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Research Article

Using Eight Crops to Show the Correlation between Paucity Irrigation and Yield Reduction of Al-Hussainiyah Irrigation Project in Karbala, Iraq

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Efficiency of water use in irrigation field always motivates researchers to find a way which could reduce irrigation quantity and obtain approximately the same crop yields. This study estimated the relationship between the paucity irrigation with the reduction in yield for eight crops (cotton, maize, alfalfa, small grain, summer vegetable, sesame, sunflower, and palms) by using various paucity irrigation stages from evapotranspiration of crops (5, 10, 15, 20, and 25%) as an indication of all crop outgrowth using medium soil. This study selected the project of Al-Hussainiyah irrigation that lies in Karbala province, which is close to Baghdad relative to the South. Also, the project has high importance because most dwellers have used the province for agriculture and drinking purposes. These are reasons of choosing it as a case study to implement paucity irrigation strategy on most crops (eight crops) within the project. The necessary records related to this study were obtained from specialized offices in Iraq, particularly water resources and agriculture ministries. Computer programs such as CROPWAT version 8.0, statistical program SPSS statistics version 20, and table curve 2D version 5.0 are considered the software for solving this model. This model was tested for its application and sensitivity by changing paucity levels for each crop. The comparison between the available and the estimated water demand showed that the paucity in irrigation water demand was very clear during the period from February to December for the average present state of agriculture. The correlation analysis gives a result that the paucity irrigation level with yield reduction manifested that the yield reduction rate of maize recorded higher than the other crops, while cotton recorded lower yield reduction rate than the other crops during all paucity stages.

1. Introduction

Paucity irrigation can be defined as the increasing water use efficiency (WUE) [1]. To combat the waste of water, the ratio of irrigation supply could be within 60–100% of full evapotranspiration (ET) [2]. In spite of many studies trialed to diminish the water used, irrigation efficiencies remain at a rate between 40 and 60% [3].

Generally, less than fifty percent of food annually comes from irrigated area [4]. In this case, water scarcity is prevailing in many parts around the world hand to hand with rapid increase of population and climate change, in addition to increased industrialization [5–7]. Paucity irrigation has been applied in many crops to save water and to achieve water use efficiency in crops such as *Phillyrea angustifolia* [7], *Beta vulgaris* L. var. cicla [8], sugar beet [9], maize [10–14], corn [15], wheat [16–19], potato [20–22], onion [23], cucumber [24], olive trees [25], almond [26], plum fruit [27], tomato [28], and other species.

Paucity irrigation was adopted using a different process such as dividing irrigation levels to three rates [8] or five soil water levels [21]. On the other hand, many researchers used models to show the best irrigation period with evapotranspiration rate (ET). Himanshu and Omani used a simulation model relative to the growing of cotton crop with efficiency of water use, and they selected northwest Texas in the United States for a case study [29]. They referred to the optimum stopping date of the irrigation period for a percentage of evapotranspiration replacement. About 85% evapotranspiration replacement irrigation planning with irrigation stopping date at 3rd week of September was recorded to be the best irrigation planning for cotton. Similarly, Klocke et al. referred to a comparison between a prediction model of crop yields with four-year field observations to calculate reference ET and irrigation and precipitation to calculate soil water balance [30]. They adopted one irrigation rate and five paucity irrigation treatment. This model can be adopted to (1) manage paucity irrigation, (2) predict crop yields, and (3) irrigation portion of selected crops.

The effect of paucity irrigation on yield by using different crops showed almost a negative linear relationship between them. Many studies focused on this relation. Klocke et al. referred to the relation between paucity irrigation and yield response of corn, and evapotranspiration and paucity irrigation schedules were executed during dry seasons, and also, paucity irrigation made more soil water to be extracted during the growing season [31]. The relation between crop evapotranspiration and yield response was linear, a quadratic relationship between irrigation and seed yields, but results showed increasing yield response against decreasing irrigation discharge. Similarly, Zaman et al. determined the effect of various paucity irrigation rates on yield and efficiency of water use for bed wheat [19]. Studies tried to convince upcoming researchers to go with adopting deficit irrigation as a better mechanism than other ways; however, they mentioned many limitations in their hypothesis such as selecting season and using some crop types for short periods.

A paucity irrigation method by adopting different levels of irrigation was selected by some researchers. Zaman et al. used four levels of irrigation to monitor the paucity irrigation outcomes, using 20% and 40% irrigation rate, which saved water by 14.30% and increased 15.66% seed yield; however, water discharge was 1.81 kg/m^3 to achieve full irrigation [19]. Similarly, Tarkalson and King chose eight irrigation cases including crop evapotranspiration with rates (100%, 65%, and 55%) [9]. Their results were the rate of expected recoverable yields increased at an average ranging from 17.3 to 22.0 kg/ha·mm current crop water evapotranspiration (Eta). Their conclusion that 100% crop evapotranspiration later had little yields consequently with large water stress in sugar beet. Similarly, Da Silva et al. used five levels of paucity irrigation (28%, 42%, 57%, 71%, and 85% of the crop coefficient value). A study evaluated Tifton 85 production, in which the greatest average yield (6126.35 $kg \cdot ha^{-1}$) was obtained through application of 71% Kc. Consequently, Gultekinand Ertek adopted one irrigation interval (5 days) with five levels of paucity irrigation, which was measured before 100, 85, 70, 55, and 40 irrigations during two years [21]. They noticed that 100 L had the highest yields of different parts of potato growing. Similarly, Tang et al. adopted three different irrigation levels (300 L, 200 L, and 100 L), and they mentioned that paucity irrigation using 200 L caused a decreasing yield of the plants less than using 100 L [8]. In addition, Tari used wheat in Central Anatolia, Turkey, by adopting four water paucity irrigation levels (0, 35, 65, and 100%), and these levels were used with different growth phases of wheat by using twenty-two test treatments [18]. He mentioned that the paucity in water significantly effected on wheat yield, quality, and water use efficiency with a varied rate on growth stage. Selecting different levels of irrigation can be considered one of the most indications of the rate of yield increasing, particularly when the recent studies used different crops, which were effected with each deficit irrigation level; however, they referred to some limitations such as the study period and volume of water.

