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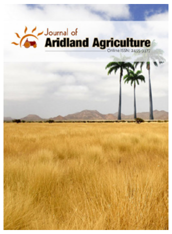
Research Article



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Impact of irrigation management on crop water footprint reduction using RZWQM2 in Baghdad, Iraq

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ABSTRACT

Water scarcity becomes a serious global challenge in several world regions and particularly in the Middle East. Appropriate irrigation practice is critical for improving crop yield and alleviating crop water footprint (WF). To alleviate water scarcity, the possibility of reducing wheat and barley water footprint has been examined through alternative surface irrigation practices. The WF was compared under farmers' irrigation practice and experimental irrigation practice to discover the impact of irrigation practices on the reduction of WF in the west of Baghdad. Weather data and crop management information were collected from 2016 to 2020 for the farmer's fields in the study area as well as for the experimental field. The Root Zone Water Quality Model (RZWQM2) was used for estimating wheat and barley evapotranspiration. The study results showed that the crop WF was well estimated using the RZWQM2 due to the model capability and accuracy for estimating the impact of field management on crop evapotranspiration and crop water use. Experimental irrigation practice could improve crop yield, water use efficiency, and water profitability by up to 28%, 35%, and 35%, respectively; while the WF was reduced by 35%, compared to the farmers' irrigation practice. The WF of the wheat crop was lower than the barley WF due to the low barley production.

KEYWORDS: Water footprint reduction, Surface irrigation practices, Wheat and barley, RZWQM2, Iraq

INTRODUCTION

Agricultural practices are consuming about 85-92% of all water in the world, which leads to facing severe irrigation scarcity due to the demand for enough food production for population growth (Hoekstra *et al.*, 2012; Nouri *et al.*, 2019; Talaviya *et al.*, 2020). The biotic and abiotic stresses cause tremendous losses in agricultural production in Iraq (Al-Ani *et al.*, 2011; Adhab *et al.*, 2019; Adhab, 2021; Adhab *et al.*, 2021; Adhab & Alkuwaiti, 2022; Khalaf *et al.*, 2023). Among those, one of the most significant stresses is draught. The shortage of irrigation water requirements is exacerbated by several factors such as dynamics of climate change, irrigation practices, and growing numbers of people in the world (Hejazi *et al.*, 2014; Kreins *et al.*, 2015; Mekonnen & Hoekstra, 2016). As a result, irrigation water deficiency affects food security by threatening the stability of agricultural production. Climate change is expected to increase temperature and apply extra pressure on the available water resources needed to supply water for crops, and indeed, it increases irrigation water requirements (Masood & Shahadha, 2021).

Water is the main requirement for crop growth and production. It is applied to the crop by one of the common irrigation methods, which are surface irrigation, sprinkler irrigation, and drip irrigation systems. Recent studies indicate that water use efficiency depends on irrigation technology and strategy (Abioye *et al.*, 2022; Bwambale *et al.*, 2022). Drip and sprinkler irrigation systems could result in better water use efficiency and crop production, compared to surface systems (Tsakmakis *et al.*, 2017; Tsakmakis *et al.*, 2018). Improving water use efficiency and crop yield can be achieved by applying the best irrigation technology and strategy, as well as through the optimization of agricultural field management, especially, irrigating the crops based on the crop requirements with just the needed water amount. This could result in alleviating the increasing water scarcity around the world (Al-Said *et al.*, 2012).

The water footprint (WF) is the amount of total water used throughout the crop production processes (Ewaid *et al.*, 2020; Wedaa *et al.*, 2022). The water footprint in the agricultural systems is expressed in three parts, blue, green, and gray. In this study, the gray part of the water footprint was ignored because of the difficulty of determining it. Therefore, the total water footprint is the sum of blue and green water footprints. The blue water footprint is the surface and groundwater used in irrigation practices, and the green water footprint is the effective precipitations. The Food and Agriculture Organization (FAO) suggested the CROPWAT model for calculating the green and blue water footprint for crops. CROPWAT model operated for just the precipitation and the result of the estimated actual crop ET is the green ET fraction. Then, re-operating the model uses the irrigation events to simulate the actual crop evapotranspiration. The blue ET fraction is the difference between obtained ET from precipitation and scheduled irrigation. In another study, Chukalla *et al.* (2015) applied the AquaCrop for calculating the water footprint fractions of crops. However, the AquaCrop model used water balance equations to calculate the daily green and blue evapotranspiration. Tsakmakis *et al.* (2018) compared the outputs of AquaCrop and CROPWAT models; they found that AquaCrop is more suitable for assessing the influence of irrigation management (irrigation technology and irrigation strategy) on the water footprint fractions while CROPWAT can evaluate only the practices of the irrigation strategy. In this study, the Root Zone Water Quality Model (RZWQM2) was used instead of other models. It is one of the most widely used models for improving field management. RZWQM2 used an extended Shuttleworth and Wallace (1985) equation, which is a double-layer version of the Penman-Monteith model for calculating crop evapotranspiration (Farahani & Ahuja, 1996).

