Effect of Weather Variability on Crop Evapotranspiration in Kayseri

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ABSTRACT

To identify the variation of weather conditions on plant evapotranspiration in Kayseri, the seasonal water consumption of the ten most produced crops (barley, safflower, sunflower, winter wheat, pumpkin, tomato, maize, potato, sugar beet, and alfalfa) was computed. Data from 34 years, from 1970 to 2013, with complete weather records, was utilized. Considering growing degree days and base temperatures, each plant's sowing and harvesting times were determined, and then crop evapotranspiration values were estimated using Cropwat 8.0 software. All data were obtained from the Turkish General Directorate of Meteorology. It was determined that crop evapotranspiration varied depending on reference evapotranspiration (ETo), which is influenced by atmospheric evaporative demand, and very strong relationships were found between them. Seasonal crop evapotranspiration ranged from 446 to 554 mm for barley, 582 to 697 mm for safflower, 567 to 683 mm for sunflower, 497 to 666 mm for winter wheat, 483 to 619 mm for pumpkin, 578 to 691 mm for tomato, 541 to 718 mm for maize, 611 to 738 mm for potato, 720 to 884 mm for sugar beet, and 720 to 962 mm for alfalfa. Net irrigation water requirements varied from 144 to 397 mm for barley, 353 to 594 mm for safflowers, 391 to 609 mm for sunflowers, 210 to 501 mm for winter wheat, 350 to 534 mm for pumpkin, 428 to 636 mm for tomato, 441 to 625 mm for silage corn, 428 to 690 mm for potato, 477 to 803 mm for sugar beet, and 513 to 875 mm for alfalfa. Precipitation, which varied considerably, greatly affected the net irrigation water requirement. Reference evapotranspiration was the weather factor that influenced the net irrigation water requirement after rainfall. Therefore, atmospheric variability should absolutely be considered during the design process of irrigation systems.

Keywords: Crop Evapotranspiration, Seasonal Weather Conditions, Irrigation Water Requirement

INTRODUCTION

In 2019, global cropland covered 1.6 billion hectares. As the population grew, cropland per capita decreased to 0.20 hectares. Increased use of irrigation, pesticides, fertilizers, and the expansion of cultivated areas contributed to a 53% rise in global primary crop production (sugar cane, maize, wheat, and rice), from 6.2 billion tons in 2000 to 9.4 billion tons in 2019. Global irrigated land increased by 18%, from 289 million hectares in 2000 to 342 million in 2019 (Anonymous, 2021). World agricultural water use was reported as 69%, freshwater use in industry was 19% and rural use was 12%. The total agricultural area of Türkiye is 23.1 million hectares, of which 9.11 million hectares are suitable for irrigation. However, only 8.5 million hectares could be irrigated economically. In 2020, the area with irrigation systems was 6.7 million hectares, and agriculture used 77% of freshwater in Türkiye (TAGEM, 2021). 33.63 billion cubic meters of water was used for irrigation in 2022. Irrigation improved yield by 254% and income by 288% in Türkiye (TÜİK, 2024).

A large portion of the water consumed by plants is used through transpiration. When soil water is not a limiting factor, plant transpiration is a process controlled by climate and leaf area. The water loss from plant organs, particularly from leaves, due to evaporation is called transpiration, while the water loss through evaporation from the soil surrounding the plant is referred to as evaporation. The combined water loss from both the plant and the soil via evaporation is called crop water consumption or evapotranspiration (ET). Crop water consumption is influenced by weather elements such as solar radiation, air temperature, wind speed, and relative humidity, as well as the available moisture level in the soil (James, 1988; Allen et al., 1998; Doorenbos and Pruitt, 1971; Doorenbos and Kassam, 1986).

Crop water consumption is an important parameter used in the design of irrigation systems and irrigation scheduling. Data on crop water consumption is required for everything from designing on-field irrigation

systems to planning water distribution networks in irrigation projects and determining reservoir capacities. Crop water consumption is also needed to schedule irrigation, enabling the determination of when plants need water and how much irrigation water is required. With proper irrigation scheduling, water losses can be reduced, and efficient production can be achieved. Crop water consumption data is also necessary to operate and evaluate irrigation systems. Additionally, crop water consumption is a key element of the hydrological cycle. It is used in determining agricultural droughts and calculating various drought indices. Numerous methods have been developed to estimate crop water consumption, which is a crucial parameter.