A prediction model to show the behavior of paucity irrigation on different types of crops was used by some researchers. For example, Martínez-Romero et al. used a model of four types of potato in Spain during three years under paucity irrigation; their results were the increasing yield of the crop for different quantities of irrigation water [22]. Adopting the prediction model was used by many researchers at any field. Therefore, it is a suitable manner to go with models to show the relationship between deficit irrigation of some crops under specified conditions.

In this study, a prediction model was built to show the correlation between paucity irrigation and yield production by using software programs such as CROPWAT 8.0, program SPSS statistics version 20, and table curve 2D V5.0. This method tried to cover the gap search in the latest models, which solve the similar matters. To cover all necessary searches in the recent studies, we include eight types of crops involving four crops, which are for the first time to be used as a case study for showing the effect of paucity irrigation on these crops. Also, the study period extended to six years (2012–2018), which is considered the enough time, which is closer or higher than the other recent studies. All contemporary studies and models selected one crop as a case study; but in our study, we adopted eight different crops with a predicted model to estimate the required discharge for each crop by using five different paucity irrigations. Another reason why we select this model was because Raja mainly adopted CROPWAT 8.0 to estimate crop water needs, and he recommended using this model for future similar works [32].

2. Study Area

The project of Al-Hussainiyah irrigation locates downstream Al-Hindiya barrage, which is built on Euphrates river in the province of Babel; this project is running towards Iraqi south within Karbala province, by manmade efforts, and Al-Hussainiyah river divides to small canals and disappears when crossing small villages within Karbala province. The project was carried out on latitudes N 32° 36′–32° 48′ and longitudes E 43° 55′–44° 17′. Figure 1 shows the study period, which extended to twelve years from 2006 to 2018.

In general, arid climate is the dominant climate at the central region of Iraq. A summary of the average climatic parameters of the study for the period between 1990 and 2018 is given in Table 1.

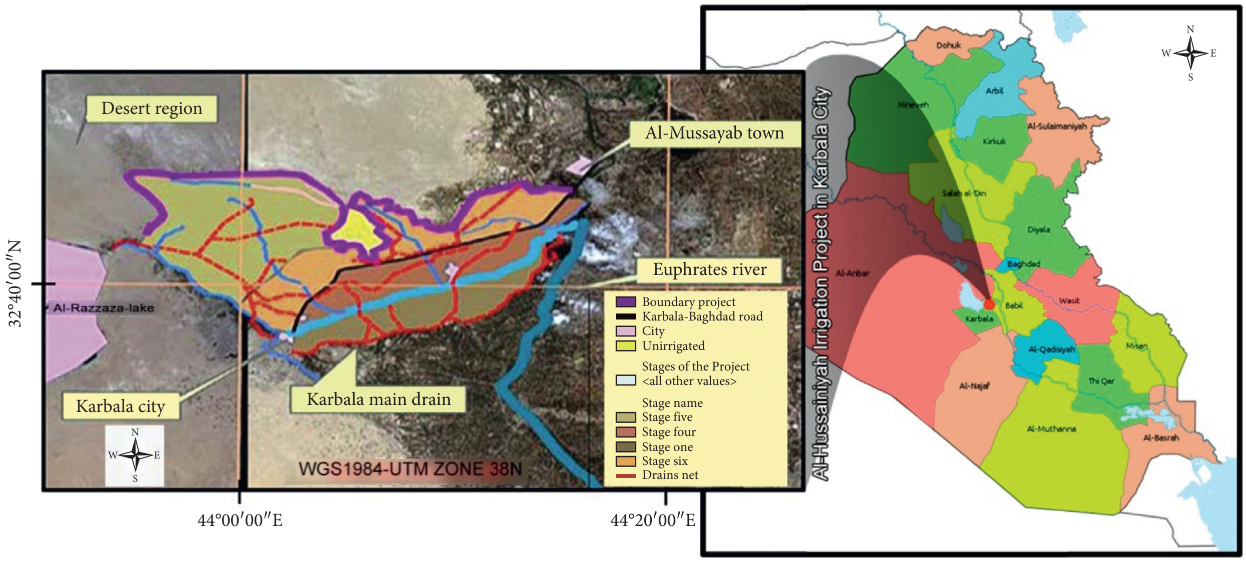

Figure 1: Al-Hussainiyah irrigation project [33].

Table 1: Summary of the average climatic parameters of the study area for the period between 1990 and 2018 [34].

Climatic parameter	January	February	March	April	May	June	July	August	September	October	November	December
Mean air temperature (°C)	10.5	13.2	17.8	24.4	30.2	34.7	37.0	36.7	32.5	26.1	17.5	12.1
Mean rainfall (mm)	16.9	13.9	10.2	12.3	1.9	0	0	0	0.4	2.8	9.6	14.1
Mean maximum air temperature (°C)	16.1	19.1	24.0	31.3	37.6	42.2	44.5	44.4	44.4	33.9	24.1	18.1
Mean minimum air temperature (°C)	4.8	7.4	11.5	17.6	22.8	27.2	29.5	29.0	24.6	18.2	11.0	6.2
Mean monthly evaporation (mm)	59.2	92.0	170	237.1	329.4	408.4	438.2	395.8	301.0	201.8	100.4	61.5
Mean relative humidity (%)	74.3	61.2	50.1	43.1	34.8	29.0	30.5	32.3	37.3	46.4	61.2	71.6
Mean sunshine duration (hr/day)	5.9	7.0	7.8	8.3	9.4	10.9	11.2	10.9	10.0	8.1	7.1	6.0
Mean wind speed at 2 m height (m/sec)	1.7	2.0	2.3	2.4	2.4	3.1	3.2	2.5	1.9	1.5	1.3	1.4

The main and branch canals were lining during the period 2011-2012. Therefore, conveyance efficiency (CE) of these canals increased. An overall CE equal 0.84 can be adopted for the period beyond 2010. This efficiency was obtained by taking the CE 0.99, 0.98, 0.94, and 0.92, respectively, for the four levels of canals [35].

