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Article

Examining Crop Yield Losses in Igdır Plain Irrigation Systems in Turkiye Amidst Water Constraints

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Abstract: Türkiye, located in the Mediterranean Basin, has started to experience the impacts of climate change, primarily manifesting in severe droughts that significantly affect agricultural output. Water stands as a crucial component in agricultural production. This study aims to propose water efficiency measures essential for climate change adaptation. By accessing pertinent data, particularly in agriculturally reliant developing nations, this research endeavours to analyse yield losses in major crops within agricultural regions using the most suitable methodologies. Furthermore, it seeks to ascertain the financial ramifications of such losses. The methodological framework devised for this purpose was implemented in Türkiye's Iğdır Plain, selected as the study site. In 2022, the Iğdır province received 40% less precipitation than its usual levels. This study anticipates substantial losses in agricultural yield due to water scarcity resulting from prolonged drought conditions. Analysis reveals that among the crops cultivated in the region, clover belonging to the field crops category exhibits the highest water dependency, while apricot demonstrates the least reliance on water resources. In light of these considerations, the recommended crop rotation for the Iğdır Plain under water constraints comprises wheat, watermelon, maize, melon, apple, and apricot. Emphasizing enhanced water transmission and utilization efficiency, particularly in irrigation zones, prioritizing water stress-resistant crops within basin crop patterns, and favouring alternative crops over those demanding excessive water will foster sustainable water resource management. This approach encourages farmers to actively engage in the adaptation process 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.

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

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1. Introduction

The globally increasing population also increases the demand for agricultural products and food [5-28-45]. Climate change-induced risks and uncertainties are on the rise, while simultaneous urbanisation and industrialisation trends are exerting pressure on agricultural production, impacting environmental integrity, soil health, and water resources [7-8-16-21-49-64]. This pressure on natural resources and the environment is intensifying both in terms of quantity and quality [4-47]. Conversely, natural resources and the environment represent scarce factors of production [62]. The self-renewal capability and capacity 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 [11], and conflicts and crises impacting food security have amplified the importance of agricultural production within the natural environment. Presently, agricultural production emerges as a strategic sector irrespective of a country's level of development. The growing population alongside the dwindling and declining quality of agricultural areas, natural environment, and water resources are transforming agricultural production into a sector that not only contributes to production but also influences economic [1], social and political decision-making [33] processes.

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In order to ensure the supply that can meet the increasing de"mand, the importance attached to awareness, efficiency, appropriate use and protection of natural resources and the environment, in addition to new technologies, is increasing. Conversely, the matter of water economy has gained greater significance due to water being subject to sectoral competition.

Agricultural irrigation involves fulfilling the water requirements of plants through artificial methods when natural precipitation is insufficient for the plants to complete their development under natural circumstances [17]. To comprehensively characterise all aspects of the water supply chain for agricultural irrigation, it's essential to gather all relevant data and assess the current situation of the irrigation area accordingly. To comprehensively characterise all aspects of the water supply chain for agricultural irrigation, it's essential to gather all 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, as well as identifying any issues within the system. The various ratios outlined below are utilised to evaluate water efficiency in irrigation areas [51]. 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 Turkiye, a nation that remains predominantly agrarian. 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 nation that remains predominantly agrarian. Positioned within the semi-arid climatic belt, Türkiye has increasingly felt the repercussions of climate change on its water resources, particularly in recent years. Consequently, institutions have intensified their efforts to address this pressing concern.

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

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

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

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

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

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

This ratio is the ratio of the total irrigation water need of the crop, to the amount of water taken from the water source to the network

$$\text{Irrigation Water Use Efficiency (Wue) (kg/ha and mm)} = Yi/ET \quad (4)$$

This ratio is the result of the yield (Yi)(kg/ha) of the irrigated crop to the evapotranspiration (ET) (seed to harvest) of the crop considered (mm).

$$\text{Water Productivity Wp (kg/m}^3\text{)} = Cp/Wu \quad (5)$$

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 to be achieved and establishing the initial measures required to achieve these goals. The general approach here is to identify Key Performance Indicators (KPIs) that will aid in monitoring the increase of productivity over time. When determining the KPI value, one should start from calculating the current value and then establish the targeted values by employing pertinent criteria, which can be attained by adopting the best international technologies and practices. Some KPIs that can be utilised are outlined in Table 1 [51].

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Table 1. Key performance indicators for agricultural irrigation [51].

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 (x100). **Transmission Performance (%):** The ratio of water directed for irrigation to the water volume at the beginning of the transmission line (x100). **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 Demands (m^3/ha):** The ratio of the amount of water used for each crop to the surface area of the crop considered. **Irrigation System Performance (for flood, sprinkler and drip irrigation systems) (%):** The ratio of the evapotranspiration of the considered crop to the volume used for irrigation by the system considered (x100). **Application Performance (%):** The ratio of the evapotranspiration of the considered crop to the volume of water allocated for irrigation of the crop considered (x100). **Crop Yield Performance (m^3/kg):** The ratio of the volume of water allocated for irrigation of the crop considered (m^3/ha) to the crop yield (kg/ha). **Water Use Performance (kg/m^3):** The ratio of (yield of the irrigated crop-yield of the non-irrigated crop) to the volume of water allocated for irrigation of the crop considered (x100).

Key Performance Indicators (KPIs) aimed at enhancing irrigation efficiency and addressing climate change and droughts can vary depending on the country, irrigation systems, and the characteristics of irrigated areas. Regardless of the indicators employed, they are founded on the principle of utilising water effectively and in alignment with the policies of the respective countries.

As cultivated areas continue to expand in the arid regions of Northwest China, which are affected by climate change and droughts, the demand for irrigation water is also on the rise, highlighting the importance of irrigation efficiency. Water balance has been employed as a Key Performance Indicator (KPI), and it has been determined that water-saving technologies enhance water efficiency. This, in turn, is expected to have a positive impact on the economy of irrigation areas [15]. Research has been conducted to enhance water transmission efficiency in the Yangtze River Economic Zone, where irrigation is regarded as a significant benchmark for economic and social progress in China. Findings suggest that the technical efficiency of water transmission is low and exhibits a gradual downward trend. It was concluded that this situation arises from the spatial structure, complexity, and distribution of water transmission, necessitating the implementation of remedial measures [26].

A research study was undertaken to assess the water application efficiency of surface irrigation methods within the Nara Canal Area Irrigation zone in Pakistan. On-site measurements were conducted to evaluate water application efficiencies for both border and furrow irrigation techniques. Key Performance Indicators (KPIs) such as moisture content, field capacity, discharge water, and irrigation time were utilized in the analysis. The study concluded that the chosen irrigation method had a notable influence on crop yield [38].

Decision support tools for precise irrigation planning are essential to enhance the efficiency of irrigation water usage globally. In a study conducted in the USA, water use and efficiency were examined, employing water retention capacity, water use rate, drainage water, leakage, and water use efficiency as Key Performance Indicators (KPIs) in irrigation planning. The 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 irrigation water savings ranging from 9% to 19%, while also reducing water losses through drainage and leakage by 25% to 45% [27].

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In the South Bekaa irrigation area in Lebanon, a further study was conducted focusing on sustainable production. This study analysed parcels where wheat, potatoes, onions, silage maize, and peaches were grown, considering annual irrigation water supply per unit irrigated area and yield performance criteria. Upon comparison with wheat, it was found that 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 per unit of irrigation supply, calculated as 3,987 €/m3 and 3,588 €/m3, respectively [31].

Utilising data from the Ministry of Water and Irrigation in Kenya, a correlation analysis was performed to ascertain any relationships between the independent and dependent variables in the trend analyses conducted on the irrigation Key Performance Indicators (KPIs). The findings indicate a robust positive correlation between water budget, irrigation services, and efficiency parameters [23].