In this study, the water consumption of crops widely grown under Kayseri conditions was estimated over many years using the Cropwat 8.0 program, a tool commonly used worldwide. By doing so, the goal was to uncover how changes in weather conditions from year to year affect crop water consumption and net irrigation water requirements. Through this method, the variations in climate were carefully analyzed to understand better their influence on the water needs of the crops, aiming to optimize irrigation practices

MATERIALS AND METHODS

This study was conducted to examine the water consumption and variability of irrigation water requirements of the ten most widely cultivated crops in Kayseri (barley, safflower, sunflower, wheat, pumpkin, tomato, corn, potato, sugar beet, and alfalfa), as well as the climatic factors affecting this variability. Kayseri is in the Central Anatolia Region at an altitude of 1054 m, covering an area of 16,917 km², situated between the latitudes of 37.75°-38.30° north and the longitudes of 34.93°-36.97° east (Anonymous, 2024). According to various climate classification systems, Kayseri has an arid climate according to the Aydeniz climate classification, a semi-arid climate according to the Erinç climate classification, a semi-arid to humid climate according to the De Marton climate classification, a cold winter and mild summer climate according to the Trewartha climate classification. Some climate data and extreme values from the long-term period (1931-2023) are presented in Table 1. The annual total rainfall is 390.5 mm, the average yearly temperature is 10.7°C, and the sunshine lasts 7 hours. The coldest month is January, with an average temperature of -1.6°C, where the recorded lowest temperature is -32.5°C, and the average minimum and maximum temperatures range between -6.7°C and 4.2°C. The hottest month is July, with an average temperature of 22.3°C, where the recorded highest temperature is 40.7°C, and the average minimum and maximum temperatures range between 12.1°C and 30.7°C. In Kayseri, total rainfall is 146 mm in spring, 61 mm in summer, 74.1 mm in autumn, and 109.4 mm in winter.

Table 1. Some long-term climate data for Kayseri Province (1931-2023)

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Ann.**
T (°C)	-1.6	0.3	4.8	10.6	15.1	19.0	22.3	22.1	17.5	11.9	5.6	0.8	10.7
T_{mak} (°C)	4.2	6.3	11.5	17.8	22.6	26.9	30.7	30.9	26.7	20.5	13.1	6.6	18.1
T_{min} (°C)	-6.7	-5.1	-1.3	3.2	6.9	9.9	12.1	11.6	7.5	3.6	-0.8	-4.3	3.1
n (h/day)	3.0	4.0	4.9	6.2	8.3	10.3	11.9	11.4	9.1	6.7	4.9	2.9	7.0
P (mm)	36.1	36.2	43.4	51.1	51.5	41.7	10.4	8.9	14.8	27.5	31.8	37.1	390.5
T_{makE} (°C)	19.3	22.6	28.6	31.2	34.2	37.6	40.7	40.6	38.4	33.6	26.0	21.0	40.7
T_{minE} (°C)	-32.5	-31.2	-28.1	-11.6	-6.9	-0.6	2.9	1.4	-3.8	-12.2	-20.7	-28.4	-32.5

T: Mean air temperature, T_{max} and T_{min}: Mean maximum and minimum air temperatures, n: mean sunshine duration, P: Precipitation, T_{makE} and T_{minE}: Extreme maximum and minimum air temperatures.

The Cropwat 8.0 software package was used to calculate plant water consumption. In the Cropwat 8.0 program, calculations of plant water consumption require monthly average minimum and maximum temperatures, average relative humidity, wind speed, and sunshine duration data. All these data were obtained from the Turkish General Directorate of Meteorology. Only the years with complete datasets were considered. For the long-term average, data provided in the Climwat 2.0 program were used to calculate plant water consumption. The ten most widely cultivated plants in Kayseri conditions were considered. The names of the plants, their base temperatures, growth periods, and total growing degree-day requirements are presented in Table 2. Information regarding the growth periods and stages of the plants was utilized from TAGEM-DSI (2018). This information was reviewed and adapted for regional conditions, and after some modifications, it was used to draw the crop coefficient (Kc) curves in the Cropwat 8.0 program. The planting dates for the crops are given in Table 2. Except for sugar beets, the harvest dates for each plant were recalculated for each year, and crop coefficient curves were adjusted for each year.