3. Methodology and Data

3.1. Crop Consumptive Use. To calculate crop consumptive use, we should calculate crop evapotranspiration (ETo), which relies on climatic features and can be calculated from weather parameters, such as temperature relative humidity and pressure. The method of Penman–Monteith to calculate ETo is shown in the following equation [35]:

$$\mathrm{ETo} = 0.408\,(\mathrm{Rn} - G) + \gamma\, 900\, T + 273\mathrm{U2}\,(\mathrm{es} - \mathrm{ea})\Delta + \gamma\,(1 + 0.34\mathrm{U2}), \quad (1)$$

where ETo is the reference crop evapotranspiration ($\mathrm{mm{\cdot}d^{-1}}$), Rn is the net radiation at the crop surface ($\mathrm{MJ{\cdot}m^{-2}{\cdot}d^{-1}}$), G is the soil heat flux ($\mathrm{MJ{\cdot}m^{-2}{\cdot}d^{-1}}$), T is the average air temperature (°C), U2 is the wind speed measured at 2 m height ($\mathrm{m{\cdot}s^{-1}}$), (es – ea) is the vapor pressure deficit (kPa), i.e., the difference between the saturation vapor pressure (es) and the actual vapor pressure (ea), γ is the psychometric constant (kPa/°C), and Δ is the slope of the vapor pressure versus temperature curve (kPa/°C). Use of crop consumptive or actual ET is typically estimated from

$$\mathrm{ET} = \mathrm{EToKc}, \quad (2)$$

where ET is the rate of using crop consumptive (mm/month), ETo is the reference evapotranspiration, and Kc is the crop coefficient, which depends upon crop type, stage of growth, and location (latitude in particular) [35].

While, information related to field irrigation efficiency of the system (IE) is essential to alter ET as a net irrigation water requirement (NIWR), the gross irrigation water requirement (GIWR) is measured by using depth per month [35]:

$$\mathrm{GIWR} = \sum \mathrm{ET}\,(\mathrm{NIWR})\mathrm{IEn}, \quad t = 1, \tag{3}$$

where t is the changes from 1 to n months of the life cycle for a plant. To calculate the monthly irrigation requirements measured as volume of water for each month,

$$\mathrm{TIWR} = \sum\sum \mathrm{GIWRjt} * \mathrm{Ajtr}, \quad \mathrm{j} = 1n,\ t = 1, \tag{4}$$

where GIWR denotes the quantity of irrigation water/unit area for every crop (j) in month (t), and (A) denotes the cropped area of each crop (j) in month (t).

Requirements of discharge at the head of the main canal can be given as

$$\mathrm{QT} = \mathrm{TIWR}\,\mathrm{CE}, \tag{5}$$

where CE is the conveyance efficiency, written as a percentage and QT is the total discharge utilized in the project head regulator in cubic meter per second.

Many studies used the FAO 56 Penman–Monteith approach to estimate ETo. [36] used this method in ChiaNan Irrigation Association, Taiwan, to estimate irrigation water requirements and reference evapotranspiration for different crops (paddy, soybean, upland crops, and rice crops); however, our study used another types of crops with different climate conditions and study periods [37]. Other studies used the Penman–Monteith method to estimate crop evapotranspiration [38, 39]. Although the Penman–Monteith model was used in the last two decades, Bai et al., adopted this model to estimate canopy transpiration (Ec) and soil evaporation (Es) in their new model to estimate evapotranspiration by using satellite data over a river basin in China [40].

3.2. Yield Response Factor. Doorenbos and Kassam derived an empirical equation related to the yield response factor (Ky) for individual outgrowth levels and also for the period of total growing [41]:

$$(\mathrm{Ya}/\mathrm{Ym}) = \mathrm{Ky}\,(1 - \mathrm{DI} * \mathrm{ETa}/\mathrm{ETm}), \tag{6}$$

where Ym is the maximum expected yield, which is obtained from utilizing full irrigation stage for every outgrowth level of the crop life (kg/ha), Ya is the expected rate of existing yield (kg/ha), and Ky is the yield response parameter of the crop for the outgrowth level. It shows the degree of the growth level sensitivity to water paucity. ETm is the maximum ET at the outgrowth level. ETa is the existing ET at a level. DI is the suggestion of the paucity irrigation level.

3.3. Crops within Al-Hussainiyah Irrigation Project. The current cropping pattern data were obtained from agriculture office in Karbala related to the study area. From the information related to the present crop pattern (2006–2018), this study has three cropping seasons, such as winter, summer, and perennial. The main winter season crops are wheat, barley, and winter vegetables. Maize and summer vegetables are the dominant summer crops, whereas the orchards, palms, and alfalfa are the dominated perennial crops. Values of the yield response factor (Ky) for crops related to the project of Al-Hussainiyah irrigation are listed in Table 2.