Enhancing water efficiency in agricultural production stands as one of the foremost 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 conducted in eastern Spain evaluated various Key Performance Indicators (KPIs) encompassing service delivery performance, applied irrigation, production efficiency, and economic efficiency. The influence of factors such as crop types, farmer profiles, and cultivation area sizes was assessed based on the productivity of orchards and irrigation performance. Productivity and economic efficiency indicators revealed that the impact of irrigation on water efficiency serves as a crucial indicator, with observed reductions of 66% in production efficiency for some crops and a 50% decrease in economic efficiency [46].

In a separate study, the correlations between water supply service performance and satisfaction in Jordan were examined. The study deduced that both water quantity and quality have an impact on satisfaction levels regarding water service. Specifically, it was found that overall satisfaction with sufficient water quantity and quality showed significant associations with operating ratio ($R=0.84$, $P < 0.01$) and weekly water supply hours ($R=0.69$, $P < 0.05$) as indicated by correlation coefficients [42].

Numerous studies have been conducted worldwide concerning 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 [2-3-14-18-22-24-29-30-34-37-41-48-50-66-67].

The primary objective of this research is to provide recommendations for water efficiency measures within the context of climate change adaptation. This is achieved by accessing and analysing data, particularly in developing countries of an agrarian nature, to assess yield losses of major crops in agricultural areas using the most suitable methods, and determining associated financial losses. The developed methodological approach was applied in the Iğdır Plain, selected as the study area, thereby demonstrating the applicability of the methodology in a specific region and elucidating potential results. Additionally, the study aimed to assess the feasibility of replicating this case study in other countries.

2. Material and Method

2.1. Working Methodology

The methodology will be applied using data obtained from the selected area, which has been designated as Turkiye-Iğdır Plain. The 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 on the irrigated cultivation area in the plain. Field crops constitute 88.11% of the cultivated area within the scope of agricultural irrigation in the plain, with cereals accounting for 29.11%, legumes for 0.14%, and forage crops for 58.86%. Among cereals, wheat is the most cultivated

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crop, 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 pattern and cultivation areas of the irrigated areas are detailed in Table 2.

Table 2. Iğdır Plain Irrigated Areas Crop Pattern and Cultivation Areas.

Crop pattern in the plain	Total (Hectares)	Ratio (%)
Barley	3,067.70	0.057
Wheat*	11,455.00	0.212
Bean (dried)	57.00	0.001
Vetch (Green Grass)	200.00	0.004
Sainfoin (green grass)	1,450.00	0.027
Maize (Grain) - First Cultivation	2.595,00	0.048
Maize (Silage) *	6,327.60	0.117
Chickpeas	31.50	0.001
Cotton (Unseed) - First Cultivation	310.00	0.006
Potato (Other) - First Cultivation	60.20	0.001
Sugar Beet	146.60	0.003
Clover (greengrass)*	28,115.00	0.520
Paddy - First Cultivation	205.00	0.004
Total of Field Crops	**54,020.60**	**100.00**
Pepper	150.30	0.042
Tomato (Table)*	949.70	0.267
Beans (Fresh)	104.30	0.029
Cucumber (Table)	234.30	0.066
Spinach	45.00	0.013
Watermelon*	858.30	0.242
Melon*	1,066.30	0.300
Aubergine	142.50	0.040
Total of Vegetables	**3,550.70**	**100.00**
Pear	35.00	0.006
Apple*	1,898.30	0.324
Plum	29.70	0.005
Apricot*	3,530.00	0.602
Cherries	40.00	0.007
Peach*	209,30	0.036
Walnut	110.00	0.019
Cherry	13.50	0.002
Total of Fruits	**5,865.80**	**100.00**
Total of Irrigated Crops	**63,437.10**	**100.00**

*Crops assessed using data in this study from 3 different crop groups grown in the plain are: field crops, vegetables and fruits.

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.

Crop water requirements and irrigation water requirements were determined based on yields. Subsequently, the irrigation water requirement was reduced by 10%, and the resulting yield losses were calculated per hectare. Following that, the overall crop losses stemming from a 10% water constraint were computed, taking into account the total cultivation area.

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Crop pattern, yields and sales prices of Iğdır Plain irrigation area are determined by the average of the data from the statistics of the Ministry of Agriculture and Forestry [57], the Directorate General for Plant Production [12], the Provincial Directorate of Agriculture and Forestry of Iğdır, and the Turkish Statistical Institute (TUIK) between 2014 and 2021 [60]. The revenue loss attributed to water constraints in each segment was determined by multiplying the productivity loss in that segment by the crop price and the cultivation area. Subsequently, the revenue loss due to water constraints was divided by the restricted water amount to obtain the water constraint value ($/m3). The crop water requirements of the crops cultivated in the plain and the yield relationships under water constraints were determined using the Water Consumption Guide of Irrigated Plants in Turkiye [54] and CROPWAT 8.0 software [21].

Where:

$$dn = ETc - Pe \tag{6}$$

dn = Net irrigation water requirement of the crop (mm),

ETc = Crop Evapotranspiration (mm),

Pe = Effective precipitation (mm) (80% of the precipitation is accepted as effective precipitation).

Total irrigation water requirement is calculated by dividing the net irrigation water need by the multiplied result of water application and transmission efficiencies [65].

$$dt = dn / (Ea*Ec) \tag{1}$$

dt = Total irrigation water need (mm), Ec = Water transmission efficiency, Ea = Water application efficiency.

Irrigation efficiency is calculated by multiplying the results of water transmission efficiency and water application efficiency, and then adjusting the proportion based on data from relevant institutions [20–52]. Based on this, the average irrigation efficiency of the plain is determined to be 34%. Subsequently, after determining the crop water requirement (dn) and irrigation water requirement (dt), the total water requirement 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.