Table 2. The base temperatures and total growing degree days of the most produced crops in Kayseri/Türkiye

Crop	Base temperature (°C)	Total Growing Degree Days (°C)	Growing season period	Growing season (day)
Barley	5	1160	25 October-11 July	259
Safflower	5	1830	1 April-23 Agust	145
Sunflower	6.7	1720	10 April- 12 September	145
Winter wheat	5	1400	15 October-21 July	279
Snack pumpkin	10	1252	1 May- 2 September	132
Tomato	7	1665	15 May-23 September	130
Silage corn	10	1191	5 May-5 September	122
Potato	7	1630	15 April -15 September	146
Sugar beet	7	2032	20 April - 15 October	178
Alfalfa	5	1444	1 April - 15 October	198

Based on a literature review, the base temperatures at which plant development begins were considered the most recommended. The total growing degree days required for the plant development period between the long-term planting and harvest dates presented in Table 2 were calculated using the following equation:

$$GDD = \sum (t_i - t_b) \cdot n \quad (1)$$

In the equation, GDD is the total growing degree days (°C), t_i is the average air temperature for month i (°C), t_b is the base temperature for plant development (°C), and n is the number of days in month i. Based on the calculated total GDD, the plant harvest date for each year was determined. The results for

effective rainfall, reference evapotranspiration (ETo), crop water requirement (CWR), and irrigation water needs observed during the plant development period for the year considered were transferred to an Excel spreadsheet using the Cropwat 8.0 program. After adding the length of the development period for each year to this data, descriptive statistical analyses were performed using the Excel program. Accordingly, the results' averages, minimum and maximum values, standard deviations, and standard errors were determined. Correlation and regression analyses were conducted on the reference evapotranspiration and plant water consumption data.

RESULTS AND DISCUSSIONS

This section presents and discusses the growing periods for each plant by year, total effective rainfall during the growing period, reference evapotranspiration, plant water consumption, and net irrigation water requirements based on Cropwat results and statistical analyses.

Reference Evapotranspiration and Crop Evapotranspiration Variability

The relationships between reference evapotranspiration and crop evapotranspiration values between 1970 and 2013 are shown in Figure 1 for the crops grown widely in Kayseri. There is a robust linear relationship between ETo and plant water consumption for all plants. Considerably different ETo values occurred in those years (Table 3 to 12). Therefore, the variation in ETo also caused variation in the water consumption of the plants.

Wheat

In Kayseri conditions, the wheat plant, which reaches harvest in 279 days, grows between 239 and 270 days, depending on the year. The harvest date is determined based on the principles that wheat is sown on October 15 and harvested after accumulating 1400-degree days above 5°C. Accordingly, the grain is harvested as early as June 20 and July 21. Ünlükara and Kocabeyoğlu (2018) reported the wheat growing period as 288 days, from October 10, 2014, to July 26, 2015, in Kayseri. During the growing season, an average of 330 mm of effective rainfall occurs, varying between 187.7 mm and 531.1 mm depending on the year. The average ETo during the plant's growing period is 686.5 mm, with the lowest recorded at 603 mm in the 1972-73 growing season and the highest at 740.8 mm in the 1986-87 season. The average plant water consumption (ETc) is 610.5 mm, with the lowest ETc recorded as 496.5 mm in 1972-73 and the highest as 665.5 mm in 1986-87. The average net irrigation water requirement is 353.3 mm, with the lowest and highest values recorded at 210.1 mm and 500.5 mm for the 1987-88 and 1993-94 seasons, respectively. The standard deviation for growing season rainfall, ETo, ETc, and net irrigation water requirements was 77.3 mm, 33.4 mm, 35.8 mm, and 72.6 mm, respectively (Table 3).

According to TAGEM-DSI (2017), the reference evapotranspiration is given as ETo= 612.5 mm. The plant’s water consumption is ETc 487 mm for the growing wheat period. Using Climwat 2.0 data and the Cropwat 8.0 program, the plant water consumption for wheat is estimated as ETc= 538.6 mm, and the net irrigation water requirement as 270 mm. Compared to the water consumption value of ETc= 487 mm provided by TAGEM-DSI (2017), the water consumption in this study is estimated to be 51.6 mm higher.