Several studies around the world were about reducing the crop water footprint by applying different management practices such as soil mulching to reduce soil water evaporation (Pi *et al.*, 2017), conservation tillage to improve the soil hydraulic properties such as water holding capacity (Azimzadeh, 2012), using crops with high drought-resistant for adapting to water deficiency (Hu & Xiong, 2014), and changing temporal and spatial cropping patterns to improve crop growth and production (Davis *et al.*, 2017). However, most studies in Iraq were focusing on calculating the crop water footprint for different crops without changing the field management practices to reduce the water footprint. For instance, the water footprint of rice was calculated in several locations in Iraq to determine the variation in water footprint and the reason behind that (Ewaid *et al.*, 2020). Also, it was calculated for the wheat crop for several Iraqi provinces (Ewaid *et al.*, 2020); they found that the total WF for the wheat in Baghdad, which is in the middle of the country, was 2094 m^3/ton for the growing season of 2016-2017. However, the total WF was about 3000 and 1500 m^3/ton for the southern and northern of the country for the same crop-growing season. In addition, the WF of wheat was around 2000 to 3400 m^3/ton for the regions around Iraq such as Syria and Iran (Mekonnen *et al.*, 2010).

This paper presents a systematic study to simulate the wheat and barley water footprint fractions (green and blue) under different irrigation management (farmers and experimental irrigation practices) for the period 2016 to 2020 in central Iraq, west of Baghdad, using the Root Zone Water Quality Model (RZWQM2). The framers' irrigation practice in the study area (west of Baghdad) was to irrigate the wheat and barley by applying six irrigation events using the surface irrigation system by flooding the crops with much more water than the crop water requirements. On the other hand, an experimental irrigation practice was conducted by using the same irrigation system, but the crop water requirements were added to the crop with an accounted amount of applied water based on the available soil water and field capacity. Therefore, the objective of this study was to estimate the possible reduction of the water footprint under suitable irrigation management for the surface irrigation system.

MATERIALS AND METHODS

The study area

The Al Nasr Wal Salam region is located approximately 30 km west of the center of Baghdad. Geographically, it can be found at a latitude of 33.3 degrees East, a longitude of 44.0 degrees North, and an altitude of 34 meters above sea level. The annual average precipitation in the study area is roughly 177 mm, with daily maximum and minimum air temperatures averaging around 31 and 15 degrees Celsius, respectively. The dominant soil types in the region are silt clay loam and silt clay. Surface irrigation is the primary system used for watering crops, with the Euphrates River serving as the main source of irrigation water. The land use of the study area is approximately 40000 hectares, with active cultivated land making up roughly 40% of the total area (as shown in Figure 1). The remaining land is either under construction or unplanted due to factors such as irrigation shortages and high field management costs. Wheat and barley are the main crops grown in the region and occupy an area of around 10000 hectares that is irrigated using the surface irrigation system. Soil samples were collected from representative areas of the region to determine information such as soil texture, bulk density, field capacity, and wilting point (as detailed in Table 1). These crops are typically planted manually in early November and harvested in early May, with a planting rate of 120 kg/ha.

The crop fertilization application for wheat and barley was applied regarding the local fertilization cultural practice. The diammonium phosphate fertilizer (DAP) was use to apply at the beginning of the crop growing seasons. DAP includes 18% N and 46% P2O5. The second fertilizer application was applied after about 50 days with 46 kg N/ha as urea. Both applications used the surface broadcast application method.

In the study area, farmers typically irrigated their crops six times during the growing season using surface irrigation, without taking into account the crop's water requirements. Data on crop yield and irrigation practices were collected from the Iraqi Ministry of Agriculture and local farmers.