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

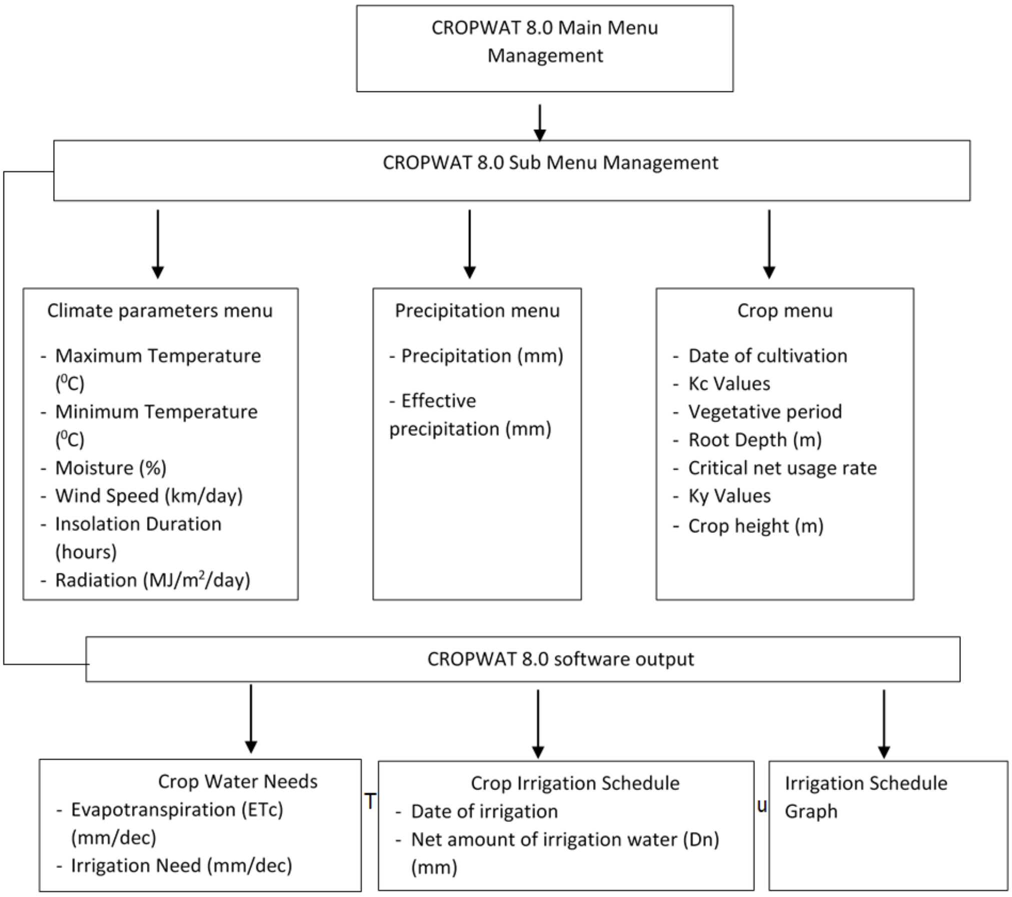

Figure 1. CROPWAT 8.0 software.

2.2. Working 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 km², while Iğdır province covers an area of 3,665 km². The location of Iğdır province within Türkiye is depicted in Figure 2 [43].

In 2022, the population of Iğdır was 203,594, with 42% of the population residing in rural areas [61]. Iğdır's main source of income is based on agricultural activities [53]. The plain has gained economic significance since the commencement of irrigation projects in the 1960s. Its features, including micro-climatic conditions, soil quality, and environmental factors, enable the cultivation of a diverse range of agricultural crops.

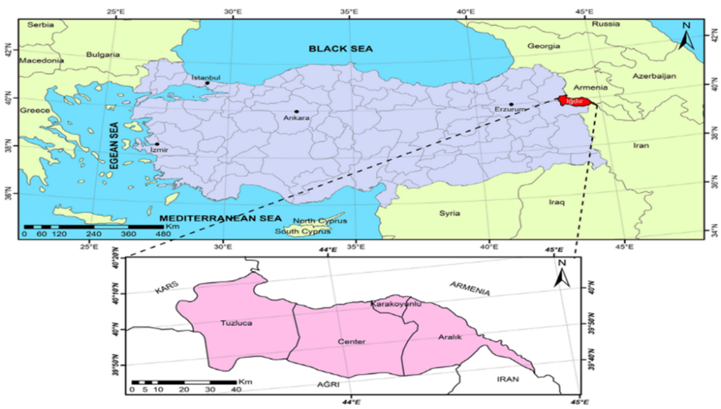

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Figure 2. The geographical location of Iğdır and Türkiye [43].

As a result of this diversity, the plain has contributed to the social, economic, and agricultural development of Iğdır. It has emerged as an agricultural hub meeting the agricultural product requirements of other provinces in the region. Recognizing its significance, the plain was designated as a Protection Area by the decision of the Council of Ministers in 2017.

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 agricultural land opened to irrigation is 71,156 ha, while the net area is 62,430 ha [19–20–55]. Based on the 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 [39,40]. According to the assessments in 2022, Iğdır province has 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 [19].

3. Results and discussion

Crops highlighted in bold in Table 2, including 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, were assessed using data from this study. The results primarily focus on the yield and revenue losses of the selected crops.

Field Crops

The total cultivation area of field crops is 54,020.60 ha, accounting for 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%), respectively. Together, these top three crops comprise 80.80% of the total field crop pattern.

Wheat

The total cultivation area of wheat, which ranks second in terms of cultivation area among the field crops group, is 11,455.00 ha. The average sales price in 2022 has been recorded as $175.85 per ton. The expected yield and revenue loss amounts in the event of water deficiency are listed in Table 3. Wheat is a crop included in the basin-based support system and holds significant importance globally and within Türkiye. It is among the most consumed, domestically processed, and exported products in Türkiye [13]. Wheat finds applications in various food and industrial sectors, particularly in bakery products. Moreover, it serves as the primary food source for 50 countries globally, providing 20% of the total calories obtained from plant-based foods. Notably, in Türkiye, this rate is even higher, accounting for 53% of total calorie intake from plant-based foods [59].

Table 3. Expected yield and revenue losses of wheat in case of water deficiency.

Dn	Dt (34%)	Irrigation rate (%)	Decrease in the yield (%)	Yield Loss (kg/ha)	Total Yield Loss (Tons)	Total Water Need (Thousand m^3)	Loss of Revenue (Thousand $)	Constraint Value of Water ($/$m^3$)
357.57	1,051.68	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	1,613.44	9,638.01	283.73	0.03

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Dn	Dt (34%)	Irrigation rate (%)	Decrease in the yield (%)	Yield Loss (kg/ha)	Total Yield Loss (Tons)	Total Water Need (Thousand m³)	Loss of Revenue (Thousand $)	Constraint Value of Water ($/m³)
250.27	736.09	70	5.03	226.35	2,592.84	8,431.91	455.96	0.05
214.53	630.97	60	6.83	307.35	3,520.69	7,227.76	619.13	0.09
178.80	525.88	50	8.80	396.00	4,536.18	6,023.96	797.70	0.13
143.03	420.68	40	9.67	435.15	4,984.64	4,818.89	876.57	0.18
107.30	315.59	30	11.87	534.15	6,118.69	3,615.08	1075.99	0.30
71.50	210.29	20	16.53	743.85	8,520.80	2,408.87	1498.41	0.62
35.77	105.21	10	19.57	880.65	10,087.85	1,205.18	1773.98	1.47

Wheat experiences significant revenue loss due to water constraints attributed to climate change and drought. Figure 3 illustrates the graph of the water constraint value based on water restrictions. According to the trend depicted, the regression coefficient is calculated to be 62.91%. As water constraints intensify for wheat cultivation, both yield and revenue decrease accordingly. Moreover, as the irrigation rate declines, the unit value of water increases.

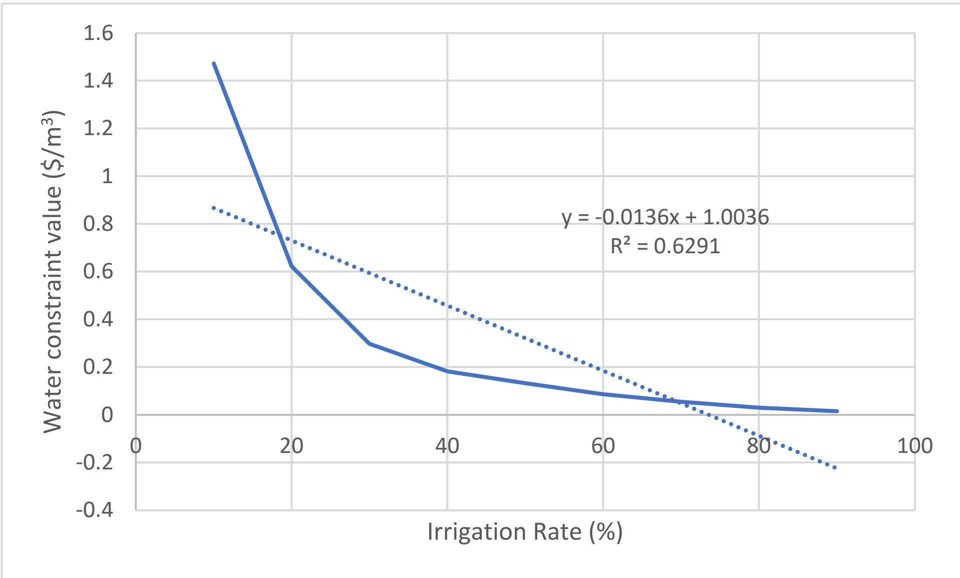

Figure 3. Water constraint value ($/m³) in case of water restrictions on wheat.