The crop coefficient ($\mathrm{K_C}$) integrates the effect of characteristics that distinguish a specific crop from the reference crop. The coefficient Kc for the crops grown in the project of Al-Hussianiyah irrigation as suggested by the general scheme of the MOWR for the middle of Iraq [35] is listed in Table 3 [34]; however, some studies used Kc values from FAO recommendation [43], and also, Langeroodi et al. assumed Kc magnitudes relative to the FAO-56 [44]. These studies used the same method for selecting Kc. On the other hand, our study used Kc by adopting twelve recorded magnitudes at every month, which give higher accurate results than the previous studies because of two reasons: (1) many researchers did not use more than two values of Kc, such as [45–48] who used single Kc, whereas [49–51] adopted dual $\mathrm{k_c}$, and (2) this study choose a new method by going with recommendations of the ministry of irrigation. In addition, methodology of selecting Kc differs on others and could be due to the following reasons: (1) study period was different between this study and others and (2) the variance in climate conditions [51, 52], irrigation methods [53], physical properties of plants [54, 55], and also quantity of soil evapotranspiration [47].

(Kc) magnitudes of the eight crops abovementioned in Table 3 are close to other Kc values, which are estimated in different crops. For example, average Kc magnitude for orange trees varied between 0.91 and 0.75 during different seasons at the whole year [50] and for rice between 0.1 and 1.2 [56]. By comparing Kc magnitudes (Table 3) with other studies, relative to the increasing in magnitudes of crop coefficients from initial months to the last months of a year, [36] referred that Kc of corn was increasing during the initial, midseason, and late-season stages, respectively; however, both sorghum and soybean were fluctuated up and down throughout their study period [37]. Both Kc values of [37] and in Table 3 have the same behavior, where maize, small grain, sunflower, cotton, sesame, and summer vegetables started from (0.0) in the initial months, and after that, they increased to selected values and then recorded to (0.0), which are relatively similar to Kc behavior magnitudes of corn, sorghum, and soybean [37]; however, both Kc magnitude forms of orchards palms and alfalfa are different of the corns [37]. These similarities and differences between both studies could be due to the difference in climate conditions, irrigation method, study period, and planting and harvesting dates.

3.4. Crop Data. The planting and harvesting patterns data (Table 4) were obtained from the general scheme of the MOWR for the central zone of Iraq [34]. According to MOWR, the recommended irrigation efficiency is 64% [57].

Data of soil physical parameters, such as soil texture and depth, infiltration rate, the available soil moisture, and bulk density, (Table 5), are required to estimate the total available water in the area of root zone and the irrigation plan.

Table 2: Values of the yield response factor (Ky) for crops related to the project of Al-Hussainiyah irrigation [42].

Crops	Ky			
	Initial	Development	Midseason	Late
Maize	0.4	0.4	1.3	0.5
Cotton	0.2	0.5	0.5	0.25
Sunflower	0.4	0.6	0.8	0.8
Sesame	0.4	0.6	1.25	0.8
Small grain	0.4	0.6	1.25	0.8
Summer vegetables	0.8	0.4	1.2	1
Palms	0.8	0.8	0.8	0.8
Alfalfa	0.7	0.9	0.8	0.7

Table 3: Values of the crop coefficient, Kc, for crops of Al-Hussainiyah irrigation project [34].

ID	Crops	January	February	March	April	May	June	July	August	September	October	November	December
1	Maize	0.00	0.00	0.58	0.82	1.08	0.80	0.00	0.00	0.00	0.00	0.00	0.00
2	Cotton	0.00	0.00	0.00	0.54	0.64	0.80	0.98	0.82	0.49	0.00	0.00	0.00
3	Sunflower	0.00	0.00	0.58	0.68	0.84	1.02	0.49	—	—	—	—	—
4	Sesame	0.00	0.00	0.00	0.00	0.52	0.70	0.94	0.75	0.40	0.00	0.00	0.00
5	Small grain	0.00	0.00	0.00	0.55	0.67	0.90	1.00	0.60	0.00	0.00	0.00	0.00
6	Summer vegetables	0.00	0.00	0.58	0.67	0.79	0.93	0.95	0.76	0.46	0.00	0.00	0.00
7	Orchards palms	1.00	1.05	1.05	1.00	0.95	0.95	0.85	0.85	0.80	0.80	0.85	0.95
8	Alfalfa	1.10	0.98	0.94	0.92	0.90	0.89	0.89	0.89	0.89	0.89	0.94	1.14

Table 4: Dates of planting and harvesting for considered crops in Al-Hussainiyah irrigation project [31].

ID	Crops	Planting date	Harvesting date
1	Maize	11/3/2017	5/7/2018
2	Cotton	1/4/2016	10/9/2016
3	Sunflower	21/3/2015	31/7/2015
4	Sesame	1/5/2017	10/9/2017
5	Small grain	6/4/2014	15/8/2014
6	Summer vegetables	21/3/2012	30/9/2012
7	Orchards palms	Perennial	
8	Alfalfa	Perennial	

Table 5: Main soil characteristics [37, 56].

No.	Soil name	Medium (loam)
1	Total available soil moisture (mm/meter)	290
2	Maximum rain infiltration rate (mm/day)	40
3	Maximum rooting depth (cm)	900
4	Initial soil moisture depletion (as % TAM)	0
5	Initial available soil moisture (mm/meter)	290

These data were collected from [35, 56]. Discharge amount, which supplied to the project head during the period 2006–2018, was collected from the related directorates of Ministry of Agriculture, 2013 [56], Table 6.

3.4.1. Water Consumption of Present State. Evapotranspiration is the basic factor in determining the irrigation water requirement. ETo is computed using the CROPWAT (8.0) program according to modified FAO Penman–Monteith equation (1) and climatic parameters, Table 1.

The crop water requirement (CWR) was calculated based on the ETo, the crop coefficient (Kc), and the crop characteristics, i.e., cropping pattern and growth stages, equation (2). However, other studies used different models to estimate net irrigation requirement and irrigation demand, particularly the growth model (EPIC) [38]; however, the EPIC model involved wide scale of areas in Europe and Switzerland.

