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Examining Crop Yield Losses in Iğdır Plain Irrigation Systems in Türkiye Amidst Water Constraints

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Abstract: Water stands as a crucial component of agricultural production. This study aims to propose water efficiency measures in agriculture as an essential element for climate change adaptation. In this study, yield losses in staple crops in agricultural regions are analyzed by using the most suitable methodologies, particularly in agriculture-reliant developing nations. Furthermore, this study seeks to determine the financial consequences of such losses. The methodology applied for this purpose was implemented in Türkiye's Iğdır Plain, selected as the study site. As the first step, the yields of the first three most cultivated products in each product group were assessed under normal climatic conditions in terms of their crop water requirements and irrigation water requirements. Subsequently, the irrigation water supply was reduced by 10%, and the resulting yield losses were calculated per hectare. Then, the overall crop losses after applying the 10% water constraint were determined in the total cultivation area. Among the crops cultivated in the region, the analysis reveals that clover from the field crops category exhibits the highest water dependence, while apricot demonstrates the least reliance on water resources. As a result, the recommended crop rotation for the Iğdır Plain under water constraints comprises wheat, apricot, watermelon, maize, melon, apple, tomato, peach, and clover. The following measures are proposed to ensure sustainable use of water resources and reduce exposure to climate change: increasing the water transmission efficiency and water use efficiency in irrigation areas, allocating more space to water-stress-resistant crops in the crop pattern in basins, and substituting crops requiring excessive water with less water-dependent crops.

Keywords: climate change; agricultural irrigation; water dependence; water efficiency

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Citation: Karaaslan, Y. Examining Crop Yield Losses in Iğdır Plain Irrigation Systems in Türkiye Amidst Water Constraints. *Sustainability* **2024**, *16*, 5859. https://doi.org/10.3390/su16145859

Academic Editors: Man Li, Tingju Zhu and Wenchao Xu

Received: 21 April 2024
Revised: 3 July 2024
Accepted: 4 July 2024
Published: 9 July 2024

1. Introduction

The rising global population also increases the demand for agricultural products and food [1–3]. On the one hand, climate change-induced risks and uncertainties are on the rise; on the other hand, simultaneous urbanization and industrialization trends are exerting pressure on agricultural production, impacting environmental integrity, soil health, and water resources [4–9]. This pressure on natural resources and the environment is intensifying both in quantity and quality [10,11]. Conversely, natural resources and the environment represent scarce factors of production [12]. The resilience and resistance of these resources have reached a critical threshold, which is being surpassed in numerous regions worldwide.

Recent climate change events such as droughts, public health crises like epidemics [13], and conflicts and crises impacting food security have increased the importance of agricultural production within the natural environment. Currently, agriculture emerges as a strategic sector irrespective of a country's level of development. The growing population and the declining quality of agricultural areas, the natural environment, and water resources transform agricultural production into a sector that not only contributes to production but also influences economic [14], social, and political decision-making [15] processes.

Attention is directed to awareness, efficient and appropriate use, and protection of natural resources and the environment to ensure a supply that can meet the increasing demand. Moreover, novel technologies are developed in this sector. Finally, the water economy has gained greater significance due to water being subject to sectoral competition.

Agricultural irrigation involves satisfying crop water demands through artificial methods when natural precipitation is insufficient for the crops to complete their development under natural circumstances [16]. To comprehensively characterize all the aspects of the water supply chain for agricultural irrigation, it is essential to gather all the relevant data and assess the current situation of the irrigation area accordingly. This assessment involves evaluating the current water efficiency in irrigation practices, predicting potential leakages, losses, and other interruptions, and identifying any issues within the system. The ratios outlined below are utilized to evaluate water efficiency in irrigation areas [17].

The water efficiency rates were derived from a manual crafted by the Directorate General for Water Management, operating under the Ministry of Agriculture and Forestry in Türkiye, a predominantly agrarian country. Positioned within the semi-arid climatic belt, Türkiye has increasingly felt the adverse impacts of climate change on its water resources, particularly in recent years. Consequently, institutions have rallied their capacities to address this pressing concern.

$$\text{Water Transmission Efficiency (Ec, \%)} = \text{Vp}/\text{Vs} \times 100 \tag{1}$$

where

Vp (m^3/year) = delivered to the irrigation area, with the water transmission line by the total water volume

Vs (m^3/year) = measured at the beginning of the transmission line

$$\text{In-field application efficiency (Ef) (\%)} = \text{Ve}/\text{Vp} \times 100 \tag{2}$$

where

Ve (m^3/year) = water used by plants during the evapotranspiration process

Vp (m^3/year) = volume reaching the irrigation area

$$\text{Irrigation Efficiency (IE) (\%)} = \text{PWD}/\text{SIV} \times 100 \tag{3}$$

where

PWD = the total plant water demand

SIV = the amount of water abstracted into the network from the water resources

This ratio is the ratio of the total irrigation water demand of the crops to the amount of water taken from the water source to the network:

$$\text{Water Productivity Wp (kg/m}^3\text{)} = \text{Cp}/\text{Wu} \tag{4}$$

This ratio is calculated by dividing the yield of the irrigated crop (Cp) (kg/ha) by the actual irrigation water used (Wu) (m^3/ha). Following the assessment of water use productivity, the next step is to outline the anticipated developments in the future, essentially defining the objectives and establishing the initial measures required to achieve these goals.

The general approach here is to determine key performance indicators (KPIs) that will aid in monitoring the increase in productivity over time. While determining the KPI values, first, the current values are calculated, and then the targeted values are established by employing pertinent criteria, which can be adopted from the best international technologies and practices. Some appropriate KPIs are provided in Table 1 [17].

Appropriate KPIs aimed at enhancing irrigation efficiency and addressing climate change and droughts can vary depending on the country, irrigation systems, and the characteristics of the irrigated areas. Regardless of the indicators employed, KPIs are designed according to the principle of efficient water use and in line with the policies of the corresponding countries.

Table 1. Key performance indicators for agricultural irrigation [17].

Key performance indicators for water production and transmission performance	Abstraction Performance (%)	The ratio of the water volume at the beginning of the transmission line to the water volume abstracted from the resource (×100).
	Transmission Performance (%)	The ratio of water directed for irrigation to the water volume at the beginning of the transmission line (×100).
	Water Losses Per the Length of Infrastructure (m^3/km)	The ratio of the volume of water loss to the length of the pipeline (ducts or pipes).
	Water Losses Per Irrigation Area (m^3/ha)	The ratio of the amount of water loss to the surface area of the irrigation area served.
Key performance indicators for irrigation and agricultural performance	Crop Water Demands (m^3/ha)	The ratio of the amount of water used for each crop to the surface area of the cultivated crop.
	Irrigation System Performance (for Flood, Sprinkler, and Drip Irrigation Systems) (%)	The ratio of the evapotranspiration of the crop to the volume used for irrigation by the system (×100).
	Application Performance (%)	The ratio of the evapotranspiration of the crop to the volume of water allocated for irrigation of the crop (×100).
	Crop Yield Performance (m^3/kg)	The ratio of the volume of water allocated for irrigation of the crop (m^3/ha) to the crop yield (kg/ha).
	Water Use Performance (kg/m^3)	The ratio of the volume of water allocated for irrigation of the crop under consideration.

As cultivated areas continue to expand in the arid regions of Northwest China, which are affected by climate change and droughts, so does the demand for irrigation water. This situation highlights the importance of irrigation efficiency. Water balance has been a key performance indicator (KPI), and water-saving technologies have enhanced the water efficiency. This, in turn, is expected to stimulate the economy of irrigation areas [18].

Another study aims to enhance the water transmission efficiency in the Yangtze River Economic Zone, where irrigation is a significant benchmark for economic and social progress in China. Its findings suggest that the technical efficiency of water transmission is low and exhibits a gradual downward trend. This situation arises from the spatial structure, complexity, and distribution of water transmission, necessitating mitigations [19].

Another example study assessed the water application efficiency of surface irrigation methods within the Nara Canal Area Irrigation zone in Pakistan [20]. On-site measurements evaluated the water application efficiencies for border and furrow irrigation techniques [20]. The KPIs used in the study were moisture content, field capacity, discharge water, and irrigation time. The study concluded that the chosen irrigation method considerably influences crop yield [20].

Decision support tools for precise irrigation planning are essential to enhance the efficiency of irrigation water usage globally. A study from the USA examined water use and efficiency and employed water retention capacity, water use rate, drainage water, leakage, and water use efficiency as KPIs in irrigation planning. Its objective was to alleviate plant stress through variable-rate irrigation. The study concluded that variable-rate irrigation for pasture plants, potatoes, and maize resulted in savings in irrigation water ranging from 9% to 19%, while reducing water losses through drainage and leakage by 25% to 45% [21].