An alternative irrigation management practice was developed to increase crop production and reduce water usage in the western region of Baghdad. The experiment was conducted on a 2-hectare plot using the same surface irrigation system as the local farmers. However, the experimental field received irrigation based on the crop's water requirements. When the available soil water level dropped to 50% of its capacity, irrigation was applied to replenish the soil to its full capacity. The main difference between the experimental and traditional irrigation practices was the frequency and amount of water applied. Farmers

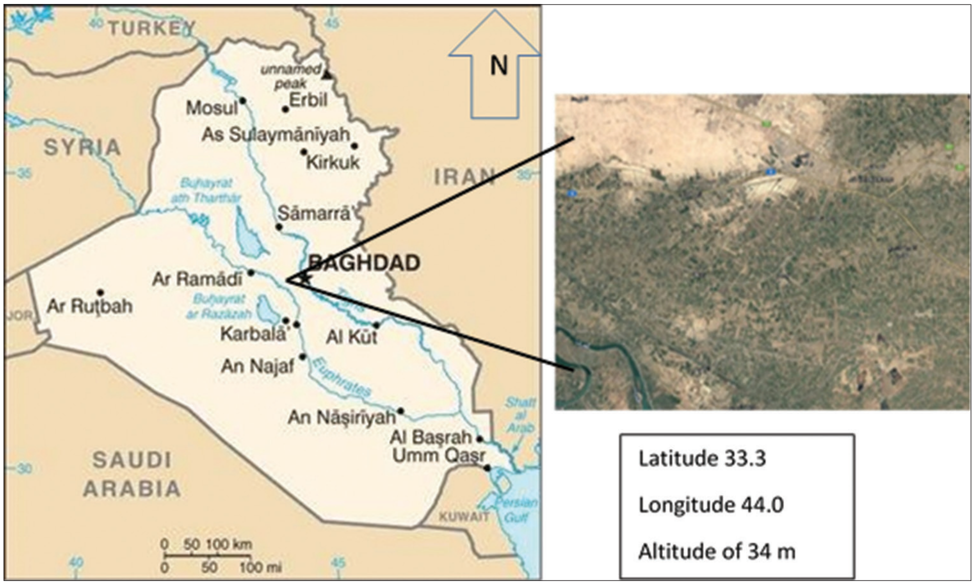

Figure 1: Location of the study area, west of Baghdad, Iraq

Table 1: The common soil properties of the study area

Soil depth	Soil Particles g/kg			Soil texture	Soil bulk density	Soil water content at different pressures (cm³/cm³)			Available soil water
(cm)	Clay	Silt	Sand		g/cm³	0 kPa	33 kPa	1500 kPa	
0-25	350	530	120	SiC	1.39	51.39	31.99	14.72	17.27
25-50	370	520	110	SiC	1.42	52.86	31.56	15.1	16.46
50-75	380	520	100	SiCL	1.46	53.22	32.26	15.36	16.89
100-75	370	530	100	SiCL	1.48	53.98	32.12	15.75	16.37

typically irrigated their crops six times with more water than necessary, while the experimental field received nine irrigations based on the available soil water and field capacity.

Climate Description

The climate of the study area is described as a continental subtropical climate. The environmental conditions are almost different from other regions because it experiences a very high variation of meteorological variables, especially, the air temperature (Figure 2). The summer season is long and extremely hot (sometimes the maximum temperature in July and August reaches 50 °C in the shade, with no precipitation). Whereas the winter season is short and cool (sometimes the minimum temperature in December and January becomes below zero °C) (Jaradat, 2003; Al-Ansari *et al.*, 2014; Abbas *et al.*, 2018; FAO, 2018; Daham *et al.*, 2019).

For this study, the daily weather data (minimum and maximum temperature, precipitations, relative humidity, wind speed, solar radiation) for the period of 2016-2020 was collected for the west of Baghdad (Al Nasr Wal Salam). Weather data was obtained from Al-Raeeid automatic meteorological station.

The meteorological data was collected to estimate crop evapotranspiration using the RZWQM2 (Ma *et al.*, 2003). The evapotranspiration was used to compute the crop water use for wheat and barley crops.