Table 3. Wheat irrigation requirements in the conditions of Kayseri and the variation of influencing factors

	Mean	Minimum	Maximum	S.error	S.deviation
T (day)	258	239	270	1.2	7.3
P (mm)	330	188	531	13.3	77.3
ETo (mm)	686.5	603.2	741	5.7	33.4
ETc (mm)	610.5	496.5	665.5	6.1	35.8
I_{net} (mm)	353.3	210	500.5	12.5	72.6

T: Duration of plant growing period (day), P: Precipitation (mm), ETo: Reference evapotranspiration (mm), ETc: Crop evapotranspiration (mm), I_{net}: Net irrigation requirement.

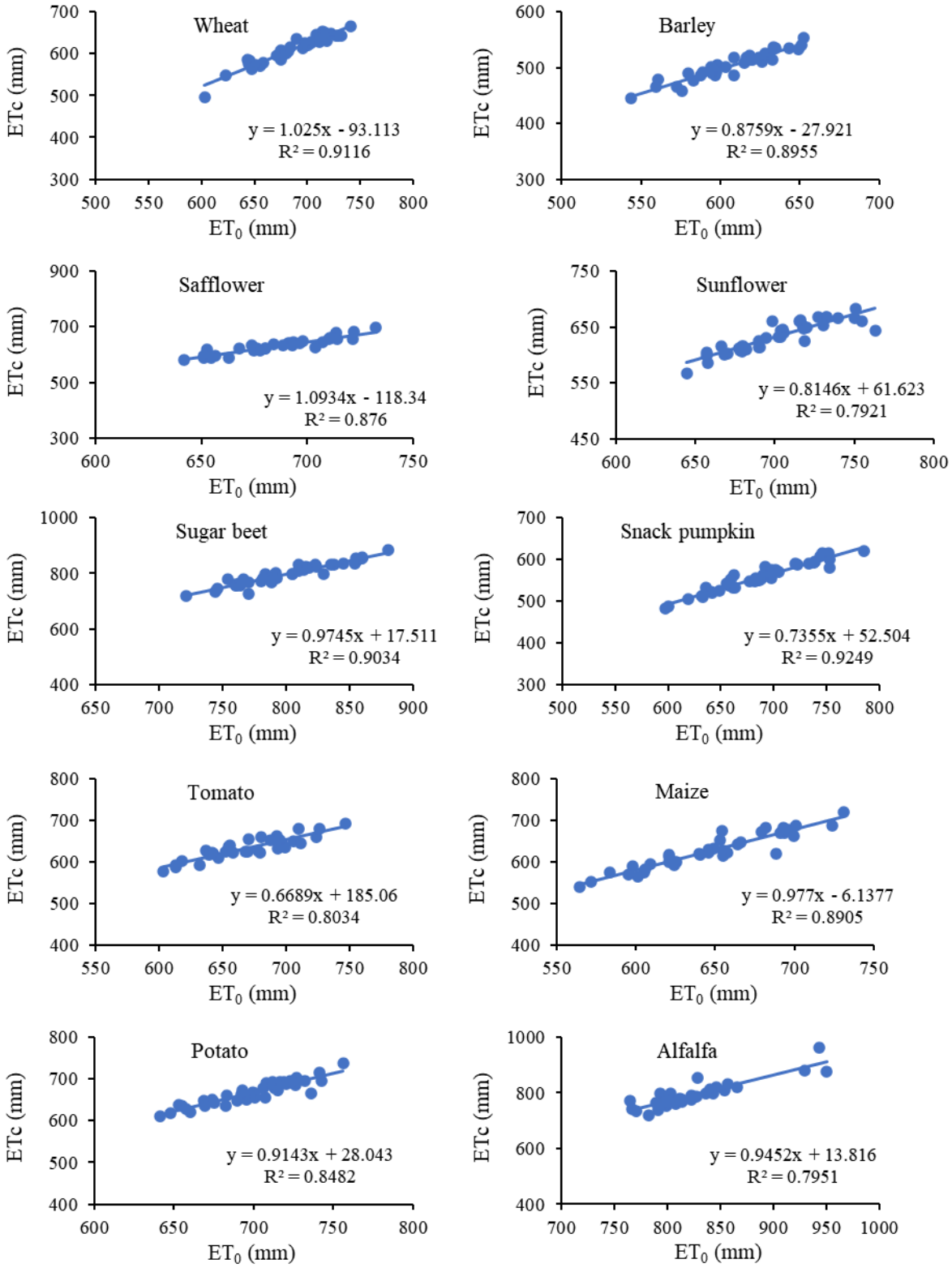


Figure 1. The relationships between crop water consumptions and the reference evapotranspiration values in Kayseri