Another study focused on sustainable production in the South Bekaa irrigation area in Lebanon. This study analyzed areas where wheat, potatoes, onions, silage maize, and peaches were grown, considering the annual irrigation water supply per unit irrigated area and yield performance criteria. Compared to wheat, maize had the highest annual irrigation water supply per unit irrigated area, while peaches and potatoes exhibited the highest yield per unit. Notably, peaches emerged as the most profitable crop in the research area, boasting the highest gross margin per unit of water and unit of irrigation supply, calculated as 3987 EUR/m^3 and 3588 EUR/m^3, respectively [22].

A correlation analysis study utilized data from the Ministry of Water and Irrigation in Kenya to ascertain any relationships between the independent and dependent variables in trend analyses on the irrigation KPIs. The findings indicate a robust positive correlation between water budget, irrigation services, and efficiency parameters [23].

Enhancing water efficiency in agricultural production is one of the critical challenges of our time. The scarcity of water, attributed to climate change and escalating food demand, underscores the urgency for researchers to identify appropriate indicators for water use efficiency. A study from eastern Spain evaluated various KPIs encompassing service delivery performance, applied irrigation, production efficiency, and economic efficiency. The impact of factors such as crop types, farmer profiles, and cultivation area sizes was assessed based on the productivity of orchards and irrigation efficiency. Productivity and economic efficiency indicators revealed that the impact of irrigation on water efficiency is a crucial indicator, with observed reductions of 66% in production efficiency for some crops and a 50% decrease in economic efficiency [24].

A separate study examined the correlations between water supply service performance and satisfaction in Jordan. The study deduced that both water quantity and quality affect satisfaction levels regarding water service. Specifically, overall satisfaction with sufficient water quantity and quality showed significant associations with the operating ratio ($R = 0.84$, $p < 0.01$) and weekly water supply hours ($R = 0.69$, $p < 0.05$) [25].

Numerous studies have been conducted worldwide on the impacts of climate change and droughts on water resources, the environment, irrigation systems, irrigation efficiency, and socio-economic structures. Each country has derived results based on performance criteria tailored to its specific conditions and policies, leading to the development of recommendations. A common theme highlighted by various researchers, particularly in the last decade, is the gradual escalation of climate change impacts and the imperative to establish measures and policies aimed at enhancing water and irrigation efficiency [26–40].

The primary objective of this study is to provide recommendations for agricultural water efficiency measures within the context of climate change adaptation. This objective is achieved by accessing and analyzing data, particularly in developing agrarian countries, and assessing the yield losses of staple crops in agricultural areas using the most suitable techniques and determining the associated financial losses. The study's methodology was applied in the Iğdır Plain, selected as the study area. Additionally, the study aimed to assess the feasibility of replicating this case study in other countries.

2. Material and Method

2.1. Methodology

The methodology was applied using data from the selected area, the Iğdır Plain in Türkiye. The existing crop pattern for the area was obtained from relevant institutions and organizations. According to the data, an average of 63,437.1 ha of agricultural production occurs in the irrigated cultivation area in the plain. Field crops constitute 88.11% of the irrigated cultivation area, with cereals accounting for 29.11%, legumes for 0.14%, and forage crops for 58.86%. Wheat is the most cultivated crop among the cereals, while chickpeas are the primary legume, and clover dominates among forage crops. Vegetable cultivation covers 5.79% of the area, with melon being the most cultivated crop. Fruit cultivation occupies 9.57% of the area, with apricots having the largest cultivation area. The crop patterns and cultivation areas of the irrigated areas are provided in Table 2.

The total cultivation area of field crops amounts to 54,020.60 hectares, constituting 85.16% of the total irrigated crop pattern. The three most cultivated crops are clover (52.00%), wheat (21.10%), and silage maize (7.70%), in descending order. These top three crops collectively represent 80.80% of the total field crop pattern.

Table 2. Iğdır Plain irrigated area crop patterns and cultivation areas [41–43].

	Crop Pattern in the Plain	Total (Hectares)	Ratio (%)
I. Crop Groups: Field Crops	Barley	3067.70	5.7
	Wheat *	11,455.00	21.2
	Beans (Dried)	57.00	0.1
	Vetch (Green Grass)	200.00	0.4
	Sainfoin (Green Grass)	1450.00	2.7
	Maize (Grain)—First Cultivation	2595.00	4.8
	Maize (Silage) *	6327.60	11.7
	Chickpeas	31.50	0.1
	Cotton (Unseeded)—First Cultivation	310.00	0.6
	Potato (Other)—First Cultivation	60.20	0.1
	Sugar Beet	146.60	0.3
	Clover (Greengrass) *	28,115.00	52.0
	Paddy—First Cultivation	205.00	0.4
	Total Field Crops	54,020.60	100
II. Crop Groups: Vegetables	Pepper	150.30	4.2
	Tomato (Table) *	949.70	26.7
	Beans (Fresh)	104.30	2.9
	Cucumber (Table)	234.30	6.6
	Spinach	45.00	1.3
	Watermelon *	858.30	24.2
	Melon *	1066.30	30.0
	Aubergine	142.50	4.0
	Total Vegetables	3550.70	100
III. Crop Groups: Fruits	Pear	35.00	0.6
	Apple *	1898.30	32.4
	Plum	29.70	0.5
	Apricot *	3530.00	60.2
	Cherries	40.00	0.7
	Peach *	209.30	3.6
	Walnut	110.00	1.9
	Cherry	13.50	0.2
	Total Fruits	5865.80	100
	Total Irrigated Crops	63,437.10	100

* Crops assessed using data in this study from three different crop groups grown in the plain are field crops, vegetables, and fruits.

Crop water demands and irrigation water demands were calculated based on the yields of the three crops with the largest cultivation areas in each crop group under normal climatic conditions. Subsequently, the irrigation water supply was reduced by 10%, and the resulting yield losses were calculated per hectare. Following this, the overall crop losses stemming from a 10% water deficiency were computed, taking into account the total cultivation area.

The crop pattern, yields, and sales prices of the Iğdır Plain irrigation area were determined according to the average of the data from the statistics of the Ministry of Agriculture and Forestry [41], the Directorate General for Plant Production [42], the Provincial Directorate of Agriculture and Forestry of Iğdır, and the Turkish Statistical Institute (TUIK) between 2014 and 2021 [43]. The revenue loss attributed to water deficiency in each segment was determined by multiplying the productivity loss in that segment by the price of the crop and the cultivation area. Subsequently, the revenue loss due to water deficiency was divided by the reduced water amount to obtain the water deficiency value ($\$/m^3$).

2.1.1. CropWAT

The water demands of the crops cultivated in the plain and the yield relationships under water deficiency were determined using the Water Consumption Guide of Irrigated Plants in Türkiye [44] and CROPWAT 8.0 software [7].

The data inputted into the CropWAT model are as follows:

- Climatic data, such as minimum and maximum temperatures, relative humidity, wind speed, solar radiation, and precipitation, were obtained from the Turkish State Meteorological Service (MGM). The climate data covered multiple years and were averaged over 10-day periods.
- Crop types, cultivation areas, and yields for the 2014–2021 period were obtained from the Turkish Statistical Institute (TUIK).
- Irrigation practices, including irrigation efficiencies and transmission losses, were gathered from field surveys conducted by the Directorate General for Water Management.

In this research, all the data regarding climate and crop pattern were used in the CROPWAT 8.0 program, utilizing real data from recent years. However, it is important to note that while the inputs were real data, the outputs of the model have not been validated with specific experimental or field data from the study area. The data were used within the scenario, water supply restrictions were entered into the CROPWAT 8.0 program, and the product losses were calculated.

In the software CROPWAT 8.0, the irrigation water demand was calculated with the following equation.

$$dn = ETc - Pe \tag{5}$$

where

dn = net irrigation water demand of the crop (mm),
ETc = crop evapotranspiration (mm),
Pe = effective precipitation (mm) (80% of the precipitation is accepted as effective precipitation).

The total irrigation water demand is calculated by dividing the net irrigation demand by the multiplied result of water application and transmission efficiencies.

$$dt = dn/(Ea \times Ec) \tag{6}$$

where

dt = total irrigation water demand (mm),
Ec = water transmission efficiency,
Ea = water application efficiency.

Irrigation efficiency is calculated by multiplying the results on the water transmission efficiency and water application efficiency and then adjusting the proportion based on data from relevant institutions [45]. Based on this, the average irrigation efficiency of the plain is determined to be 34%. Subsequently, after determining the crop water demand (dn) and irrigation water demand (dt), the total water demand was calculated by multiplying it by the average cultivation area. Climate data, including minimum temperature, maximum temperature, relative humidity, wind speed, insolation, and precipitation parameters, were utilized in calculations as 10-day averages spanning multiple years.