Maize (Silage)

The total cultivation area of first cultivation silage maize, which ranks third in terms of cultivation area among the field crops group, is 4,182.60 ha. The average sales price in 2022 has been recorded as $29.19 per ton. The expected yield and revenue loss amounts in the event of water deficiency are listed in Table 4. Silage maize, utilized in livestock farming, holds significance as a forage crop used in feed rations, particularly during periods when juicy and green grass is scarce. It is a product included in the basin-based support system.

Table 4. Expected yield and revenue loss of first cultivation silage maize in case of water deficiency.

Dn	Dt (34%)	Irrigation rate (%)	Decrease in the yield (%)	Yield Loss (kg/ha)	Total Yield Loss (Tons)	Total Water Need (Thousand m³)	Loss of Revenue (Thousand $)	Constraint Value of Water ($/m³)
486.13	1,4291.80	100	0.00	0.00	0.00	5,980.30	0.00	-----
437.50	1,286.76	90	2.20	953.33	3,987.41	5,382.00	116.39	0.02
388.90	1,143.82	80	4.33	1,877.78	7,853.99	4,784.14	229.26	0.05
340.30	1,000.88	70	7.80	3,380.00	14,137.19	4,186.28	412.67	0.10
291.67	857.84	60	10.70	4,636.67	19,393.32	3,588.00	566.10	0.16
243.10	715.00	50	14.03	6,081.11	25,434.85	2,990.56	742.45	0.25

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Dn	Dt (34%)	Irrigation rate (%)	Decrease in the yield (%)	Yield Loss (kg/ha)	Total Yield Loss (Tons)	Total Water Need (Thousand m³)	Loss of Revenue (Thousand $)	Constraint Value of Water ($/m³)
194.47	571.96	40	17.83	7,727.78	32,322.20	2,392.28	943.49	0.39
145.83	428.92	30	29.43	12,754.44	53,346.74	1,794.00	1557.20	0.87
87.23	256.57	20	33.40	14,473.33	60,536.16	1,073.13	1767.06	1.65
48.63	143.04	10	47.03	20,381.11	85,246.03	598.28	2488.35	4.16

First cultivation silage maize experiences significant revenue loss due to water constraints associated with climate change and drought. Figure 4 displays the graph of the water constraint value based on water restrictions. According to the depicted trend, the regression coefficient is calculated to be 61.33%. As water constraints intensify for first cultivation silage maize, both yield and revenue decrease accordingly. Furthermore, as the irrigation rate decreases, the unit value of water increases.

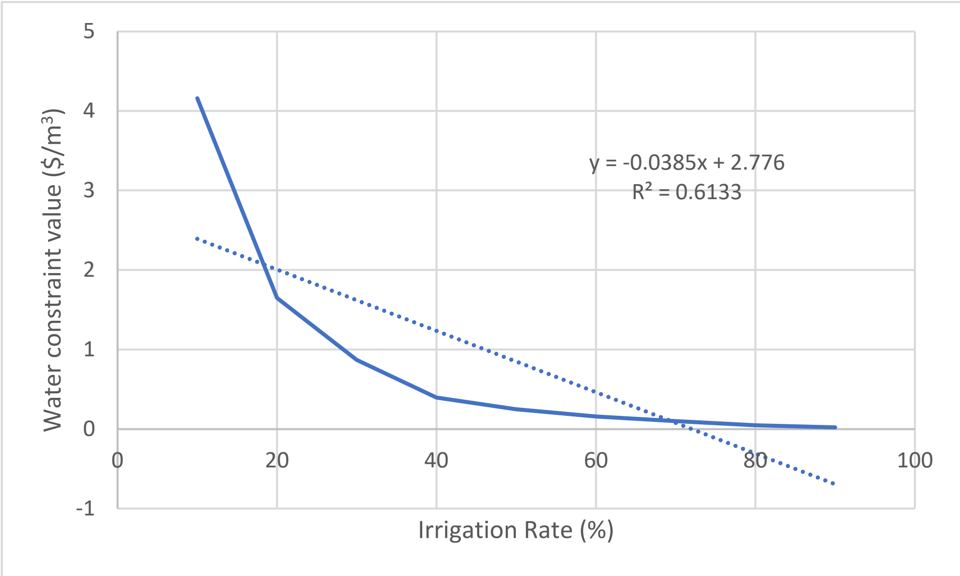

Figure 4. Water constraint value ($/m³) in case of water restrictions on first cultivation silage maize.

Clover

The total cultivation area of clover, which holds the largest cultivation area among the field crops group, is 28,115.00 ha. The average sales price in 2022 has been $96.11 per ton. The expected yield and revenue loss amounts in the event of water deficiency are listed in Table 5. The Eastern Anatolia Region is one of the most crucial livestock regions in Türkiye. In the livestock sector, feed constitutes the most significant cost, accounting for approximately 70% of the total expenses [6,7]. Clover is a forage crop and is included in the basin-based product support system. This system is applied to crops that experience a supply deficit and are deemed strategically important in Turkiye [58]. Clover holds significant importance as a forage crop utilised for animal fodder. Additionally, it can be employed for pasture improvement, erosion control, and green manure within the framework of environmental protection and sustainable agricultural practices.

Table 5. Expected yield and revenue losses of clover in case of water deficiency.

Dn	Dt (34%)	Irrigation rate (%)	Decrease in the yield (%)	Yield Loss (kg/ha)	Total Yield Loss (Tons)	Total Water Need (Thousand m³)	Loss of Revenue (Thousand $)	Constraint Value of Water ($/m³)
568.37	1,671.67	100	0.00	0.00	0.00	46,999.00	0.00	----
511.53	1,504.51	90	1.40	20,066.66	5,641.74	42,299.30	54225.11	1.28
454.70	1,337.35	80	2.30	32,966.66	9,268.58	37,599.60	89084.12	2.37
397.87	1,170.20	70	4.53	64,977.76	18,268.50	32,900.17	175586.07	5.34
341.00	1,002.94	60	7.20	103,199.98	29,014.67	28,197.66	278872.02	9.89

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Dn	Dt (34%)	Irrigation rate (%)	Decrease in the yield (%)	Yield Loss (kg/ha)	Total Yield Loss (Tons)	Total Water Need (Thousand m³)	Loss of Revenue (Thousand $)	Constraint Value of Water ($/m³)
284.23	835.98	50	8.97	128,522.19	36,134.01	23,503.58	347298.93	14.78
227.37	668.73	40	11.97	171,522.18	48,223.46	18,801.35	463495.60	24.65
170.53	501.57	30	15.57	223,122.17	62,730.80	14,101.64	602931.61	42.76
113.67	334.31	20	23.93	343,044.36	96,446.92	9,399.13	926991.20	98.63
56.87	167.25	10	32.27	462,488.78	130,028.72	4,702.24	1249759.74	265.78

Clover experiences a considerable loss of revenue due to water constraints associated with climate change and drought. Figure 5 illustrates the graph of the water constraint value based on water restrictions. According to the depicted trend, the regression coefficient is calculated to be 58.20%. As water constraints intensify for clover cultivation, both yield and revenue decrease accordingly. Moreover, as the irrigation rate declines, the unit value of water increases.