RZWQM2 input data

The RZWQM2 requires four major model inputs, which are categorized under the soil, crop, field management, and climatic data (Shahadha *et al.*, 2021; Chen *et al.*, 2022; Shahadha & Wendroth, 2022). The main soil input data are soil texture, soil bulk density, soil water content at different pressures, and saturated hydraulic conductivity. In addition, the field management input requirements are all the field activities such as the tillage, irrigation, and fertilization information. The main climatic datasets required are daily values of maximum and minimum air temperatures, precipitations, relative humidity, solar radiation, and wind speed.

Crop Water Requirement (CWR)

The Crop Water Requirement (CWR) is the water volume needed for a crop to grow. In other words, CWR is the actual crop evapotranspiration. In this study, the actual evapotranspiration was obtained based on the simulated actual evapotranspiration using the extended Shuttleworth–Wallace (1985) ET model in the RZWQM2 (Ma *et al.*, 1999). Extended Shuttleworth–Wallace model is a double-layer version of the Penman–Monteith equation (Farahani & Ahuja, 1996; Ma *et al.*, 2017; Shahadha *et al.*, 2019, 2022).

Crop water use (CWU) is the amount of water required for evapotranspiration. It is divided into two parts, first, the

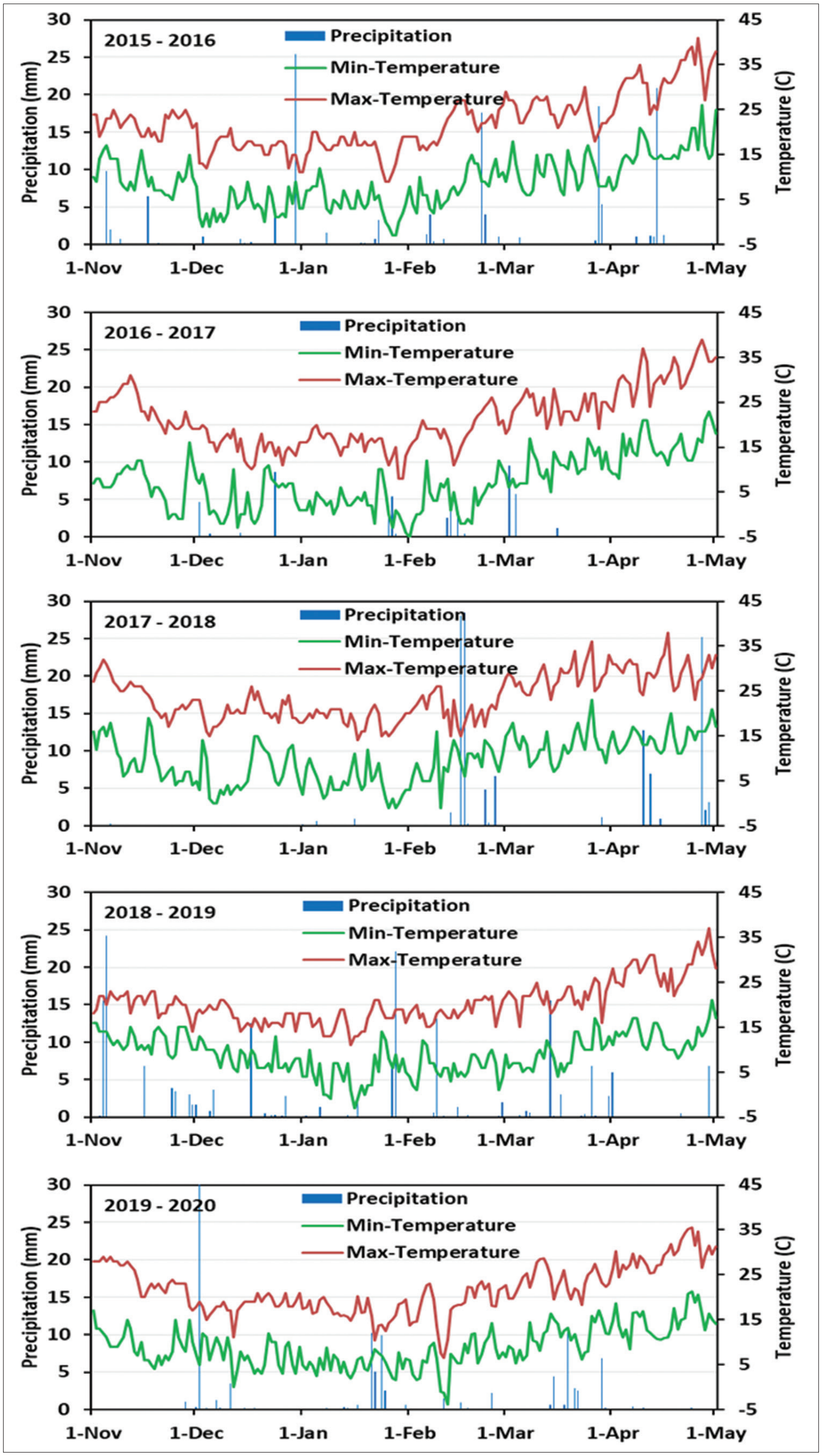

Figure 2: Daily precipitation and maximum and minimum air temperature values for the wheat and barley growing seasons during the study period of 2015-2020

green crop water use (CWU_G, m^3/ha), which is the amount of precipitation used as crop ET.

$$CWE_G = 10 * \sum_{d=1}^{lgp} ET_G \quad 1$$

Where the ET_G is the Eff. rain; Igp is the period of the growing season, and factor 10 is for converting the water depth (mm) into water volume (m^3/ha).

The second part of the crop water use is the blue crop water use (CWU_B, m^3/ha). It is the volume of irrigation water used as crop evapotranspiration (Allen *et al.*, 1998; Ewaid *et al.*, 2019).

$$CWE_B = 10 * \sum_{d=1}^{lgp} ET_B \quad 2$$

Where, the ET_B is the irrigation requirements. When the Eff. rain is above the *ETc*, the ET_B is equal to zero.

The crop water footprint (WF) (m^3/ton) is the sum of green and blue components of WF (Hoekstra *et al.*, 2011).

$$WF = WF_G + WF_B \quad 3$$

The WF_G is calculated by dividing green CWU_G by crop yield.

$$WF_G = \frac{CWE_G(\frac{m^3}{ha})}{Y(\frac{ton}{ha})} \quad 4$$

The WF_B is calculated by dividing blue CWU_B by crop yield.

$$WF_B = \frac{CWE_B(\frac{m^3}{ha})}{Y(\frac{ton}{ha})} \quad 5$$