The monthly CWR can be estimated based on the climatic data, main characteristics of present state of agriculture (Ky), crop coefficient (Kc), planting date of each crop, and development stages.

After subtracting the effective rainfall from the CWR and adopting irrigation efficiency of 64%, the NIWR is determined by using equation (3).

Requirements of discharge at the head of the main canal for an average present state (2006–2018) were estimated using equations (4) and (5) adopting using $CE = 0.84$.

Calculation of net irrigation water requirement (NIWR) differs from another approach, which was depended by Smith [58]; he estimated net irrigation requirement per unit area (mm/day), but this study preferred another way, which used net irrigation requirement as a discharge (cubic meter/second). However, both our study and [57] used the CROPWAT approach, which is the same method, but we used CROPWAT 8.0, which is newer than (Smith) [51]. The reason behind choosing this approach rather than the others could be that the approach of [51] was used by another researcher to estimate net irrigation requirement for rice crop [56], whereas this study includes seven different crops without using rice. In addition, Kuo et al. used the same model CROPWAT to estimate the irrigation water requirements in Taiwan for paddy and upland crops, but we

Table 6: Available discharge m^3/sec at the head of the project [56].

No.	Months	Discharge 2012	Discharge 2013	Discharge 2014	Discharge 2015	Discharge 2016	Discharge 2017	Discharge 2018
1	January	11.60	10.00	5.00	5.32	5.67	9.00	12.00
2	February	10.00	11.40	6.03	5.53	7.71	5.70	12.00
3	March	16.19	13.06	5.64	6.70	8.00	7.70	13.29
4	April	17.60	15.90	12.50	12.16	13.23	11.00	15.36
5	May	19.19	17.60	19.84	16.10	16.22	20.00	16.51
6	June	20.00	14.66	18.70	19.50	18.00	20.00	27.80
7	July	18.87	20.00	20.00	19.94	17.74	22.70	28.68
8	August	17.10	20.00	13.87	14.20	16.80	23.63	25.87
9	September	19.00	19.16	9.50	13.13	12.10	16.30	17.10
10	October	10.96	12.30	5.00	11.41	10.40	12.00	12.00
11	November	10.00	5.00	5.67	7.66	7.00	12.00	12.00
12	December	10.00	5.96	4.70	4.20	11.22	12.00	12.00

used a new version of the program CROPWAT 8.0, and they estimated the requirements for both spring and fall seasons only [36]. However, they should mention to the other seasons. Also, this study depended on the irrigation depth instead of discharge to mention the irrigation required.

3.4.2. Correlating Paucity Irrigation with Yield Reduction. The CROPWAT 8.0 computer program was adopted to compute the monthly irrigation demand by using planned software module. The ETc reduction per every stage was the CROPWAT option, which selected irrigation scheduling, and irrigation is almost working by refilling soil to field capacity (FC). This explains that the percentage of ETc was focused on the stage. In this study, we have eight crop types (maize, cotton, sunflower, sesame, small grain, summer vegetables, alfalfa, and palms) during summer season, while the soil of the project is medium. According to the deficit level, which is selected according to the deficit in the irrigation demand, and considering the climatic parameters, cropping patterns for summer season, Ky for each crop, Kc, date of crop planting and harvesting over the year, and the percent of yield reduction for each crop can be estimated using equation (6).

3.4.3. Model Analysis. In order to analyze the sensitivity of the model, six scenarios for each crop were used. They were based on changes in paucity irrigation levels. The scenarios are as follows:

(1) Apply full irrigation stage, which corresponds to critical depletion (S_0)

(2) Apply irrigation at crop evapotranspiration by a reduction of 5% at this stage (S_1)

(3) Apply irrigation at crop evapotranspiration by a reduction of 10% at this stage (S_2)

(4) Apply irrigation at crop evapotranspiration by a reduction of 15% at this stage (S_3)

(5) Apply irrigation at crop evapotranspiration by a reduction of 20% at this stage (S_4)

(6) Apply irrigation at crop evapotranspiration by a reduction of 25% at this stage (S_5)

The reason behind choosing these scenarios was many recent studies adopted different stages of the irrigation reduction, which gave them excellent results as shown in the literature above (Section 1). In addition, these rates can be implemented within the study area.

3.5. Summary of Methodology. Mechanism of the study implemented across many steps could summarize it by the following flowchart for each crop, as shown in Figure 2.

4. Results and Discussion

After explaining the main climatic features, estimating results of ETo are calculated by using CROPWAT software (Table 7).

The estimated values of ETo, Table 7, show that ETo are low during the period from January to April, but ETo increased from May to September, which reached to a maximum value of 320.65 mm in July month. Minimum monthly value of 47.23 mm was recorded during January and decreased during October–December months. This change in ETo magnitudes is attributed to combine effects of specified parameters such as change in temperature, sunshine hours during different seasons, radiation effects, wind speed records, and humidity rates. The estimated average requirements of discharge at the head of the main canal for the period from 2012 to 2018 (Figure 3).

The average required discharge exceeds the average available discharge by approximately 25% at the head of project during all months except January.

The estimated maximum deficit (25%) was divided into five levels: 5, 10, 15, 20, and 25%. These deficit levels were used to estimate the yield reduction for each crop.