2.1.2. Statistical Analysis

Linear and non-linear models were tested to explore the relationship between the water deficiency value ($\$/m^3$) and the irrigation rate (%). It was found that a linear model on the logarithmic transformation of the dependent variable demonstrated a significantly better fit with high R-squared values.

The linear model used is

$$\log(y) = a + bx + \epsilon \tag{7}$$

where

log(y) is the natural logarithm of the water deficiency value,
x is the irrigation rate,
a and b are the model parameters,
ϵ is the error term.

This transformation was chosen to linearize the relationship between the irrigation rate and water deficiency cost, providing a more accurate and interpretable model. The inclusion of the error term (ϵ) accounts for the variability not explained by the model.

The dependent variable was transformed using the natural logarithm, and linear regression was applied to the transformed data for the estimation of the model parameters.

The menus used in CROPWAT 8.0 software are presented in Figure 1.

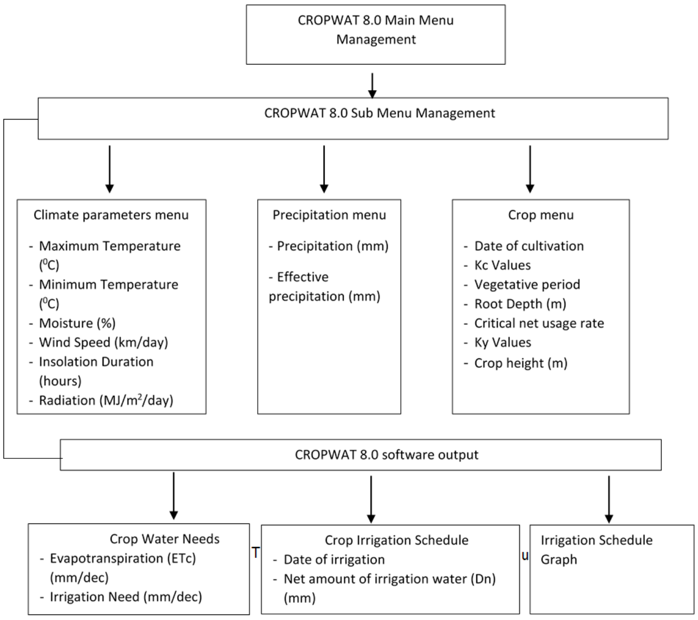
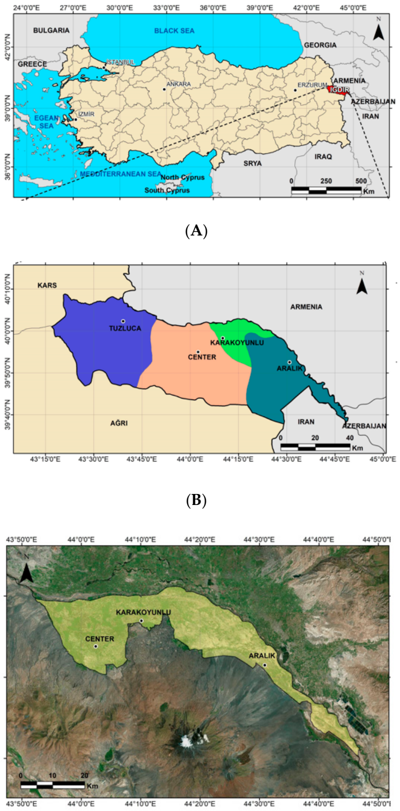


Figure 1. CROPWAT 8.0 software.

2.2. Study Area

The Iğdır Plain is situated alongside the Aras River in the province of Iğdır, within the Eastern Anatolia Region of Türkiye. Türkiye has a total surface area of 783,562 km^2, while Iğdır province covers an area of 3665 km^2. The location of Iğdır province within Türkiye is depicted in Figure 2 [46].



(A)

(B)

(C)

Figure 2. Maps showing the study area: (**A**) the geographical location of Iğdır within Türkiye, (**B**) detailed map of Iğdır province, (**C**) specific study area within the Iğdır Plain [47].

In 2022, the population of Iğdır was 203,594, with 42% of the population residing in rural areas [47]. Iğdır's main source of income is based on agricultural activities [48]. The features of the Iğdır Plain, including micro-climatic conditions, soil quality, and environmental factors, enable the cultivation of a diverse range of agricultural crops.

The Iğdır Plain encompasses approximately 26% of the total area of Iğdır province. The total arable agricultural land within the plain is estimated at 103,243 ha, with economically irrigable agricultural land covering 83,481 ha. The gross area of irrigated agricultural land is 71,156 ha, while the net area is 62,430 ha [49,50]. Based on long-term climate data for Iğdır spanning from 1941 to 2022, the daily average temperature is recorded at 12.3 °C. The highest temperature observed during this period is 42 °C, while the lowest temperature recorded is −30.3 °C. On average, there are 85.3 rainy days annually, with an average rainfall of 258.7 mm per year [51,52]. According to the assessments in 2022, Iğdır province received 40% less precipitation than the long-term average. The total annual surface water potential of Iğdır is estimated at 162.29 million m^3, while the annual groundwater potential is 455.94 million m^3. Consequently, the total annual water potential is calculated to be 618.23 million m^3 [49].

3. Results

The main three crops with the largest cultivation areas in each crop group, as indicated in Table 2 (marked with asterisks), were assessed. These included wheat, maize (silage), and clover from the field crops group; tomatoes, watermelons, and melons from the vegetable group; and apples, apricots, and peaches from the fruit group. The calculated yield loss, total yield loss, total water demands, and the corresponding revenue losses under varying irrigation rates in the case of water deficiency cost are presented in Tables A1–A9.

3.1. Field Crops

The water deficiency value ($/$m^3$), representing the revenue loss divided by the reduced water supply, was plotted against varying levels of irrigation rates (%), indicating the supplied water relative to the demand (Figure 3). The irrigation rate ranges from 10% to 90% on the *x*-axis, while the water deficiency costs are shown on a logarithmic scale on the *y*-axis.

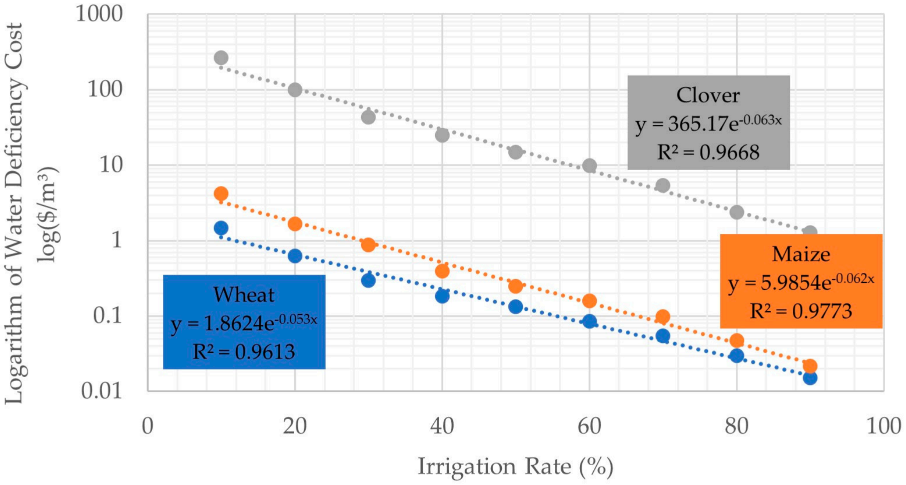


Figure 3. Linear relationship between irrigation rate (%) and the logarithm of water deficiency cost log(($/$m^3$)) due to yield and revenue losses in field crops.

The regression equations in Figure 3 show that the logarithm of the water deficiency cost for field crops decreases linearly as the irrigation rate increases. The high determination coefficients (R^2) for field crops indicate that the linear model with logarithmic transformation is highly appropriate for describing the relationship between irrigation rate and water deficiency cost. The coefficient (b) in these models represents the percent change in the water deficiency cost for each unit change in the irrigation rate. For example, in the case of clover, a point estimate of (b = −0.063) suggests that a 1% increase in irrigation rate is associated with an approximate 6.3% decrease in water deficiency cost. This interpretation is consistent across other crops, highlighting the practical significance of the point estimates in managing irrigation practices to reduce economic losses due to water stress. The regression analysis provided in Figure 3 illustrates the relationship between the irrigation rates and water deficiency costs for selected crops. For example, clover has the highest average water deficiency cost at USD 51.69/m^3 and an R^2 value of 0.9668. Conversely, apricot, with an R^2 of 0.9902 and an average water deficiency cost of USD 1.96/m^3, shows greater resilience to water deficiencies.

Notably, clover has a high initial water deficiency cost, implying that even small reductions in irrigation can lead to significant economic losses. Conversely, wheat shows a lower initial cost, indicating it is less economically sensitive to water shortages.