The total required volume of water (total water footprint, m^3/year) for crop production during the specific period is the summation of WF_G and WF_B.

$$WF_G(m^3/year) = WF_G(m^3/ton)\ X\ crop\ production\ (ton/year) \quad 6$$

$$WF_B(m^3/year) = WF_B(m^3/ton)\ X\ crop\ production\ (ton/year) \quad 7$$

In addition, the water use efficiency (WUE) was calculated for both crops during all growing seasons using the following equation,

$$WUE = \frac{crop\ \ yield(\frac{kg}{ha})}{applied\ \ water(\frac{m^3}{ha})} \quad 8$$

The water profitability (WP) for wheat and barley was calculated for all crop-growing seasons as well.

$$WP(\frac{ID}{m^3}) = \frac{yield\left(\frac{kg}{ha}\right)\ x\ \ Price(\frac{ID}{kg})}{applied\ \ water(\frac{m^3}{ha})} \quad 9$$

Where, the price is 750 and 500 Iraqi Dinar (ID) for each kg of wheat and barley, respectively. The price is an average governmental price during the last five years.

RESULTS AND DISCUSSIONS

The daily values of the precipitations and the maximum and minimum air temperature for the growing seasons (2015-2020) are presented in Figure 2. The growing season of wheat and barley in Iraq is from the beginning of November to the beginning of May. The cumulative precipitation was 139, 52, 125, 179, and 106 mm for the growing seasons of 2016, 2017, 2018, 2019, and 2020, respectively. The average maximum air temperature was around 22 °C for all crop-growing seasons, and the average minimum air temperature was around 8 °C for all crop-growing seasons as well.

Figure 3 presents the crop yield of wheat and barley under farmer and experimental management. The experimental irrigation practice resulted in higher values of wheat and barley yield than the yield values under farmer irrigation practices by about 28% for all crop growing seasons. Wheat yield was arranged between 4.8 and 5.6 t/ha under the experimental irrigation practice. While under the farmer irrigation practice, the yield is arranged between 3.4 and 4 t/ha. The planted area was differentiated from year to year due to the available irrigation water and governmental support for the farmers. The planted area of the wheat crop in the Al Nasr Wal Salam was 8750, 8750, 5000, 8000, and 6750 hectares for the growing season of 2016, 2017, 2018, 2019, and 2020, respectively. While, the planted area of the barley crop was 339, 438, 362, 505, and 1079 hectares for the growing season of 2016, 2017, 2018, 2019, and 2020, respectively. The planted area affected the total crop yield per year in the study area as shown in Figure 3. The results of this study are comparable with the finding of Ewaid *et al.* (2019) and Masood and Shahadha (2021).