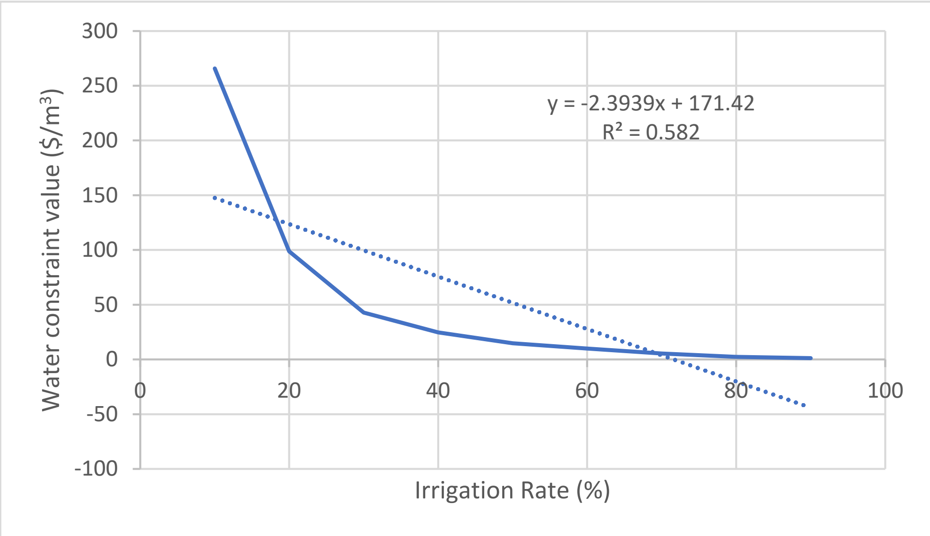

Figure 5. Water constraint value ($/m³) in case of water restrictions on clover.

Vegetable Crops Group

The total cultivation area in the irrigated lands amounts to 3,550.70 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.

Tomatoes

The cultivation area of table tomatoes, which ranks second among the vegetable crops group, is 949.70 ha. The average sales price in 2022 has been $94.34 per ton. The expected yield and revenue loss amounts in the event of water deficiency are listed in Table 6. 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 [32].

Table 6. Expected yield and revenue loss of table tomatoes in case of water deficiency.

Dn	Dt (34%)	Irrigation rate (%)	Decrease in the yield (%)	Yield Loss (kg/ha)	Total Yield Loss (Tons)	Total Water Need (Thousand m³)	Loss of Revenue (Thousand $)	Constraint Value of Water ($/m³)
560.00	1,647.06	100	0.00	0.00	0.00	1,564.21	0.00	----
504.00	1,482.35	90	2.20	836.00	793.95	1,407.79	74.90	0.05
448.00	1,317.65	80	4.90	1,862.00	1,768.34	1,251.37	166.82	0.13
392.00	1,152.94	70	8.57	3,255.33	3,091.59	1,094.95	291.64	0.27
335.97	988.14	60	13.57	5,155.33	4,896.02	938.44	461.86	0.49
280.03	823.63	50	18.90	7,182.00	6,820.75	782.20	643.43	0.82

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Dn	Dt (34%)	Irrigation rate (%)	Decrease in the yield (%)	Yield Loss (kg/ha)	Total Yield Loss (Tons)	Total Water Need (Thousand m³)	Loss of Revenue (Thousand $)	Constraint Value of Water ($/m³)
224.03	658.92	40	25.30	9,614.00	9,130.42	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 tomatoes experience significant revenue loss due to water constraints associated with climate change and drought. Figure 6 illustrates the graph of the water constraint value based on water restrictions. According to the depicted trend, the regression coefficient is calculated to be 63.15%. As water constraints intensify for table tomatoes, both yield and revenue decrease accordingly. Furthermore, as the irrigation rate declines, the unit value of water increases.

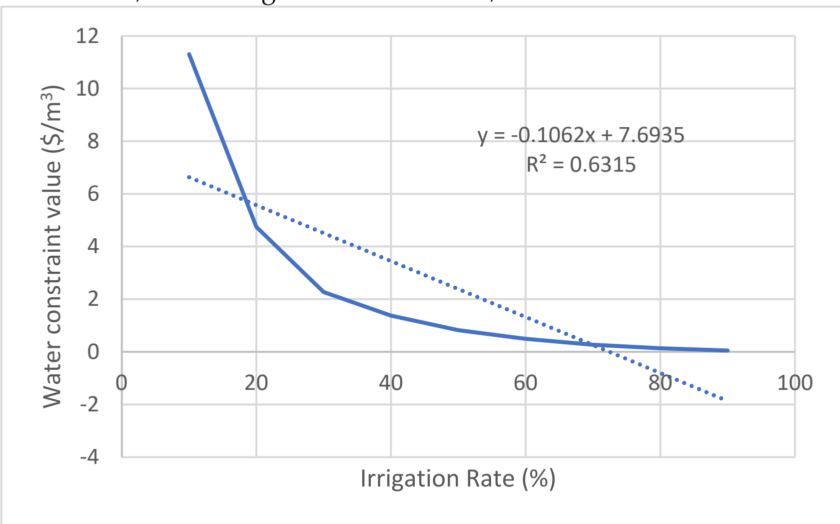

Figure 6. Water constraint value ($/m³) in case of water restrictions on table tomato.

Watermelon

Table 858. 30 ha. The average sales price in 2022 has been $86.86 per ton. The expected yield and revenue loss amounts in the event of water deficiency are listed in Table 7. Besides their rich nutritional content, watermelon and melon offer various advantages. They can be consumed fresh, their seeds can be used as snacks, and their rinds hold export value. Moreover, the utilisation of melon and watermelon rinds in the food, natural medicine, and cosmetics sectors has gained importance recently, positioning them as strategic export products [9].

Table 7. Expected yield and revenue loss of watermelon in case of water deficiency.

Dn	Dt (34%)	Irrigation rate (%)	Decrease in the yield (%)	Yield Loss (kg/ha)	Total Yield Loss (Tons)	Total Water Need (Thousand m³)	Loss of Revenue (Thousand $)	Constraint Value of Water ($/m³)
450.57	1,325.20	100	0.00	0.00	0.00	1,137.42	0.00	-----
405.50	1,192.65	90	1.97	662.11	568.29	1,023.65	49.36	0.05
360.47	1,060.20	80	4.20	1,414.00	1,213.64	909.97	105.41	0.12
315.40	927.65	70	6.60	2,222.00	1,907.14	796.20	165.65	0.21
270.33	795.10	60	10.40	3,501.33	3,005.19	682.44	261.03	0.38
225.23	662.45	50	14.93	5,027.56	4,315.15	568.58	374.81	0.66
180.23	530.10	40	18.60	6,262.00	5,374.68	454.99	466.84	1.03
135.17	397.55	30	23.83	8,023.89	6,886.90	341.22	598.19	1.75
90.10	265.00	20	27.53	9,269.56	7,956.06	227.45	691.05	3.04
45.07	132.55	10	33.83	11,390.56	9,776.51	113.77	849.18	7.46

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Watermelon experiences a considerable revenue loss due to water constraints associated with climate change and drought. Figure 7 depicts the graph of the water constraint value based on water restrictions. According to the depicted trend, the regression coefficient is calculated to be 64.81%. As water constraints on watermelon cultivation intensify, both yield and revenue decrease accordingly. Additionally, as the irrigation rate declines, the unit value of water increases.