3.1.1. Wheat

Wheat ranks second in terms of its cultivation area among the field crops group, covering a total area of 11,455 hectares. The average sales price in 2022 was USD 175.85 per ton. Wheat is one of the main crops subsidized by the state due to its national and global importance. It is one of the most consumed, domestically processed, and exported products in Türkiye [53]. Wheat is used in various food and industrial sectors, particularly in bakery products, and serves as the primary food source for 50 countries worldwide, providing 20% of the total calories obtained from plant-based foods. In Türkiye, this rate is even higher, accounting for 53% of the total calorie intake from plant-based foods [54]. Wheat faces significant revenue losses due to water deficiencies caused by climate change and drought.

Table A1 presents the potential yield and revenue losses in wheat cultivation due to varying irrigation rates and the resulting water deficiency cost. At 90% irrigation, the yield loss is 81 kg/ha, resulting in a total yield loss of 927.86 metric tons and a revenue loss of USD 163,170. This loss increases dramatically at 10% irrigation, with a yield loss of 880.65 kg/ha, a total yield loss of 10,087.85 metric tons, and a revenue loss of USD 1,773,980. The water deficit cost, which measures the economic impact per cubic meter of water not supplied, escalates from USD 0.02/m^3 at 90% irrigation to USD 1.47/m^3 at 10% irrigation.

The relationship between irrigation rate (%) and the logarithm of water deficiency cost (log(USD/m^3)) for wheat (Figure 3) is given by the equation $\log(y) = 1.8624 - 0.053x$ with a determination coefficient (R^2) of 0.9613. This indicates a strong fit of the model to the data, suggesting that as the irrigation rate decreases, the logarithm of the water deficiency cost increases linearly. The coefficient b = −0.053 (SE = 0.006) suggests that each 1% increase in irrigation rate results in an approximate 5.3% decrease in water deficiency cost.

3.1.2. Silage Maize (First Cultivation)

Silage maize, which ranks third in terms of cultivation area among the field crops, covers 4182.60 ha. In 2022, the average sales price was USD 29.19 per ton. Silage maize, important for livestock farming, is utilized in fodder rations, especially during periods when juicy and green grass is scarce. It is also a subsidized crop in Türkiye.

Table A2 presents the potential yield and revenue losses in maize cultivation due to varying irrigation rates and the resulting water deficiency cost. As irrigation rates decrease from 100% to 20%, there is a corresponding increase in the yield loss, both in percentage and absolute terms. For instance, at 90% irrigation, the yield loss is 953.33 kg/ha, resulting in a total yield loss of 3987.41 metric tons and a revenue loss of USD 116,390. This loss increases dramatically at 20% irrigation, with a yield loss of 14,473.33 kg/ha, a total yield loss of 60,536.16 metric tons, and a revenue loss of USD 1,767,060. The water deficit cost escalates from USD 0.02/m^3 at 90% irrigation to USD 1.65/m^3 at 20% irrigation.

The relationship between irrigation rate (%) and the logarithm of water deficiency cost (log(USD/m^3)) for maize (Figure 3) is given by the equation $\log(y) = 5.9854 - 0.062x$ with a determination coefficient (R^2) of 0.9773. This high R-squared value indicates an excellent fit, showing a significant increase in the water deficiency cost as the irrigation rate decreases. Maize shows a steeper curve compared to wheat, indicating higher sensitivity to irrigation rate changes. The coefficient b = −0.062 (SE = 0.007) suggests that each 1% increase in irrigation rate results in an approximate 6.2% decrease in water deficiency cost.

3.1.3. Clover

Clover, with the largest cultivation area among field crops, spans 28,115 ha. In 2022, the average sales price was USD 96.11 per ton. The Eastern Anatolia Region is a crucial livestock breeding region in Türkiye, where fodder constitutes about 70% of the total expenses in the livestock sector [1,4]. Clover is a subsidized forage crop because it is deemed strategically important in Türkiye [55]. Clover is vital for animal fodder, pasture improvement, erosion control, and green manure within sustainable agricultural practices.

Table A3 presents the potential yield and revenue losses in clover cultivation due to varying irrigation rates and the resulting water deficiency cost. At 90% irrigation, the yield loss is 20,066.66 kg/ha, resulting in a total yield loss of 5641.74 metric tons and a revenue loss of USD 54,225.11. This loss increases dramatically at 10% irrigation, with a yield loss of 462,488.78 kg/ha, a total yield loss of 130,028.72 metric tons, and a revenue loss of USD 1,249,759.74. The water deficit cost escalates from USD 1.28/m^3 at 90% irrigation to USD 265.78/m^3 at 10% irrigation.

Clover experiences significant revenue losses due to water supply deficiency (Figure 3). The determination coefficient (R^2) of the trend is calculated as 96.68%, indicating a strong fit. As water supply deficiencies intensify, both yield and revenue decrease. Furthermore, as the irrigation rate declines, the unit water deficiency cost increases.

The relationship between irrigation rate (%) and the logarithm of water deficiency cost (log(USD/m^3)) for clover (Figure 3) is given by the equation $\log(y) = 365.17 - 0.063x$ with a determination coefficient (R^2) of 0.9668, also indicating a strong fit. The coefficient b = −0.063 (SE = 0.007) suggests that a 1% increase in irrigation rate is associated with an approximate 6.3% decrease in water deficiency cost. The high initial value and steep decline for clover suggest a substantial economic impact per unit of water deficiency, much higher than that for both wheat and maize.

3.2. *Vegetable Crops*

The total cultivation area in the irrigated lands amounts to 3550.70 ha, constituting 5.60% of the total irrigation area. The top three cultivated crops in this group are melons (30.00%), table tomatoes (26.70%), and watermelons (24.20%), respectively. Together, these top three crops represent 80.90% of the total vegetable crop pattern.

Figure 4 illustrates the water deficiency cost change versus varying levels of irrigation rate for vegetable crops.

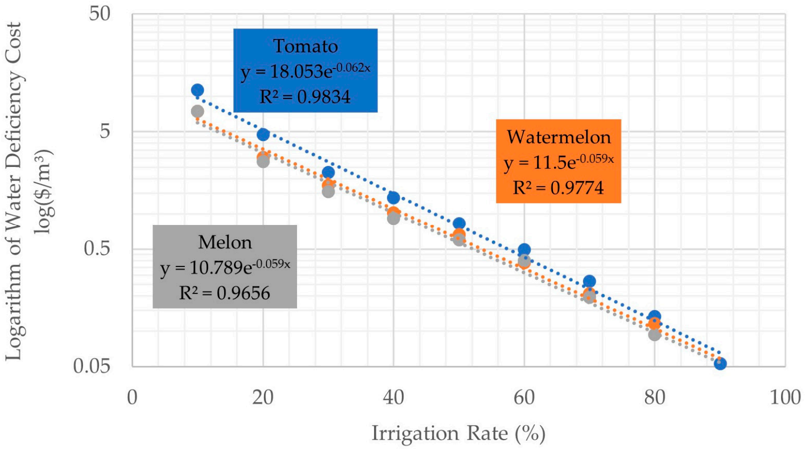


Figure 4. Linear relationship between irrigation rate (%) and the logarithm of water deficiency cost (log(USD/m^3)) due to yield and revenue losses in vegetable crops.

The regression equations in Figure 4 show that the logarithm of water deficiency cost for vegetable crops decreases linearly as the irrigation rate increases. The high determination coefficients (R^2) indicate that the linear model with logarithmic transformation is highly appropriate for describing the relationship between irrigation rate and water deficiency cost. The coefficient (b) in these models represents the percent change in water deficiency cost for each unit change in irrigation rate. For example, in the case of melon and watermelon, a point estimate of $b = -0.059$ ($SE = 0.006$) suggests that a 1% increase in irrigation rate is associated with an approximate 5.9% decrease in water deficiency cost. This interpretation is consistent across other vegetable crops, highlighting the practical significance of the point estimates in managing irrigation practices to reduce economic losses due to water stress.

3.2.1. Tomatoes

The cultivation area of table tomatoes ranks the second among the vegetable crops group. Its average sales price in 2022 was USD 94.34 per ton. Tomatoes, being one of the most consumed fresh crops globally and in Türkiye, are agricultural products extensively used in the processed food industry and are known to support the immune system [56].

Table A4 presents the potential yield and revenue losses in tomato cultivation due to varying irrigation rates and the resulting water deficiency cost. At 90% irrigation, the yield loss is 836 kg/ha, resulting in a total yield loss of 793.95 metric tons and a revenue loss of USD 74,900. This loss increases dramatically at 10% irrigation, with a yield loss of 19,734.67 kg/ha, a total yield loss of 18,742.01 metric tons, and a revenue loss of USD 1,768,010. The water deficit cost escalates from USD 0.05/m^3 at 90% irrigation to USD 11.30/m^3 at 10% irrigation.