The farmers' fields consumed more water than the experimental field for all the crop-growing seasons of wheat and barley due to the used irrigation practices. In the farmers' field, irrigation water was applied about six times during the crop growing season for both wheat and barley, but in each application event, they applied much more water than the required water due to the irrigation water was applied without taking into account the available water in the soil as soil moisture and the maximum required water amount (threshold point), which is the point at the field capacity.

Table 2 shows the green, blue, and total water footprint for wheat and barley under farmer fields and experimental fields

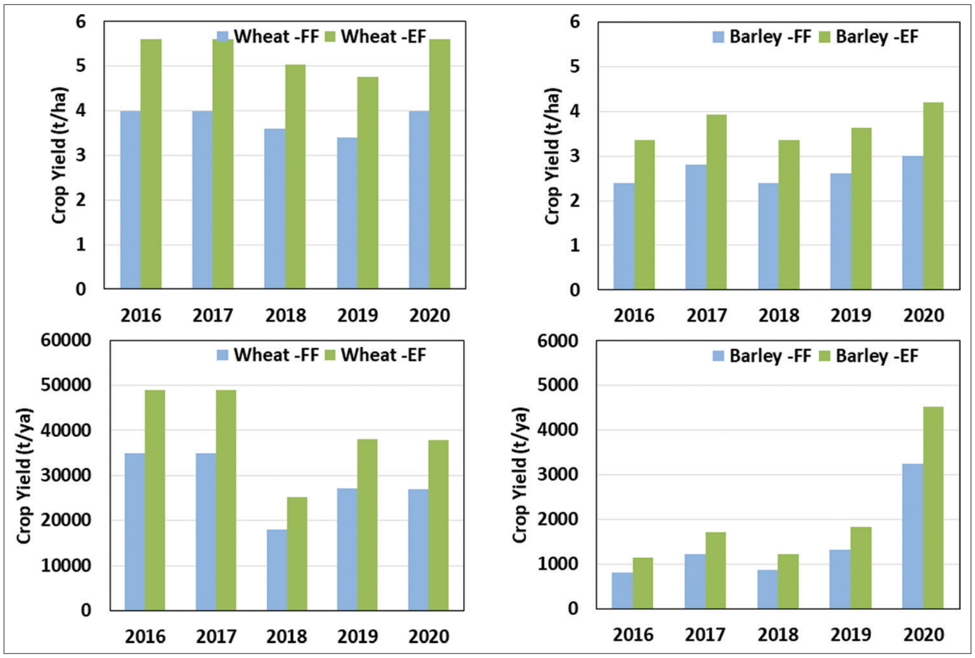

Figure 3: Crop yield of wheat and barley (ton/hectare and ton/year) under farmer field (FF) and experimental field (EF) for five growing seasons of 2015-2020

Table 2: Green, blue and total water footprint for wheat and barley under farmer field (FF) and experimental field (EF) for five growing seasons

Wheat Crop						
Farmers Field (FF)				Experimental Field (EF)		
Date	WF_G (m^3/ton)	WF_B (m^3/ton)	Total-WF_{G+B} (m^3/ton)	WF_G (m^3/ton)	WF_B (m^3/ton)	Total-WF_{G+B} (m^3/ton)
2016	1029	759	1788	735	433	1169
2017	929	809	1738	663	462	1126
2018	1107	829	1937	791	474	1265
2019	1084	708	1793	774	405	1179
2020	909	689	1598	649	393	1043
Mean	1012	759	1771	723	434	1157
SD	90	61	122	64	35	81
Barley Crop						
Farmers Field (FF)				Experimental Field (EF)		
Date	WF_G (m^3/ton)	WF_B (m^3/ton)	Total-WF_{G+B} (m^3/ton)	WF_G (m^3/ton)	WF_B (m^3/ton)	Total-WF_{G+B} (m^3/ton)
2016	1717	1267	2984	1226	724	1950
2017	1338	1168	2506	956	667	1623
2018	1690	1273	2963	1207	727	1935
2019	1415	924	2339	1010	528	1539
2020	1230	936	2166	878	535	1413
Mean	1478	1114	2592	1056	637	1692
SD	216	173	369	155	99	240