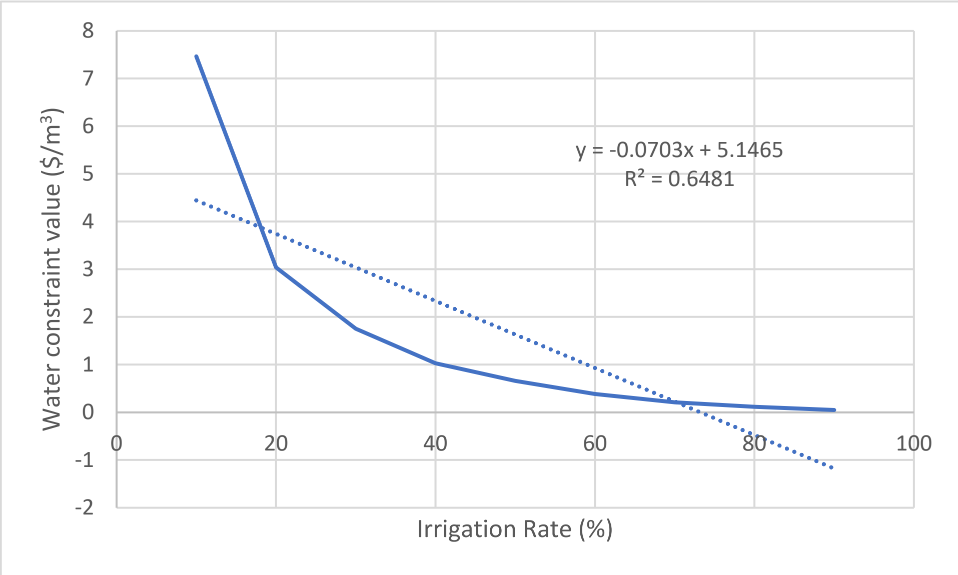

Figure 7. Water constraint value ($/m^3) in case of water restrictions on watermelon.

Melon

The cultivation area of melon, which is the most planted crop among the vegetable product group, is 1,066.30 ha. The average sales price in 2022 has been $124.59 per ton. The expected yield and revenue loss amounts in the event of water deficiency are listed in Table 8. Melon and watermelon are among the most produced and consumed vegetables globally and in Türkiye [9]. 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 8. Expected yield and revenue loss of melon in case of water deficiency.

Dn	Dt (34%)	Irrigation rate (%)	Decrease in the yield (%)	Yield Loss (kg/ha)	Total Yield Loss (Tons)	Total Water Need (Thousand m^3)	Loss of Revenue (Thousand $)	Constraint Value of Water ($/m^3)
465.33	1,368.63	100	0.00	0.00	0.00	1,459.37	0.00	----
418.83	1,231.86	90	2.10	471.74	503.02	1,313.53	62.67	0.05
372.27	1,094.90	80	3.67	823.67	878.28	1,167.49	109.43	0.09
325.73	958.04	70	6.63	1,490.10	1,588.89	1,021.56	197.96	0.19
279.20	821.18	60	11.63	2,613.29	2,786.55	875.63	347.18	0.40
232.70	684.41	50	14.63	3,287.20	3,505.14	729.79	436.71	0.60
186.13	547.45	40	17.90	4,021.02	4,287.61	583.75	534.20	0.91
139.63	410.69	30	22.80	5,121.75	5,461.32	437.92	680.44	1.55
93.07	273.73	20	27.17	6,102.67	6,507.27	291.88	810.76	2.78
46.53	136.86	10	36.30	8,154.36	8,694.99	145.93	1083.33	7.42

Melon experiences a significant revenue loss due to water constraints associated with climate change and drought. Figure 8 illustrates the graph of the water constraint value based on water restrictions. According to the depicted trend, the regression coefficient is calculated to be 61.83%. As water constraints on melon cultivation intensify, both yield and revenue decrease accordingly. Additionally, as the irrigation rate declines, the unit value of water increases.

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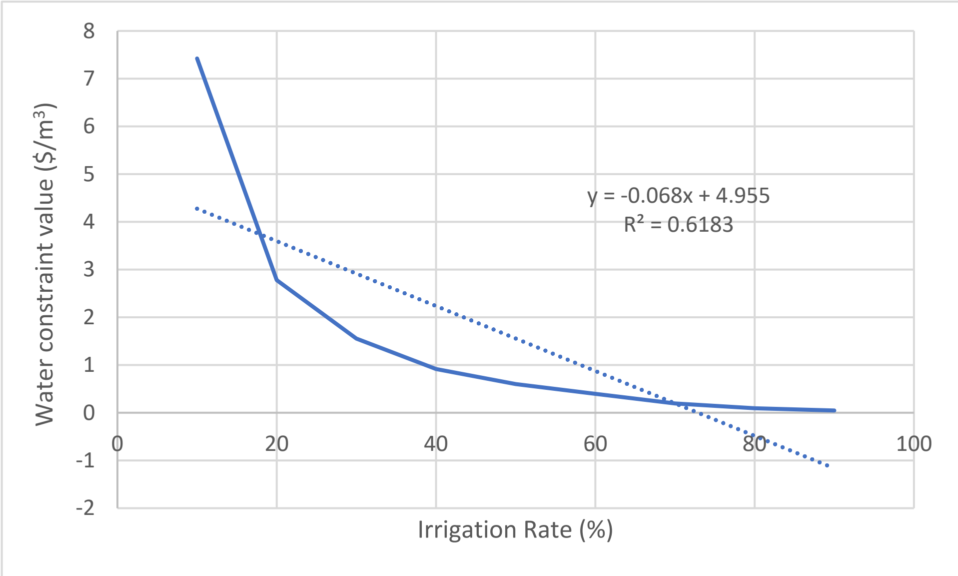

Figure 8. Water constraint value ($/m^3$) in case of water restrictions on melon.

Fruit Group

The fruit growing industry is one of Türkiye's most significant agricultural sectors, contributing significantly to income, employment, and economic development [10]. The total irrigated fruit area amounts to 5,865.80 ha, representing 9.25% of the total irrigation area. The top three most planted 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.

Apple

The cultivation area of apple, which ranks second in terms of cultivation area among the fruit product group, is 1,898.30 ha. The average sales price in 2022 has been $126.73 per ton. The expected yield and revenue loss amounts in the event of water deficiency are listed in Table 9. Türkiye holds the fourth position in world apple production and ranks eighth in exports [56]. Apple accounts for 5.3% of Türkiye's total fruit area and 0.7% of its total agricultural area [10].

Table 9. Expected yield and revenue loss of apple in case of water deficiency.

Dn	Dt (34%)	Irrigation rate (%)	Decrease in the yield (%)	Yield Loss (kg/ha)	Total Yield Loss (Tons)	Total Water Need (Thousand m³)	Loss of Revenue (Thousand $)	Constraint Value of Water ($/m³)
604.20	1,777.06	100	0.00	0.00	0.00	3,373.39	0.00	----
543.80	1,599.41	90	2.00	600.00	1,138.98	3,036.16	144.34	0.05
483.37	1,421.67	80	4.97	1,490.00	2,828.47	2,698.76	358.45	0.13
422.93	1,243.92	70	7.37	2,210.00	4,195.24	2,361.33	531.66	0.23
362.50	1,066.18	60	10.37	3,110.00	5,903.71	2,023.93	748.17	0.37
302.10	888.53	50	13.53	4,060.00	7,707.10	1,686.70	976.71	0.58
241.70	710.88	40	17.97	5,390.00	10,231.84	1,349.46	1296.66	0.96
181.27	533.14	30	22.23	6,670.00	12,661.66	1,012.06	1604.59	1.59
120.83	355.39	20	28.53	8,560.00	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

Apple experiences significant revenue loss due to water constraints associated with climate change and drought. Figure 9 illustrates the graph of the water constraint value based on water restrictions. According to the depicted trend, the regression coefficient is calculated to be 62.79%. As water constraints on apple cultivation intensify, both yield and revenue decrease accordingly. Additionally, as the irrigation rate declines, the unit value of water increases.