Barley

In Kayseri conditions, the barley plant, which reaches harvest in 259 days, has a growing period that lasts between 240 and 271 days depending on the year. The harvest date is determined based on the principles that barley is sown on October 25 and harvested after accumulating 1160 growing degree days above 5°C. Accordingly, barley is harvested as early as June 21 and July 22. During the growing season, an average of 321.8 mm of effective rainfall occurs, varying between 187.7 mm and 493 mm depending on the year. The average ETo during the plant's growing period is 607 mm, with the lowest recorded at 544 mm in the 2012-13 growing season and the highest at 652 mm in the 1986-87 season. The average ETc is 504 mm, with the lowest ETc recorded as 445 mm in 2012-13 and the highest as 554 mm in 1986-87. The average net irrigation water requirement is 264.2 mm, with the lowest and highest values recorded at 144 mm and 397 mm for the 1987-88 and 2011-12 seasons, respectively. The standard deviations for growing season rainfall, ETo, ETc, and net irrigation water requirements were 67.5 mm, 27.4 mm, 25.3 mm, and 62.3 mm, respectively (Table 4). The variability observed in rainfall, ETo, and ETc has increased the variability in the net irrigation water requirements.

TAGEM-DSI (2017) states that the barley growing period's reference evapotranspiration is ETo= 575 mm. The plant water consumption as ETc= 427 mm. Using Climwat 2.0 data and the Cropwat 8.0 program, the plant water consumption for barley is estimated to be 493 mm. The net irrigation water requirement is estimated to be 247 mm. Based on TAGEM-DSI (2017)'s estimate of plant water consumption at 427 mm, this study found the water consumption to be 66 mm higher. According to the lowest calculated plant water consumption of 446 mm, the TAGEM-DSI (2017) estimate is 19 mm lower. Although the plant water consumption appears similar according to the Cropwat 8.0 program, the average net irrigation water requirement is 64 mm higher according to the Cropwat 8.0 results.

Table 4. Barley irrigation requirements in the conditions of Kayseri and the variation of influencing factors

	Mean	**Minimum**	**Maximum**	**S.error**	**S.deviation**
T (day)	259	240	271	1.23	7.14
R (mm)	321.8	187.7	493	11.6	67.5
ETo (mm)	607.1	543.7	652.4	4.69	27.4
ETc (mm)	503.9	445.5	553.6	4.33	25.3
I_{net} (mm)	264.2	143.8	397.2	10.68	62.3

T: Duration of plant growing period (day), P: Precipitation (mm), ETo: Reference evapotranspiration (mm), ETc: Crop evapotranspiration (mm), I_{net}: Net irrigation requirement.

Safflower

In Kayseri conditions, the safflower plant, which reaches harvest in 149 days, has a growing period that lasts between 134 and 167 days depending on the year. The harvest date is determined based on the principles that safflower is sown on April 1 and harvested after accumulating 1830 degrees days above 5°C. Accordingly, safflower is harvested as early as August 12 and September 14. During the growing season, an average of 151 mm of effective rainfall occurs, varying between 65 mm and 265 mm depending on the year. The average ETo during the plant's growing period is 687 mm, with the lowest recorded at 647 mm in 2010 and the highest at 651 mm in 1990. The average ETc is 632 mm, with the lowest ETc recorded as 655 mm in 2010 and the highest as 554 mm in 1990. The average net irrigation water requirement is 496 mm, with the lowest and highest values recorded at 353 mm and 594 mm for 1988 and 2003, respectively. The standard deviations for growing season rainfall, ETo, ETc, and net irrigation water requirement were 8.75 mm, 52.76 mm, 24.0 mm, and 55.5 mm, respectively (Table 5). The rainfall, ETo, ETc variability has increased the net irrigation water requirement variability.

According to TAGEM-DSI (2017), the reference evapotranspiration for the safflower growing period is given as ETo= 661 mm, and the plant water consumption as ETc= 588 mm. Using Climwat 2.0 data and the Cropwat 8.0 program, the plant water consumption for safflowers is estimated to be 625 mm. The net irrigation water requirement is estimated to be 480 mm. Therefore, while the safflower plant water

consumption provided by TAGEM-DSI falls within the calculated range of 582-697 mm established in this study, it is 45 mm lower than the average plant water consumption (633 mm).