for five growing seasons. The mean value of the green water footprint of the wheat crop under the irrigation practice of farmers' fields was 1012 m^3/ton for the five growing seasons, with a standard deviation of 89.6 m^3/ton. While the mean value of the blue water footprint of the wheat crop under the same irrigation practice was 759 m^3/ton with a stander deviation of 61 m^3/ton. As a result, the mean and stander deviation values of the wheat total WF were 1771 and 122 m^3/ton for the farmers' fields. The water footprint of the wheat crop under the impact of the irrigation practice of the experimental fields was reduced by about 35% m^3/ton. Where the total wheat WF under the impact of experimental irrigation practice were 1169, 1126, 1265, 1179, and 1043 m^3/ton for the growing season of 2016, 2017, 2018, 2019, and 2020, respectively. The experimental irrigation practice achieved a reduction of 35% of the WF, which could be considered a very well economic achievement.

The WF details for the barley are presented in Table 2. The total WF of the barley under farmers' irrigation practice was 1788, 1738, 1937, 1793, and 1598 M3/ton for the growing season of 2016, 2017, 2018, 2019, and 2020, respectively. Moreover, under the impact of the experimental irrigation practice, the total WF was 1169, 1126, 1265, 1179, and 1043 m_3/ton for the same crop-growing seasons respectively. The mean values of the total WF were 2592 and 1692 m^3/ton for the farmers' irrigation practice and experimental irrigation practice, respectively; and the standard deviation values were 368 and 240 m^3/ton for the farmers' irrigation practice and experimental irrigation practice, respectively.

The total water footprint for wheat and barley under farmers' fields (FF) and experimental fields (EF) for five growing seasons is presented in Figure 4. The total WF of the wheat crop presented low variation among the five growing seasons. Where most of the WF values were very close to the mean values for both irrigation practices. However, the total WF of the barley crop showed higher variation among the five crop growing seasons compared to the WF of the wheat for both irrigation practices. The WF of the barley was higher than the WF of the wheat due to the low barley production. The WF results of both irrigation practices were comparable with the finding of Ewaid *et al.* (2019, 2020).

Farmers' irrigation practice consumes much higher water compared to experimental irrigation practice. Adding more irrigation water than the crop demand may keep the soil saturated for several days, which affects the soil aeration and as a result decreases crop development and production, which indeed increases the WF.

The crop water use efficiency (WUE) of wheat and barley over five growing seasons (2016 and 2020) is shown in Figure 5. Seasonal crop WUE varied between the irrigation practices due to the difference in applied irrigation water amount in each practice. Experimental practice produced better water use efficiency compared to the farmers' practice for both crops. Under the experimental irrigation practice, the average WUE of five growing seasons was around 0.9 and 0.6 kg/m^3 for wheat and barley, respectively. However, under the farmers' irrigation practice, the mean WUE of five growing seasons was around 0.6 and 0.4 kg/m^3 for wheat and barley, respectively. The WUE was increased under experimental irrigation practice by about

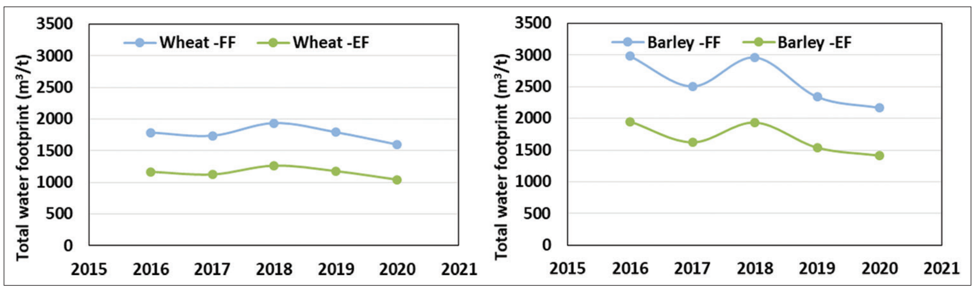

Figure 4: Total water footprint for wheat and barley under farmers' fields (FF) and experimental fields (EF) for five growing seasons of 2015-2020

