation, the productivity decreases by (7, 10, 11) kg/ha, respectively, since the effect of the irrigation date at the second irrigation will have a greater effect than the change in the amount of the added water.

Numerous studies have been conducted in the Iraq region, such as those by Hachum, A. Y., & Al-Talib (2007), Jajjo (2010), AL-Talib, D., & O. Mahmood (2011), Al-Shammari *et al*. (2020), and Al-Mansor *et al*. (2021), which employed deficit irrigation for all growing seasons and crops of corn and soybeans. However, this present study is the first to employ alternating deficit watering with a modification in irrigation time. One of the key findings is that determining an appropriate irrigation schedule is crucial when implementing alternate deficit irrigation techniques.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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