The relationship between irrigation rate (%) and the logarithm of water deficiency cost (log(USD/m^3)) for tomatoes (Figure 4) is given by the equation $\log(y) = 18.053 - 0.062x$ with a determination coefficient (R^2) of 0.9834. This indicates a strong fit of the model to the data, suggesting that as the irrigation rate decreases, the logarithm of the water deficiency cost increases linearly. The coefficient b represents the percent change in water stress costs for each unit change in irrigation rate. For instance, a point estimate of $b = -0.062$ ($SE = 0.006$) indicates that for each 1% increase in irrigation rate, the water stress cost decreases by approximately 6.2%. The higher initial value and steep curve for tomatoes indicate a significant sensitivity to irrigation rate changes.

3.2.2. Watermelon

The cultivation area of watermelon, which is the third most cultivated among the vegetable product group, is 858.30 hectares, and its average sales price in 2022 was USD 86.86/ton. Besides their rich nutritional content, watermelon and melon offer various advantages. They can be consumed fresh. Moreover, the utilization of melon and watermelon peels and seeds in the food, natural medicine, and cosmetics sectors has gained importance recently, positioning them as strategic export products [57].

Table A5 presents the potential yield and revenue losses in watermelon cultivation due to varying irrigation rates and the resulting water deficiency cost. At 90% irrigation, the yield loss is 662.11 kg/ha, resulting in a total yield loss of 568.29 metric tons and a revenue loss of USD 49,360. This loss increases dramatically at 10% irrigation, with a yield loss of 11,390.56 kg/ha, a total yield loss of 9776.51 metric tons, and a revenue loss of USD 849,180. The water deficit cost escalates from USD 0.05/m^3 at 90% irrigation to USD 7.46/m^3 at 10% irrigation.

The relationship for watermelon (Figure 4) between irrigation rate (%) and the logarithm of water deficiency cost (log(USD/m^3)) is represented by the equation $\log(y) = 11.5 - 0.059x$ with a determination coefficient (R^2) of 0.9774. This high R-squared value indicates an excellent fit, showing a considerable increase in the water deficiency cost as the irrigation rate decreases, though this is slightly less steep compared to that for tomatoes.

3.2.3. Melon

The cultivation area of melon, which is the most cultivated crop among the vegetable product group, is 1066.30 ha. Its average sales price in 2022 was USD 124.59 per ton. Melon and watermelon are among the most consumed vegetables in Türkiye [57]. Melon in particular is a summer food rich in vitamins A, B, and especially C, as well as iron, magnesium, potassium, and minerals. It is considered a health-promoting product and is recommended for consumption.

Table A6 presents the potential yield and revenue losses in melon cultivation due to varying irrigation rates and the resulting water deficiency cost. At 90% irrigation, the yield loss is 471.74 kg/ha, resulting in a total yield loss of 503.02 metric tons and a revenue loss of USD 62,670. This loss increases dramatically at 10% irrigation, with a yield loss of 8154.36 kg/ha, a total yield loss of 8694.99 metric tons, and a revenue loss of USD 1,083,330. The water deficit cost escalates from USD 0.05/m^3 at 90% irrigation to USD 7.42/m^3 at 10% irrigation.

The relationship between irrigation rate (%) and the logarithm of water deficiency cost (log(USD/m^3)) for melons (Figure 4) is $\log(y) = 10.789e - 0.059x$ with a determination coefficient (R^2) of 0.9656, also indicating a strong fit. Similar to tomatoes and watermelons, the logarithm of the water deficiency cost for melons rises linearly as the irrigation rate declines.

3.3. Fruits

The fruit-growing industry is one of Türkiye most significant agricultural sectors, contributing significantly to income, employment, and economic development [58]. The total irrigated fruit area amounts to 5865.80 ha, representing 9.25% of the total irrigation area. The top three most cultivated crops in this product group are apricot (60.20%), apple (32.40%), and peach (3.60%), respectively. Together, these top three crops constitute 96.20% of the total fruit crop pattern.

Figure 5 illustrates the water deficiency cost change versus varying levels of irrigation rate for fruit crops.

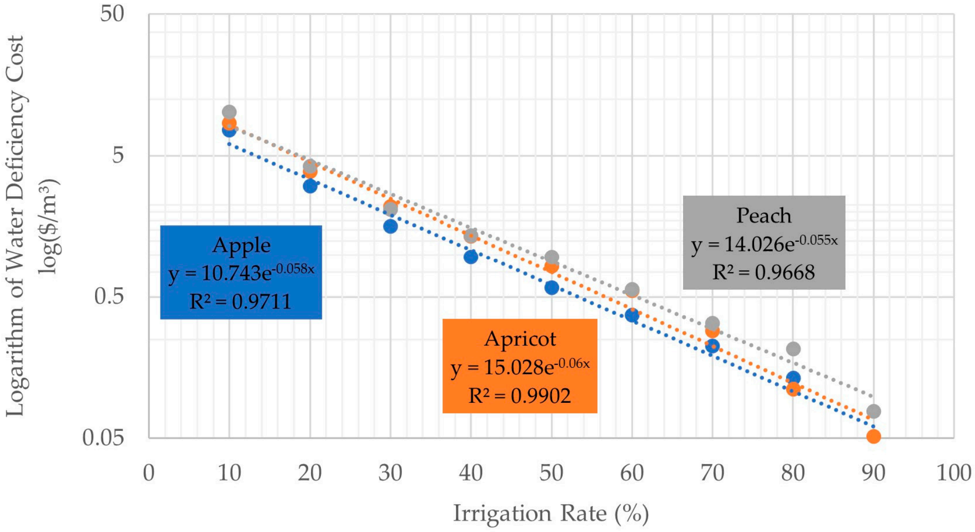


Figure 5. Linear relationship between irrigation rate (%) and the logarithm of water deficiency cost ($\log(\$/\mathrm{m}^3)$) due to yield and revenue losses in fruit crops.

The regression equations in Figure 5 show that the logarithm of water deficiency cost for fruit crops decreases linearly as the irrigation rate increases. The high determination coefficients (R^2) indicate that the linear model with logarithmic transformation is highly appropriate for describing the relationship between irrigation rate and water deficiency cost. The coefficient (b) in these models represents the percent change in water deficiency cost for each unit change in irrigation rate. For example, in the case of apricots, a point estimate of $b = -0.06$ (SE = 0.006) suggests that a 1% increase in irrigation rate is associated with an approximate 6% decrease in water deficiency cost. This interpretation is consistent across other fruit crops, highlighting the practical significance of the point estimates in managing irrigation practices to reduce economic losses due to water stress.

3.3.1. Apple

The cultivation area of apple, which ranks the second in terms of cultivation area among the fruit product group, is 1898.30 ha. Its average sales price in 2022 was USD 126.73 per ton. Türkiye holds the fourth position in world apple production and ranks eighth in terms of exports [59]. Apple accounts for 5.3% of Türkiye's total fruit area and 0.7% of its total agricultural area [58].

Table A7 presents the potential yield and revenue losses in apple growing due to varying irrigation rates and the resulting water deficiency cost. At 90% irrigation, the yield loss is 600 kg/ha, resulting in a total yield loss of 1138.98 metric tons and a revenue loss of USD 144,340. This loss increases dramatically at 10% irrigation, with a yield loss of 10,620 kg/ha, a total yield loss of 20,159.95 metric tons, and a revenue loss of USD 2,554,840. The water deficit cost escalates from USD 0.05/m^3 at 90% irrigation to USD 7.58/m^3 at 10% irrigation.

The relationship (Figure 5) between irrigation rate (%) and the logarithm of water deficiency cost (USD/m^3) for apples is given by the equation $\log(y) = 10.743e - 0.058x$ with a determination coefficient (R^2) of 0.9711. This indicates a strong fit of the model to the data, suggesting that as the irrigation rate decreases, the logarithm of water deficiency cost increases linearly. The point estimate of (b) in the model provides a clear interpretation: it quantifies the percent change in water deficiency cost for each unit change in irrigation rate. For instance, a point estimate of $b = -0.058$ (SE = 0.007) means that for each 1% increase in irrigation rate, the water deficiency cost decreases by approximately 5.8%.

3.3.2. Apricot

The cultivation area of apricot, which is the most cultivated crop among the fruit product group, is 3530.00 ha. Its average sales price in 2022 was USD 249.19 per ton. Apricot is a versatile crop used fresh, dried, or processed in the food industry, and it is not very ecologically selective. Türkiye accounts for 20% of the world's apricot production, making it a product with high commercial value [60].