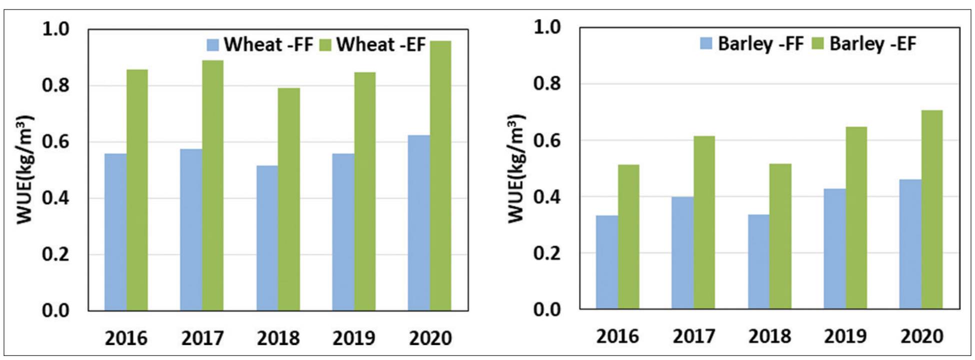

Figure 5: Water use efficiency of wheat and barley under farmers' fields (FF) and experimental field (EF) for five growing seasons of 2015-2020

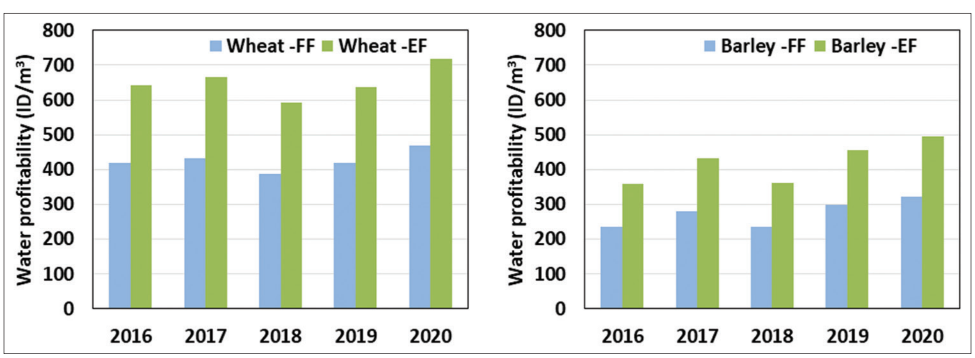

Figure 6: Water profitability for wheat and barley under farmers' fields (FF) and experimental field (EF) for five growing seasons of 2015-2020

35% compared to the farmers' irrigation practice. WUE is one of the best indicators of improving the productivity of applied irrigation water (Sarker *et al.*, 2016); which supports the expected benefits of following the experimental irrigation practice in the study area.

Figure 6 depicts the water profitability of wheat and barley for the west of Baghdad. Experimental irrigation practice yielded an increase of 35% ID/m^3 compared to the farmers' irrigation practice for the wheat and barley crops. Under the experimental practice, each m^3 of irrigation water yielded an average of 650 and 450 ID for wheat and barley, respectively. While, under the farmers' practice, each m^3 of irrigation water yielded an average of 425 and 294 ID for wheat and barley, respectively. The highest revenue was yielded in the growing season of 2020 for both crops due to the suitable weather conditions compared to the other growing seasons. Furthermore, the water revenue of wheat was found to be better than the water revenue of barley for all growing seasons due to that, the productivity of wheat is higher than the barley productivity in Iraq (Qader *et al.*, 2018).

CONCLUSION

This study aimed to determine whether it is possible to reduce the water footprint (WF) of wheat and barley and save more irrigation water in the western part of Baghdad, Iraq. To achieve the best irrigation management, the researchers compared experimental irrigation practices with those used by farmers. Information about crops, field management, and weather data was collected over a period of five years, from 2016 to 2020. The results of the study showed that the experimental irrigation practice achieved a 35% reduction in crop WF for both wheat and barley, while also improving crop yield, water use efficiency, and water productivity by 28%, 35%, and 35%, respectively. The study suggests that irrigating crops at 50% depletion of available soil water and then raising the soil water level to field capacity can be economically beneficial for farmers in the western area of Baghdad. To ensure the success of this approach, the government should support farmers with new irrigation and agricultural strategies and technologies to reduce the negative impacts on crop production and water resources in the study area.

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