The estimated yield reduction according to the computed monthly irrigation demand by using a schedule module for the considered eight crop kinds (maize, cotton, sunflower, sesame, small grain, summer vegetables, alfalfa, and palms) in the project during summer is given in Table 8. During the study period, we noticed that available irrigation discharges are less than the required irrigation discharges except January. Therefore, studies focused on the relationship between deficit irrigation and yield reduction which becomes very important to show how deficit irrigation will

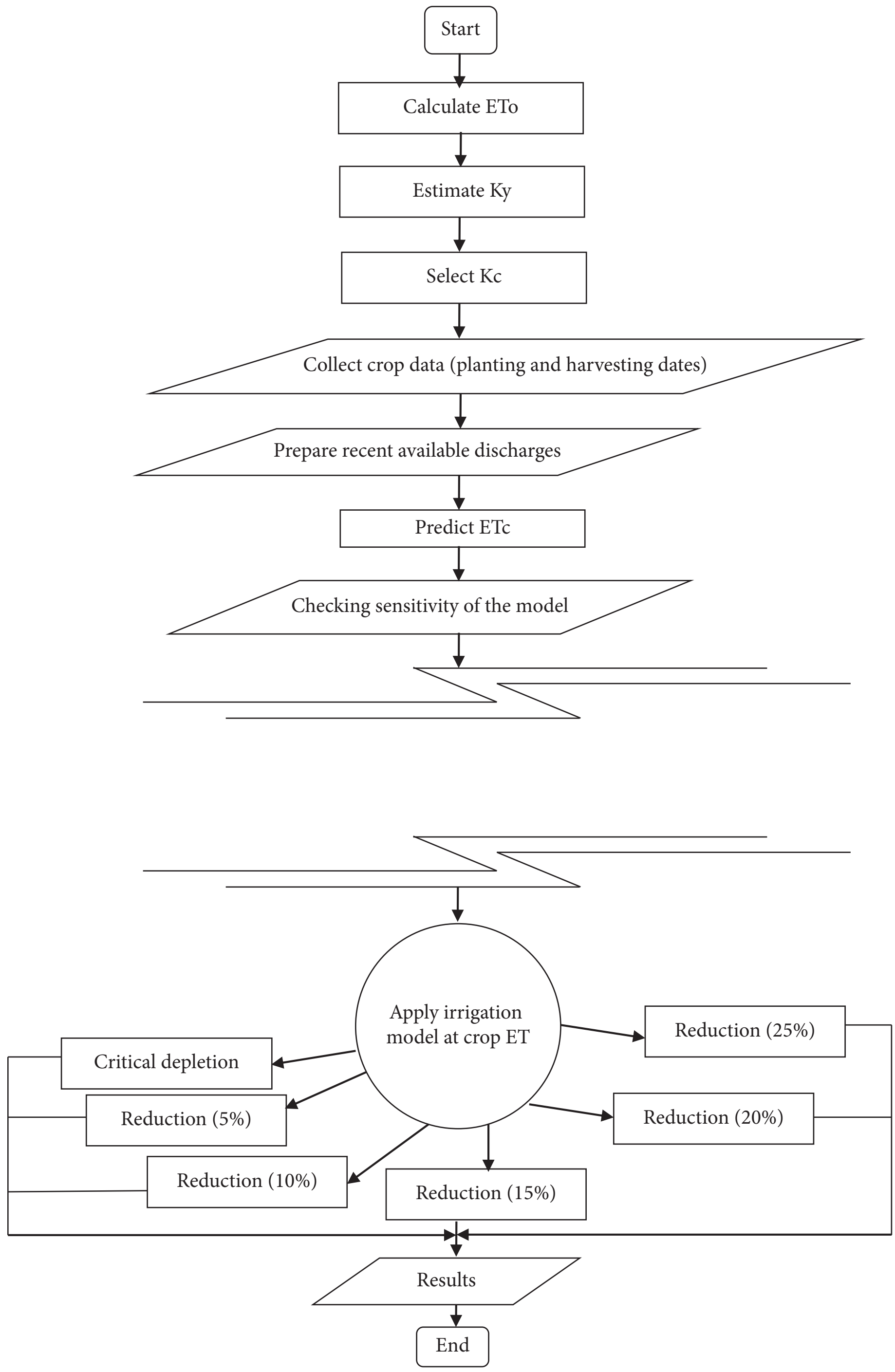

Figure 2: Flow chart of methodology for each crop.

have effect on the production of crops. Many researchers tested different types of crops individually to show the effect of deficit irrigation on that crop only by studying the effect of deficit irrigation on the properties of the crop related to grain, straw, and the highest of net return. For example, Ali et al. studied the effect of deficit irrigation on wheat, and they did not find a high effect on grain and straw when they were tested under different cases of deficit irrigation [16]. Also, they suggested a suitable way to support the economic. This study focused on one type of crop; however, there are other types, in which some of them should be selected to test it hand to hand with wheat crop to give us the clear idea on other crops.

These results were adopted to show the relationship between paucity irrigation and yield reduction for every crop type for the medium soil. The SPSS results (Table curve 2D V5.0) were adopted for this purpose, Figure 4.

Figure 4 clarifies that it has different relationships between paucity irrigation and yield reduction for crops, and there are two groups of crops that appear clearly when using

Table 7: Input climate features data and estimated results of ETo for Al-Hussainiyah project

Country: Iraq		Latitude 32.00 N				Station Al-Hussainiyah Longitude 44.00 E	
Altitude: 28 m Month	Minimum temperature (°C)	Maximum temperature (°C)	Humidity (%)	Wind (m/s)	Sun hours	Radiation (MJ/m^2/day)	ETo (mm/month)
January	4.7	16.1	74	1.6	5.9	10.9	47.23
February	7.4	19.1	61	1.9	6.6	13.7	67.48
March	11.5	24.0	51	2.3	7.8	17.9	120.77
April	17.6	31.3	43	2.4	8.4	21.1	171.03
May	22.8	37.6	34	2.4	9.4	23.8	230.54
Jun	27.2	42.2	29	3.0	10.8	26.2	288.10
July	29.4	44.5	30	3.2	11.1	26.4	320.65
August	28.9	44.4	32	2.5	10.8	24.9	278.32
September	24.6	40.4	37	1.9	9.9	21.4	202.80
October	18.2	33.9	46	1.5	8.1	16.2	137.33
November	11.0	24.1	61	1.3	7.2	12.6	75.05
December	6.2	18.3	72	1.3	6.0	10.3	48.77
Average	17.5	31.3	47.5	2.1	8.5	18.8	165.7