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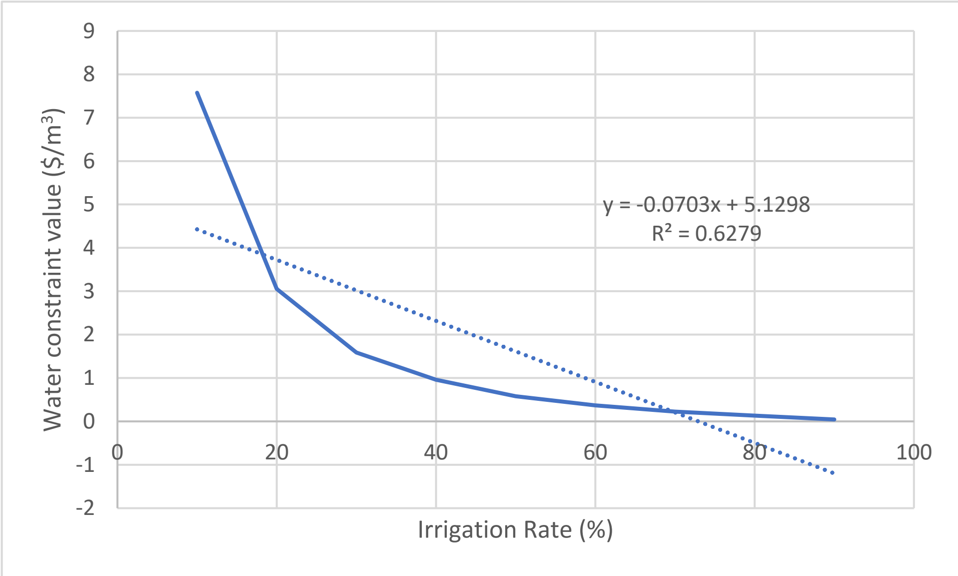

Figure 9. Water constraint value ($/m³) in case of water restrictions on apple.

Apricot

The cultivation area of apricot, which is the most planted crop among the fruit product group, is 3,530.00 ha. The average sales price in 2022 has been $249.19 per ton. The expected yield and revenue loss amounts in the event of water deficiency are listed in Table 10. 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 [44].

Table 10. Expected yield and revenue loss of apricot in case of water deficiency.

Dn	Dt (34%)	Irrigation rate (%)	Decrease in the yield (%)	Yield Loss (kg/ha)	Total Yield Loss (Tons)	Total Water Need (Thousand m³)	Loss of Revenue (Thousand $)	Constraint Value of Water ($/m³)
589.97	1,735.20	100	0.00	0.00	0.00	6,125.26	0.00	-----
531.07	1,561.96	90	2.20	321.04	1,133.27	5,513.72	282.39	0.05
472.03	1,388.33	80	4.23	617.76	2,180.68	4,900.81	543.40	0.11
413.03	1,214.80	70	9.57	1,396.03	4,927.99	4,288.24	1227.98	0.29
354.00	1,041.18	60	15.80	2,305.64	8,138.92	3,675.37	2028.09	0.55
295.07	867.84	50	19.60	2,860.16	10,096.38	3,063.48	2515.86	0.82
236.07	694.31	40	25.80	3,764.91	13,290.13	2,450.91	3311.70	1.35
177.03	520.69	30	31.33	4,572.37	16,140.47	1,838.04	4021.96	2.19
118.03	347.16	20	36.80	5,370.10	18,956.46	1,225.48	4723.66	3.85
59.00	173.53	10	40.50	5,910.03	20,862.41	612.56	5198.59	8.49

Apricot experiences a significant revenue loss due to water constraints associated with climate change and drought. Figure 10 illustrates the graph of the water constraint value based on water restrictions. According to the depicted trend, the regression coefficient is calculated to be 68.55%. As water constraints on apricot cultivation intensify, both yield and revenue decrease accordingly. Additionally, as the irrigation rate declines, the unit value of water increases.

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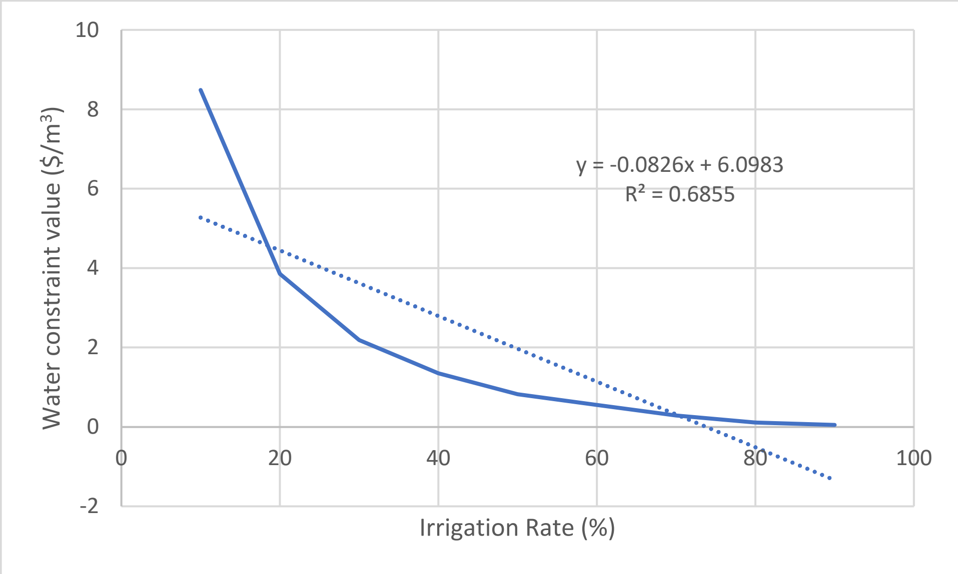

Figure 10. Water constraint value ($/m³) in case of water restrictions on apricot.

Peach

The cultivation area of peach, which ranks third in terms of cultivation area among the fruit product group, is 209.30 ha. The average sales price in 2022 has been $126.73 per ton. The expected yield and revenue loss amounts in the event of water deficiency are listed in Table 11. Peach is an agricultural product that can be consumed fresh or processed. It requires water and holds economic value in the regions where it is grown. Turkiye ranks fifth in the world in peach production and fourth in its exports [63].

Table 11. Expected yield and revenue loss of peach in case of water deficiency.

Dn	Dt (34%)	Irrigation rate (%)	Decrease in the yield (%)	Yield Loss (kg/ha)	Total Yield Loss (Tons)	Total Water Need (Thousand m³)	Loss of Revenue (Thousand $)	Constraint Value of Water ($/m³)
571.55	1,681.03	100	0.00	0.00	0.00	351.84	0.00	-----
514.40	1,512.94	90	2.85	513.00	107.37	316.66	24.46	0.08
457.25	1,344.85	80	7.00	1,260.00	263.72	281.48	60.08	0.21
400.05	1,176.62	70	9.35	1,683.00	352.25	246.27	80.25	0.33
342.90	1,008.53	60	13.90	2,502.00	523.67	211.09	119.31	0.57
285.80	840.59	50	19.70	3,546.00	742.18	175.94	169.09	0.96
228.65	672.50	40	22.35	4,023.00	842.01	140.76	191.83	1.36
171.50	504.41	30	25.65	4,617.00	966.34	105.57	220.16	2.09
114.30	336.18	20	34.60	6,228.00	1,303.52	70.36	296.98	4.22
57.15	168.09	10	41.70	7,506.00	1,571.01	35.18	357.92	10.17

Peach experiences significant revenue loss due to water constraints associated with climate change and drought. Figure 11 illustrates the graph of the water constraint value based on water restrictions. According to the depicted trend, the regression coefficient is calculated to be 63.43%. As water constraints on peach cultivation intensify, both yield and revenue decrease accordingly. Additionally, as the irrigation rate declines, the unit value of water increases.