Table A8 presents the potential yield and revenue losses in apricot farming due to varying irrigation rates and the resulting water deficiency cost. At 90% irrigation, the yield loss is 321.04 kg/ha, resulting in a total yield loss of 1133.27 metric tons and a revenue loss of USD 282,390. This loss increases dramatically at 10% irrigation, with a yield loss of 5910.03 kg/ha, a total yield loss of 20,862.41 metric tons, and a revenue loss of USD 5,198,590. The water deficit cost escalates from USD 0.05/m^3 at 90% irrigation to USD 8.49/m^3 at 10% irrigation.

The relationship (Figure 5) for apricots between irrigation rate (%) and the logarithm of water deficiency cost (log(USD/m^3)) is represented by the equation $\log(y) = 15.028 - 0.06x$ with a determination coefficient (R^2) of 0.9902. This high R-squared value indicates an excellent fit, showing a significant increase in the water deficiency cost as the irrigation rate decreases.

3.3.3. Peach

The cultivation area of peach, which ranks the third in terms of cultivation area among the fruit product group, is 209.30 ha. Its average sales price in 2022 was USD 126.73 per ton. Peaches are an agricultural product that can be consumed fresh or processed. They require water and hold economic value in the regions where they are grown. Türkiye ranks the fifth in the world in peach production and the fourth in its exports [61].

Table A9 presents the potential yield and revenue losses in peach farming due to varying irrigation rates and the resulting water deficiency cost. At 90% irrigation, the yield loss is 513 kg/ha, resulting in a total yield loss of 107.37 metric tons and a revenue loss of USD 24,460. This loss increases dramatically at 10% irrigation, with a yield loss of 7506 kg/ha, a total yield loss of 1571.01 metric tons, and a revenue loss of USD 357,920.

The water deficit cost escalates from USD 0.08/m^3 at 90% irrigation to USD 10.17/m^3 at 10% irrigation.

The relationship (Figure 5) between irrigation rate (%) and the logarithm of water deficiency cost (log(USD/m^3)) for peaches is $\log(y) = 14.026 - 0.055x$ with a determination coefficient (R^2) of 0.9668, also indicating a strong fit. Similar to apples and apricots, the logarithm of water deficiency cost for peaches rises linearly as the irrigation rate declines.

4. Discussion

The results of this study demonstrate significant economic impacts of deficit irrigation on crop yield and revenue. The high determination coefficients (R^2) for the regression models indicate a strong fit to the data. The coefficient (b) in these models provides valuable insights into the percent change in water deficiency cost for each unit change in irrigation rate. For example, the coefficient b (-0.063) for clover indicates that a 1% increase in irrigation rate results in an approximate 6.3% decrease in water deficiency cost. Similarly, for tomatoes, a point estimate of b (-0.062) indicates a 6.2% decrease in water deficiency cost for each 1% increase in irrigation rate. These results highlight the significant role of irrigation management in reducing economic losses due to water stress. These interpretations underscore the importance of precise irrigation strategies. By understanding the specific percent changes in water stress costs associated with changes in irrigation rates, farmers and agricultural managers can make informed decisions to optimize water use and minimize economic impacts. This approach is particularly crucial for crops such as clover and tomatoes, which show a substantial response to changes in irrigation. The standard errors of the coefficients, detailed in Table A10 in the annex, provide further confidence in the robustness of these estimates. The high precision of the point estimates indicates reliable results, which can be effectively used to guide irrigation practices and improve economic outcomes in agriculture.

The findings of this study align with existing research on the economic implications of deficit irrigation. For example, studies have shown that optimized irrigation can significantly enhance water use efficiency and reduce yield losses. By applying the insights from our regression models, agricultural practices can be better tailored to mitigating the adverse effects of water deficiencies, ensuring sustainable crop production and economic viability. The significant economic impacts of water supply deficiencies on crop yield and revenue notably vary among different crops. This research highlights the heightened sensitivity of clover to water deficiencies, resulting in substantial revenue losses even with minor reductions in irrigation. Conversely, apricot demonstrates more resilience, showing lower economic sensitivity to water deficiencies. This differential sensitivity underscores the importance of strategic crop selection and irrigation management to mitigate economic losses under water-scarce conditions.

In this study, the CROPWAT 8.0 model was used to estimate the crop water requirements and yield losses under water constraint scenarios using real-world data as inputs. However, the model's outputs have not been validated with experimental data specific to the Iğdır Plain. This lack of validation represents a limitation of the study, as the model relies on assumptions that may not fully capture the unique conditions of the study area. This study highlights the significant economic impacts of deficit irrigation, particularly on clover, which is highly sensitive to water deficiencies, resulting in the highest revenue losses. In contrast, apricot shows more resilience under similar conditions. The relationship between irrigation rate and the logarithm of the water deficiency cost is linear, suggesting that even small reductions in irrigation can lead to substantial economic losses. These findings are crucial for regions with similar climatic conditions and agricultural practices, emphasizing the need for efficient water management and strategic crop selection to mitigate the adverse effects of climate change on agriculture.

The regression analysis provided in Table 3 illustrates the relationship between irrigation rates and water deficiency costs for selected crops. The standard errors of these estimates are provided in Table A10 in the annex. For example, clover has the highest average water deficiency cost at USD 51.69/m^3 and an R^2 value of 0.9668, indicating a strong linear relationship between irrigation rate and the logarithm of the water deficiency cost. Conversely, apricot, with an R^2 of 0.9902 and an average water deficiency cost of USD 1.96/m^3, shows greater resilience to water deficiencies. These findings highlight the importance of considering both the sensitivity and economic impact of water deficiencies on different crops when planning irrigation strategies.

Table 3. Regression analysis of irrigation rate (x) and water deficiency cost (y) for selected crops.

Crop	The Relationship between Irrigation Rate (x) and Water Deficiency Cost (y)	R^2	Average Water Deficiency Cost (\$/m^3)	Average Product Loss (Tons)
Wheat	$\log(y) = 1.8624 - 0.053x$	0.9613	0.32	4767
Maize	$\log(y) = 5.9854 - 0.062x$	0.9773	0.85	33,584
Clover	$\log(y) = 365.16 - 0.063x$	0.9668	51.69	48,417
Tomato	$\log(y) = 18.053 - 0.062x$	0.9834	2.39	5945
Watermelon	$\log(y) = 11.5 - 0.059x$	0.9774	0.80	3469
Melon	$\log(y) = 10.789 - 0.059x$	0.9656	1.56	3801
Apple	$\log(y) = 10.743 - 0.058x$	0.9711	1.61	9008
Apricot	$\log(y) = 15.028 - 0.06x$	0.9902	1.96	10,636
Peach	$\log(y) = 14.026 - 0.055x$	0.9668	2.22	741

Deficit irrigation is a common agricultural practice that involves applying less water than the full crop water demand, aiming to conserve water while maintaining acceptable levels of crop yield and quality. The economic benefits of deficit irrigation vary widely depending on crop type, local conditions, and water pricing, emphasizing the need for optimization to balance yield and water use [62,63]. For example, Yu et al. conducted a meta-analysis on deficit irrigation in wheat, finding that while it improved the water use efficiency by 6.6%, it resulted in an average yield reduction of 16.2% [64]. Deficit irrigation in corn leads to significant yield losses and economic risks as well [65,66]. Likewise, the estimated cost of water deficiencies in rice production in Taiwan was about USD 169 million during 1945–1994 [67]. Conversely, some studies underscore that deficit irrigation in maize can maintain high yields with reduced water usage, emphasizing the importance of timing in deficit irrigation [68,69]. These insights collectively highlight the need for strategic adaptation and efficient water management to mitigate the economic impacts of water deficiencies, supporting our findings that precise irrigation management is crucial for minimizing yield and revenue losses while balancing water use efficiency.

The findings demonstrate that coefficient b in the linear regression models, which represents the percent change in the water deficiency cost for each unit change in irrigation rate, is a critical factor. For instance, a coefficient $b = -0.053$ for wheat indicates that each 1% increase in irrigation rate reduces the water deficiency cost by about 5.3%. Similarly, for clover and tomatoes, the coefficients $b = -0.063$ and $b = -0.062$, respectively, suggest substantial decreases in the water deficiency costs with increased irrigation rates. These interpretations provide actionable insights for optimizing irrigation strategies to mitigate the economic impact of water deficiencies on crop yield and revenue. The standard errors of the coefficients, detailed in Table A10 in the annex, provide further confidence in the robustness of these estimates. This comprehensive understanding of the model's implications ensures that the findings can be effectively used to guide irrigation management practices and improve economic outcomes in agriculture.

5. Conclusions

The analyses conducted within the framework of this research have revealed the potential for significant reductions in agricultural production yields in cases of water constraints induced by droughts. Such constraints can impair rural development, the national economy, welfare, and food security. Given the multifaceted impact of agricultural production, it is imperative to prioritize the sustainable utilization of natural resources and the environment alongside agriculture.