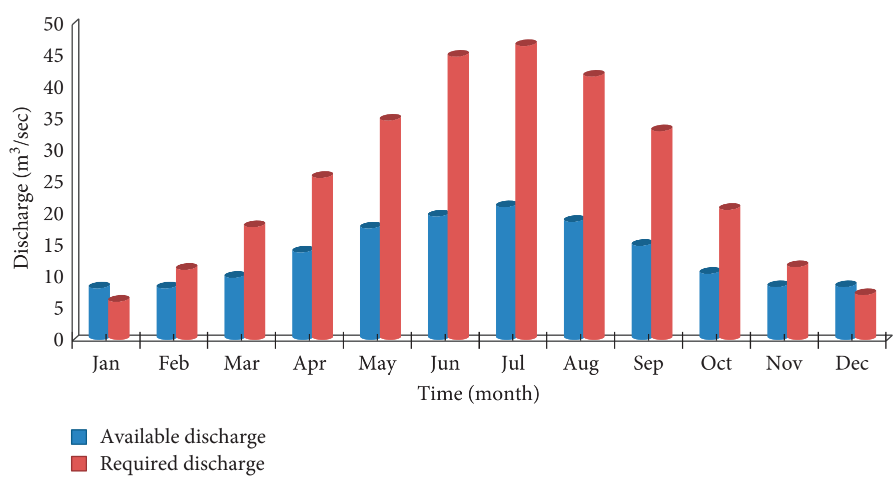

Figure 3: Requirements of discharge at the head of the main canal for the period from 2012 to 2018.

Table 8: Estimated yield reduction % with total gross irrigation (mm) in medium soil.

ID	Crop	*S*0		*S*1		*S*2		*S*3		*S*4		*S*5	
		Yield reduction (%)	Total gross (mm)	Yield reduction (%)	Total gross (mm)	Yield reduction (%)	Total gross (mm)	Yield reduction (%)	Total gross (mm)	Yield reduction (%)	Total gross (mm)	Yield reduction (%)	Total gross (mm)
1	Maize	0.0	1066.8	6.5	1048.4	9.7	724.3	15.2	765.5	22.1	806.4	31.4	844.9
2	Cotton	0.0	1738.9	4.3	1555.0	6.0	1071.5	10.2	1128.0	14.9	1170.6	19.8	1203.9
3	Sunflower	0.0	1152.7	4.5	1229.8	6.6	870.2	11.7	940.4	17.0	996.5	23.8	513.7
4	Sesame	0.0	1286.8	5.4	1311.3	8.5	1042.3	14.2	1113.3	20.5	1165.4	21.0	800.8
5	Small grain	0.0	1371.8	5.0	1280.5	10.1	901.6	11.6	946.0	17.2	984.4	23.2	1012.8
6	Summer vegetables	0.0	1934.6	6.0	1861.9	10.7	1724.9	15.3	1483.1	20.0	1377.7	25.6	1241.9
7	Alfalfa	0.0	2658.4	5.0	2384.4	10.9	2556.6	14.0	1977.7	20.3	2085.1	27.6	2175.3
8	Palms	0.0	2521.9	4.1	1959.9	7.2	2128.1	11.8	2251.6	13.7	1573.6	16.5	1628.8

the range of deficit is 5–25%. The first group includes cotton and sunflower crops, while the second group contains maize, sesame, small grain, summer vegetable, alfalfa, and palms. The portion of yield reduction at the first group was less than the second for the paucity irrigation less than 25%; when applying deficit higher than 25%, the yield reduction increases rapidly. Yield reduction rate of the maize crop was the highest at all deficit irrigation levels, whereas cotton has

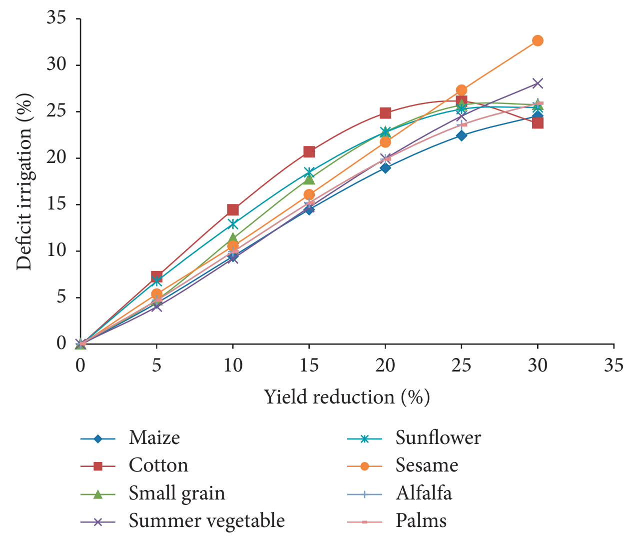

Figure 4: Deficit irrigation against yield reduction for eight crops in medium soil.

the least reduction rate at any level. Similarly, most researchers tried to show the relation between deficit irrigation and yield reduction, but they did not choose many crops. For example, Klocke et al. adopted corn to test the yield response with crop evapotranspiration [31]. They found a linear relation between crop evapotranspiration and yield response; however, the relation between irrigation and seed yields was quadratic. They should use more than one type to see what are the similarities and differences between them and/or which one is the highest and the lowest. In addition, Da Silva et al. tested Tifton 85 grass relative to the production rate, particularly dry matter production, leaf/stem ratio, height, dead plant material, and leaf properties including (1) area index and ratio, (2) leaf weight ratio, and (3) specific leaf area. They did not mention to any effect on these variables except when crop coefficient (Kc) was equal to 71%. Another study also used wheat crop in Turkey to know the effect of deficit irrigation on crop parts reactions such as (1) growth of stem elongation and heading and (2) milk stage [18]. However, these studies focused on one crop like the other studies. Also, Gultekin and Ertek selected potato with different deficit irrigation levels to verify which irrigation volume is the best to use corresponding to the optimum of water use efficiency; however, selecting one type of crop is still not valid to take a decision about the relation between deficit irrigation and production [21].