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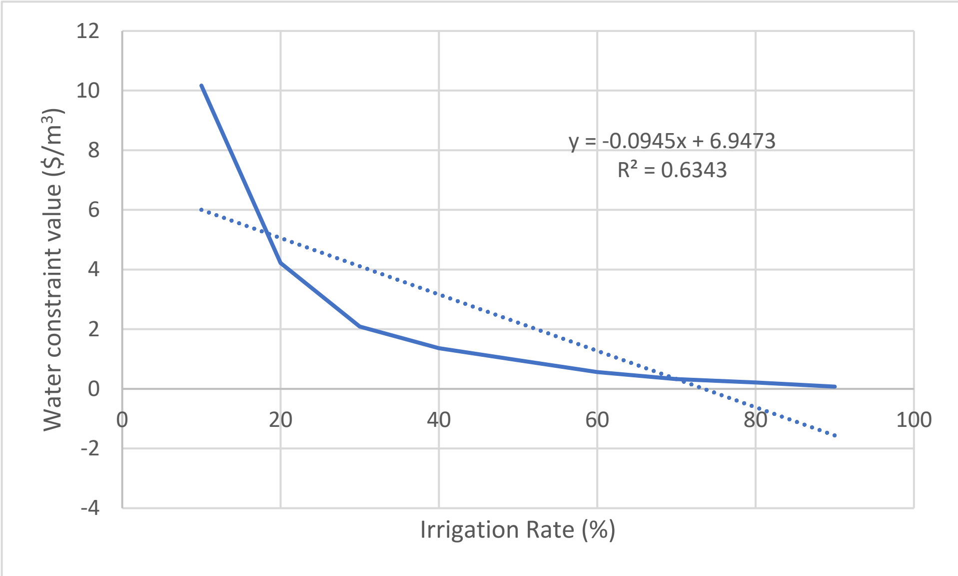

Figure 11. Water constraint value ($/m^3) in case of water restrictions on peach.

The findings of this study highlight the significant influence of irrigation rates and water use on yield and revenue in agricultural production. Upon analysing major crops, it's evident that clover, belonging to the field crops group, is most sensitive to water constraints, while apricot, part of the fruit group, is least affected. In regions where agricultural production serves as the primary income source and is conducted intensively, irrigation rates, programmes, and efficiencies play crucial roles. The adoption of the soil-water budget approach aids in developing irrigation programs tailored to local conditions and predicting alterations under diverse circumstances [25]. Furthermore, employing such approaches is crucial for achieving the anticipated social, economic, and political outcomes associated with irrigation. However, it's imperative to acknowledge that natural resources and the environment are finite, necessitating their sustainable utilisation to be safeguarded.

This study underscores the substantial effects of irrigation rates and the volume of water utilised in agricultural production on both yield and revenue. The regression coefficient (R^2) serves as a statistical metric determining the proportion of variance in the dependent variable that can be accounted for by the independent variable. Generally, the regression coefficients of the nine crops fluctuate within a narrow range, ranging from 0.5820 to 0.6855, indicating values that are closely aligned with each other (Table 12).

Based on the analysis, apricot emerges as the crop most resilient to water constraints, exhibiting the highest compatibility between irrigation rate and the water constraint value (R^2). Conversely, clover, belonging to the field crops group, demonstrates the least resistance to water constraints, characterized by the lowest compatibility between irrigation rate and the water constraint value (R^2).

Table 12. Relation and R^2 values between the irrigation rate of the crops (x) and the constraint value of water (y).

Crop	Relation between the irrigation rate (x) and the constraint value of water (y)	R^2	Average constraint value of water ($/m^3)	Average product loss (Tons)
Apricot	y = -0.0826x + 6.0983	0.6855	1.96	10636
Watermelon	y = -0.0703x + 5.1465	0.6481	0.80	3469
Peach	y = -0.0945x + 6.9473	0.6343	2.22	741
Tomato	y = -0.1062x + 7.6935	0.6315	2.39	5945
Wheat	y = -0.0136x + 1.0036	0.6291	0.32	4767
Apple	y = -0.0703x + 5.1298	0.6279	1.61	9008
Melon	y = -0.068x + 4.955	0.6183	1.56	3801

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Crop	Relation between the irrigation rate (x) and the constraint value of water (y)	R^2	Average constraint value of water ($/m³)	Average product loss (Tons)
Maize	y = -0.0385x + 2.776	0.6133	0.85	33584
Clover	y = -2.3939x + 171.42	0.5820	51.69	48417

As illustrated in Table 12, within the Iğdır Plain, crops experiencing the greatest devaluation in the event of water constraints are clover, tomato, peach, apricot, apple, melon, maize, watermelon, and wheat, in descending order. Furthermore, concerning quantity loss under water constraints, the crops most affected are clover, corn, apricot, apple, tomato, wheat, melon, watermelon, and peach, respectively.

4. Conclusion

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

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 among 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, crops that incur the highest value losses under water constraints are clover, tomato, peach, apricot, apple, melon, maize, watermelon, and wheat, respectively. Similarly, in terms of quantity losses, the crops most affected by water constraints are clover, corn, apricot, apple, tomato, wheat, melon, watermelon, and peach, respectively.

Given these findings, the recommended crop pattern for the Iğdır Plain under water constraint conditions includes wheat, watermelon, maize, melon, apple, and apricot. To mitigate agricultural revenue losses, it is advisable to conduct crop pattern optimization studies. 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 higher revenue but sensitive to water constraints (e.g., clover).

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

There are several measures aimed at enhancing water use efficiency within the agricultural sector:

Measures to mitigate high water losses in transmission and distribution lines: This involves the construction of closed systems and the renewal or modernization of existing irrigation infrastructures.

Measures to enhance water use efficiency in in-field application systems: This includes extending the network to the field head with parcel transmission lines and installing sprinkler-drip irrigation infrastructure within the field.

Measures pertaining to water management: Implementation of Automation and Telecontrol Systems (SCADA) to optimize water distribution and use.

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Other complementary measures: These encompass improving farmers' capacities through training and education programs, implementing water pricing mechanisms to encourage efficient use, and adopting measures for better irrigation management practices.

Indeed, in the face of climate change and increasing water stress, it is crucial to implement measures aimed at adaptation. Some key strategies include:

Increasing Water Transmission Efficiency: Upgrading infrastructure and implementing closed systems to minimize losses during water transmission.

Enhancing Water Use Efficiency: Promoting the adoption of efficient irrigation methods such as drip and sprinkler systems, and encouraging precision irrigation techniques to optimize water usage.

Promoting Resilient Crop Patterns: Prioritizing the cultivation of crops that are resilient to water stress and require less water, thereby reducing overall water demand in agricultural areas.

Supporting Farmers' Adaptation: Providing training, resources, and support to help farmers adapt to changing climatic conditions and adopt sustainable farming practices.

Policy Interventions: Implementing policies that incentivize the adoption of water-efficient practices, such as providing subsidies for the installation of efficient irrigation systems and promoting the cultivation of drought-resistant crop varieties.

Crop Pattern Optimization: Identifying and promoting crop patterns that require less water while maintaining agricultural productivity, thus ensuring the sustainable use of water resources.

By implementing these measures in a coordinated manner, stakeholders can work towards enhancing agricultural resilience to climate change and ensuring the sustainable management of water resources.

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