According to the analysis, apricot emerges as the crop most resilient to water constraints, displaying the highest compatibility between irrigation rate and the water constraint value (R^2). Conversely, clover, categorized within the field crops group, exhibits the least resistance to water constraints, characterized by the lowest compatibility between irrigation rate and the water constraint value (R^2).

In the context of the Iğdır Plain, the crops that incur the highest value losses under water constraints are clover, tomato, peach, apricot, apple, melon, maize, watermelon, and wheat. Similarly, in terms of yield losses, the crops most affected by water constraints are clover, maize, apricot, apple, tomato, wheat, melon, watermelon, and peach.

Given these findings, the recommended crop pattern for the Iğdır Plain under water constraints includes wheat, apricot, watermelon, maize, melon, apple, tomato, peach, and clover. Crop pattern optimization studies are advisable to mitigate agricultural revenue losses. These studies should explore alternatives such as reducing water allocation to crops more resilient to water constraints during drought conditions (e.g., apricots) and reallocating water to crops yielding a higher revenue but sensitive to water constraints (e.g., clover).

These results highlight the significant role of crop pattern optimization and irrigation management in reducing economic losses due to water stress. By understanding the specific percent changes in water stress costs associated with changes in irrigation rates, farmers and agricultural managers can make informed decisions to optimize water use and minimize economic impacts.

This study, which assesses the applicability of the developed methodology in a designated area, is recommended for implementation in countries like Türkiye, where agriculture plays a significant economic role. Upon the application of the procedures in this study, further detailed studies in the relevant agricultural regions, incorporating area-specific data and analyses similar to the provided example, can offer valuable insights into strategies for drought conditions. Accordingly, the procedures in this study are available to scientists worldwide to facilitate their utilization in similar contexts globally.

Moreover, the following operations ensure the sustainable use of water resources: (1) managing irrigation practices, including improving water transmission efficiency and water use efficiency in irrigation areas; (2) allocating more space to water-stress-resistant crops in the crop pattern in basins; and (3) substituting crops requiring excessive water with less water-dependent crops. This approach encourages farmers to actively engage in the process of adaptation to climate change and drought conditions while minimizing the agricultural sector's vulnerability to the impacts of climate change, which heavily relies on water consumption.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Most of the data used in this study are not publicly available.

Acknowledgments: I appreciate the insightful comments and suggestions from the reviewers, which greatly improved the quality of this manuscript.

Conflicts of Interest: The author declares no conflicts of interest.

Appendix A

Tables A1–A9 illustrate the impact of varying irrigation rates on yield loss, total yield loss, total water demands, and the corresponding revenue losses in the case of water deficiency. The columns in these tables are as follows:

- Crop Water Demand represents the calculated water demand of a crop in millimeters. The crop water demand decreases as the irrigation rate reduces.
- Irrigation Water Demand shows the total irrigation water demand of a crop in millimeters, calculated by dividing the net irrigation water demand by the average irrigation efficiency of 34% in the Iğdır Plain.
- Irrigation Rate (%) indicates the percentage of the irrigation water supplied, ranging from 100% (full irrigation) to 10% (severe water constraint).

- Yield Decrease (%) shows the percentage decrease in crop yield due to the reduction in irrigation water. The yield loss increases as the irrigation rate decreases.
- Yield Loss (kg/ha) quantifies the yield loss in kilograms per hectare, corresponding to each irrigation rate.
- Total Yield Loss calculates the total yield loss across the irrigation plain in metric tons.
- Irrigational water volume shows the total irrigational water demand in thousand cubic meters.
- Loss of Revenue presents the revenue loss due to the reduced yield in thousand dollars. The revenue loss increases with the severity of the water constraint.
- Water Deficiency Cost is the economic value of the water deficiency, representing the cost per cubic meter of water not supplied. This value rises significantly as the irrigation rate decreases, highlighting the increased economic impact of severe water constraints.

Table A1. Potential yield and revenue losses of wheat due to varying irrigation rates.

Crop Water Demand (dn, mm)	Irrigation Water Demand (dt, m^3/ha/y)	Irrigation Rate (%)	Yield Decrease (%)	Yield Loss (kg/ha)	Total Yield Loss (Metric Tons)	Irrigational Water Volume (Thousand m^3)	Loss of Revenue (Thousand USD)	Water Deficiency Cost (USD/m^3)
357.57	1051.68	100	0.00	0.00	0.00	12,046.95	0.00	-----
321.80	946.47	90	1.80	81.00	927.86	10,841.81	163.17	0.02
286.07	841.38	80	3.13	140.85	1613.44	9638.01	283.73	0.03
250.27	736.09	70	5.03	226.35	2592.84	8431.91	455.96	0.05
214.53	630.97	60	6.83	307.35	3520.69	7227.76	619.13	0.09
178.80	525.88	50	8.80	396.00	4536.18	6023.96	797.70	0.13
143.03	420.68	40	9.67	435.15	4984.64	4818.89	876.57	0.18
107.30	315.59	30	11.87	534.15	6118.69	3615.08	1075.99	0.30
71.50	210.29	20	16.53	743.85	8520.80	2408.87	1498.41	0.62
35.77	105.21	10	19.57	880.65	10,087.85	1205.18	1773.98	1.47

Table A2. Expected yield and revenue loss of first-cultivation silage maize in case of water constraints.

Crop Water Demand (dn, mm)	Irrigation Water Demand (dt, m^3/ha/y)	Irrigation Rate (%)	Yield Decrease (%)	Yield Loss (kg/ha)	Total Yield Loss (Metric Tons)	Irrigational Water Volume (Thousand m^3)	Loss of Revenue (Thousand USD)	Water Deficiency Cost (USD/m^3)
486.13	14,291.80	100	0.00	0.00	0.00	5980.30	0.00	-----
437.50	1286.76	90	2.20	953.33	3987.41	5382.00	116.39	0.02
388.90	1143.82	80	4.33	1877.78	7853.99	4784.14	229.26	0.05
340.30	1000.88	70	7.80	3380.00	14,137.19	4186.28	412.67	0.10
291.67	857.84	60	10.70	4636.67	19,393.32	3588.00	566.10	0.16
243.10	715.00	50	14.03	6081.11	25,434.85	2990.56	742.45	0.25
194.47	571.96	40	17.83	7727.78	32,322.20	2392.28	943.49	0.39
145.83	428.92	30	29.43	12,754.44	53,346.74	1794.00	1557.20	0.87
87.23	256.57	20	33.40	14,473.33	60,536.16	1073.13	1767.06	1.65
48.63	143.04	10	47.03	20,381.11	85,246.03	598.28	2488.35	4.16

Table A3. Expected yield and revenue losses of clover in case of water constraints.

Crop Water Demand (dn, mm)	Irrigation Water Demand (dt, m^3/ha/y)	Irrigation Rate (%)	Yield Decrease (%)	Yield Loss (kg/ha)	Total Yield Loss (Metric Tons)	Irrigational Water Volume (Thousand m^3)	Loss of Revenue (Thousand USD)	Water Deficiency Cost (USD/m^3)
568.37	1671.67	100	0.00	0.00	0.00	46,999.00	0.00	----

Table A3. *Cont.*

Crop Water Demand (dn, mm)	Irrigation Water Demand (dt, m^3/ha/y)	Irrigation Rate (%)	Yield Decrease (%)	Yield Loss (kg/ha)	Total Yield Loss (Metric Tons)	Irrigational Water Volume (Thousand m^3)	Loss of Revenue (Thousand USD)	Water Deficiency Cost (USD/m^3)
511.53	1504.51	90	1.40	20,066.66	5641.74	42,299.30	54,225.11	1.28
454.70	1337.35	80	2.30	32,966.66	9268.58	37,599.60	89,084.12	2.37
397.87	1170.20	70	4.53	64,977.76	18,268.50	32,900.17	175,586.07	5.34
341.00	1002.94	60	7.20	103,199.98	29,014.67	28,197.66	278,872.02	9.89
284.23	835.98	50	8.97	128,522.19	36,134.01	23,503.58	347,298.93	14.78
227.37	668.73	40	11.97	171,522.18	48,223.46	18,801.35	463,495.60	24.65
170.53	501.57	30	15.57	223,122.17	62,730.80	14,101.64	602,931.61	42.76
113.67	334.31	20	23.93	343,044.36	96,446.92	9399.13	926,991.20	98.63
56.87	167.25	10	32.27	462,488.78	130,028.72	4702.24	1,249,759.74	265.78

Table A4. Expected yield and revenue loss of table tomatoes in case of water constraints.