On one other hand, some studies used one crop such as cotton to know which was the best time to stop irrigation with a decreasing rate of evapotranspiration replacement irrigation (Himanshu and Omani), but they did not include other crops to verify the best time to other crops [29].

On the other hand, some studies tried to explain the effect of deficit irrigation on chemical contents of the crop. For example, Eissa and Roshdy selected maize to show the best rate of nitrogen quantity by using two various deficit irrigation; however, they did not select more than one to show the similarities and differences between them relative to nitrogen and/or other parameters by choosing many deficit irrigation levels [13]. Similarly, Zaman et al. used one crop (bed wheat) to show the effect of four deficit irrigation levels on the properties of the plant, such as height, grain yield, and spike per meter square, which means they did not mention to other crops relative to their properties when using different stages of irrigation water [19].

Other researcher used *Beta vulgaris* L. var. cicla as a case study to test the effect on different irrigation stages on chemical parameters of plant by using different irrigation stages [8].

By contrast, some types of sunflower did not show the high effect on deficit irrigation levels, but they mentioned to seed yield of sunflower and not the total general yield. However, they referred to some types which were effective, but the others were not [42].

By reviewing the contemporary studies, this study includes four types of crops: (1) small grain, (2) summer vegetable, (3) alfalfa, and (4) palms, which are considered for the first time to be used for showing the effect of deficit irrigation on yield reduction.

Figures 5 and 6 illustrate the relationship between the average and maximum, minimum deficit irrigation, and yield reduction, respectively, for medium soil. Similarly, Martínez-Romero et al. referred that yield reduction increased when deficit irrigation increased; however, they used a model using four types of one kind of crop (potato) during three years, but they used different irrigation water levels [22].

According to the FAO 56, application of the yield response factor Ky for planning, designing, and operation of irrigation projects allows quantification of water supply and water use in terms of crop yield and total production for the project area. Under conditions of limited water distributed equally over the total growing season, involving crops with different Ky values, a crop with higher Ky value will suffer a

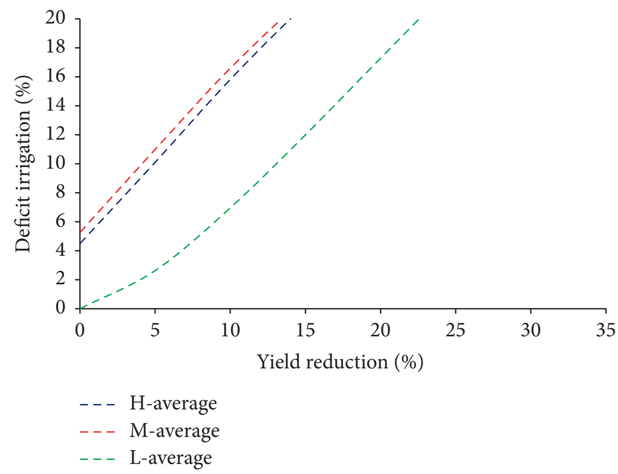

Figure 5: Average deficit irrigation and yield reduction of the eight crops for height, medium, and light soil relative to all crops.

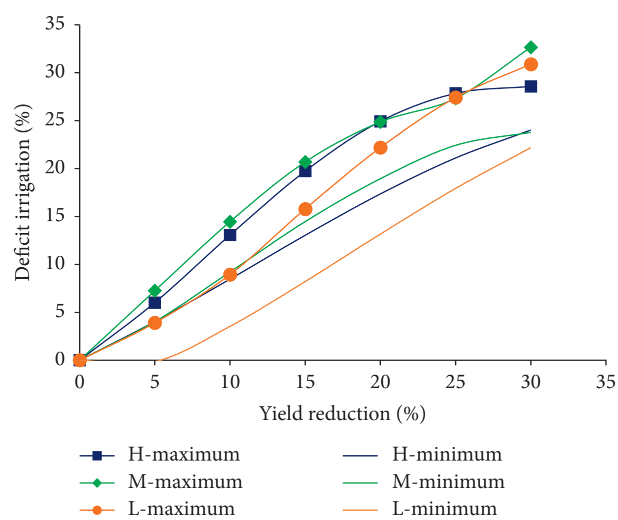

Figure 6: Maximum and minimum deficit irrigation against yield reduction for height, medium, and light soil relative to all crops.

greater yield loss than the crop proportional to a lower Ky value.

5. Conclusions

This study showed the relationship between paucity irrigation and yield reduction for eight crop types within AL-Hussainiyah irrigation project in Karbala city, Iraq. Five different deficit irrigations were tested for all eight crops during the study period, which extended for five years. The most important result is that all crop yields were affected by decreasing irrigation water within all the five stages of deficit irrigation; however, both cotton and sesame were highly effective than the others, whereas maize was less effective than the others. Overall, the relation between deficit irrigation and yield reduction was positive nonlinear. From these results, we can conclude that all crops with AL-Hussainiyah irrigation project could be affected negatively by reducing irrigation discharge; however, we can depend on maize crop to adopt deficit irrigation strategy in summer seasons where there is a lack of irrigation water because of no rain at this season in Iraq. Although there are many studies which focused on the effects of deficit irrigation on yield, this study is considered as the first try to test more than one crop at the same time and showing the relations between them and which crop suffered more than the others and which one can adopt instead of the others.

Data Availability

The data used to support the finding of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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