Crop Water Demand (dn, mm)	Irrigation Water Demand (dt, m^3/ha/y)	Irrigation Rate (%)	Yield Decrease (%)	Yield Loss (kg/ha)	Total Yield Loss (Metric Tons)	Irrigational Water Volume (Thousand m^3)	Loss of Revenue (Thousand USD)	Water Deficiency Cost (USD/m^3)
560.00	1647.06	100	0.00	0.00	0.00	1564.21	0.00	----
504.00	1482.35	90	2.20	836.00	793.95	1407.79	74.90	0.05
448.00	1317.65	80	4.90	1862.00	1768.34	1251.37	166.82	0.13
392.00	1152.94	70	8.57	3255.33	3091.59	1094.95	291.64	0.27
335.97	988.14	60	13.57	5155.33	4896.02	938.44	461.86	0.49
280.03	823.63	50	18.90	7182.00	6820.75	782.20	643.43	0.82
224.03	658.92	40	25.30	9614.00	9130.42	625.78	861.31	1.38
168.00	494.12	30	31.23	11,868.67	11,271.67	469.27	1063.30	2.27
112.00	329.41	20	43.60	16,568.00	15,734.63	312.84	1484.31	4.74
56.00	164.71	10	51.93	19,734.67	18,742.01	156.43	1768.01	11.30

Table A5. Expected yield and revenue loss of watermelon in case of water constraints.

Crop Water Demand (dn, mm)	Irrigation Water Demand (dt, m^3/ha/y)	Irrigation Rate (%)	Yield Decrease (%)	Yield Loss (kg/ha)	Total Yield Loss (Metric Tons)	Irrigational Water Volume (Thousand m^3)	Loss of Revenue (Thousand USD)	Water Deficiency Cost (USD/m^3)
450.57	1325.20	100	0.00	0.00	0.00	1137.42	0.00	-----
405.50	1192.65	90	1.97	662.11	568.29	1023.65	49.36	0.05
360.47	1060.20	80	4.20	1414.00	1213.64	909.97	105.41	0.12
315.40	927.65	70	6.60	2222.00	1907.14	796.20	165.65	0.21
270.33	795.10	60	10.40	3501.33	3005.19	682.44	261.03	0.38
225.23	662.45	50	14.93	5027.56	4315.15	568.58	374.81	0.66
180.23	530.10	40	18.60	6262.00	5374.68	454.99	466.84	1.03
135.17	397.55	30	23.83	8023.89	6886.90	341.22	598.19	1.75
90.10	265.00	20	27.53	9269.56	7956.06	227.45	691.05	3.04
45.07	132.55	10	33.83	11,390.56	9776.51	113.77	849.18	7.46

Table A6. Expected yield and revenue loss of melon in case of water constraints.

Crop Water Demand (dn, mm)	Irrigation Water Demand (dt, m^3/ha/y)	Irrigation Rate (%)	Yield Decrease (%)	Yield Loss (kg/ha)	Total Yield Loss (Metric tons)	Irrigational Water Volume (Thousand m^3)	Loss of Revenue (Thousand USD)	Water Deficiency Cost (USD/m^3)
465.33	1368.63	100	0.00	0.00	0.00	1459.37	0.00	----
418.83	1231.86	90	2.10	471.74	503.02	1313.53	62.67	0.05
372.27	1094.90	80	3.67	823.67	878.28	1167.49	109.43	0.09
325.73	958.04	70	6.63	1490.10	1588.89	1021.56	197.96	0.19
279.20	821.18	60	11.63	2613.29	2786.55	875.63	347.18	0.40
232.70	684.41	50	14.63	3287.20	3505.14	729.79	436.71	0.60
186.13	547.45	40	17.90	4021.02	4287.61	583.75	534.20	0.91
139.63	410.69	30	22.80	5121.75	5461.32	437.92	680.44	1.55
93.07	273.73	20	27.17	6102.67	6507.27	291.88	810.76	2.78
46.53	136.86	10	36.30	8154.36	8694.99	145.93	1083.33	7.42

Table A7. Expected yield and revenue loss of apple in case of water constraints.

Crop Water Demand (dn, mm)	Irrigation Water Demand (dt, m^3/ha/y)	Irrigation Rate (%)	Yield Decrease (%)	Yield Loss (kg/ha)	Total Yield Loss (Metric Tons)	Irrigational Water Volume (Thousand m^3)	Loss of Revenue (Thousand USD)	Water Deficiency Cost (USD/m^3)
604.20	1777.06	100	0.00	0.00	0.00	3373.39	0.00	----
543.80	1599.41	90	2.00	600.00	1138.98	3036.16	144.34	0.05
483.37	1421.67	80	4.97	1490.00	2828.47	2698.76	358.45	0.13
422.93	1243.92	70	7.37	2210.00	4195.24	2361.33	531.66	0.23
362.50	1066.18	60	10.37	3110.00	5903.71	2023.93	748.17	0.37
302.10	888.53	50	13.53	4060.00	7707.10	1686.70	976.71	0.58
241.70	710.88	40	17.97	5390.00	10,231.84	1349.46	1296.66	0.96
181.27	533.14	30	22.23	6670.00	12,661.66	1012.06	1604.59	1.59
120.83	355.39	20	28.53	8560.00	16,249.45	674.64	2059.26	3.05
60.40	177.65	10	35.40	10,620.00	20,159.95	337.23	2554.84	7.58

Table A8. Expected yield and revenue loss of apricot in case of water constraints.

Crop Water Demand (dn, mm)	Irrigation Water Demand (dt, m^3/ha/y)	Irrigation Rate (%)	Yield Decrease (%)	Yield Loss (kg/ha)	Total Yield Loss (Metric tons)	Irrigational Water Volume (Thousand m^3)	Loss of Revenue (Thousand SUD)	Water Deficiency Cost (USD/m^3)
589.97	1735.20	100	0.00	0.00	0.00	6125.26	0.00	-----
531.07	1561.96	90	2.20	321.04	1133.27	5513.72	282.39	0.05
472.03	1388.33	80	4.23	617.76	2180.68	4900.81	543.40	0.11
413.03	1214.80	70	9.57	1396.03	4927.99	4288.24	1227.98	0.29
354.00	1041.18	60	15.80	2305.64	8138.92	3675.37	2028.09	0.55
295.07	867.84	50	19.60	2860.16	10,096.38	3063.48	2515.86	0.82
236.07	694.31	40	25.80	3764.91	13,290.13	2450.91	3311.70	1.35
177.03	520.69	30	31.33	4572.37	16,140.47	1838.04	4021.96	2.19
118.03	347.16	20	36.80	5370.10	18,956.46	1225.48	4723.66	3.85
59.00	173.53	10	40.50	5910.03	20,862.41	612.56	5198.59	8.49

Table A9. Expected yield and revenue loss of peach in case of water constraints.

Crop Water Demand (dn, mm)	Irrigation Water Demand (dt, m^3/ha/y)	Irrigation Rate (%)	Yield Decrease (%)	Yield Loss (kg/ha)	Total Yield Loss (Metric tons)	Irrigational Water Volume (Thousand m^3)	Loss of Revenue (Thousand USD)	Water Deficiency Cost (USD/m^3)
571.55	1681.03	100	0.00	0.00	0.00	351.84	0.00	-----
514.40	1512.94	90	2.85	513.00	107.37	316.66	24.46	0.08
457.25	1344.85	80	7.00	1260.00	263.72	281.48	60.08	0.21
400.05	1176.62	70	9.35	1683.00	352.25	246.27	80.25	0.33
342.90	1008.53	60	13.90	2502.00	523.67	211.09	119.31	0.57
285.80	840.59	50	19.70	3546.00	742.18	175.94	169.09	0.96
228.65	672.50	40	22.35	4023.00	842.01	140.76	191.83	1.36
171.50	504.41	30	25.65	4617.00	966.34	105.57	220.16	2.09
114.30	336.18	20	34.60	6228.00	1303.52	70.36	296.98	4.22
57.15	168.09	10	41.70	7506.00	1571.01	35.18	357.92	10.17

Table A10. Standard errors of regression coefficients for the relationship between irrigation rate (x) and logarithm of water deficiency cost (log(y)).

Crop	Coefficient a	Standard Error (a)	Coefficient b	Standard Error (b)	R^2
Wheat	1.8624	0.053	−0.053	0.006	0.9613
Maize	5.9854	0.065	−0.062	0.007	0.9773
Clover	365.16	3.65	−0.063	0.007	0.9668
Tomato	18.053	0.180	−0.062	0.006	0.9834
Watermelon	11.5	0.115	−0.059	0.006	0.9774
Melon	10.789	0.108	−0.059	0.006	0.9656
Apple	10.743	0.107	−0.058	0.006	0.9711
Apricot	15.028	0.150	−0.060	0.007	0.9902
Peach	14.026	0.140	−0.055	0.006	0.9668

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