Table 5. Safflower irrigation requirements in the conditions of Kayseri and the variation of influencing factors

	Mean	Minimum	Maximum	S.error	S.deviation
T (day)	148	134	167	1.55	8.75
R (mm)	151	64.6	265.1	9.32	52.76
ETo (mm)	687	642	732	4.24	24.0
ETc (mm)	633	581.6	696.5	4.96	28.0
I_{net} (mm)	496	352.7	594	9.81	55.5

T: Duration of plant growing period (day), P: Precipitation (mm), ETo: Reference evapotranspiration (mm), ETc: Crop evapotranspiration (mm), I_{net}: Net irrigation requirement.

The net irrigation water requirement decreased during rainy periods and increased during low rainfall (Figure 2). Of the average 633 mm of water consumed during the plant's growing period, a portion (151 mm) is supplied by rainfall. The percentage of net irrigation water based on plant water consumption ranged between 57.1% and 90.1% for safflowers, and the proportion of rainfall meeting water consumption varied between 9.9% and 42.9%.

Sunflower

In Kayseri conditions, the sunflower plant, which reaches harvest in 145 days, has a growing period that lasts between 124 and 180 days depending on the year. The harvest date is determined based on the principle that sunflowers are sown on April 20 and harvested after accumulating 1720 degrees days above 6.7°C. Accordingly, sunflowers are harvested as early as August 21 and October 16. During the sunflower's growing period, an average of 126 mm of rainfall occurs, varying between a minimum of 43 mm and a maximum of 248.4 mm. The average ETo during the plant's growing period is 702 mm, with the lowest recorded at 645 mm in 2010 and the highest at 763 mm in 1984. The average ETc is 633 mm, with the lowest ETc recorded as 567 mm in 2010 and the highest as 683 mm in 1987. The average net irrigation water requirement is 522 mm, with the lowest and highest values recorded at 391.4 mm and 608.5 mm for 1988 and 1994, respectively. The standard deviations for growing season rainfall, ETo, ETc, and net irrigation water requirement were found to be 47.8 mm, 30 mm, 27.6 mm, and 48.6 mm, respectively (Table 6). Rainfall, ETo, ETc variability has increased the variability of net irrigation water requirement.

Table 6. Sunflower irrigation requirements in the conditions of Kayseri and the variation of influencing factors

	Mean	Minimum	Maximum	S.error	S.deviation
T (day)	145	124	180	2.2	13.6
R (mm)	125.8	43	248.4	7.8	47.8
ETo (mm)	701.8	644.6	763	4.9	30.2
ETc (mm)	633.3	567.3	683	4.5	27.6
I_{net} (mm)	521.7	391.4	608.5	7.9	48.6

T: Duration of plant growing period (day), P: Precipitation (mm), ETo: Reference evapotranspiration (mm), ETc: Crop evapotranspiration (mm), I_{net}: Net irrigation requirement.

According to TAGEM-DSI (2017), sunflower planting in the Central Anatolia Region is done in the third ten days of April, and the growing period lasts 145 days. Accordingly, the ETo is reported as 657 mm, and the plant water consumption of sunflower is reported as 614 mm for the growing period. Using Climwat 2.0 data and the Cropwat 8.0 program, the plant water consumption for sunflower is estimated to be 623 mm, and the net irrigation water requirement is estimated to be 504 mm. Therefore, the plant water consumption of 623 mm is 9 mm higher than the TAGEM-DSI (2017) estimate.

Sugar Beet

Calculations were made based on the assumption that sugar beet is sown on April 20 in Kayseri and harvested at the end of a 178-day growing period, which lasts until October 15. The sowing date was set as April 20 to ensure that the sugar beet, with a base temperature of 1.1°C, could survive the frost typically seen at the end of April. During the growing period, the average precipitation for sugar beet is 143.4 mm, ranging from 59.6 mm to a maximum of 282.3 mm. The average reference evapotranspiration (ETo) during the growing period is 800.6 mm, with the lowest value recorded in 1992 at 721 mm and the highest in 2001 at 881 mm. The average crop evapotranspiration (ETc) is 798 mm, with the lowest at 720 mm in 1992 and the highest at 884 mm in 2001. The net irrigation water requirement averages 664 mm, with the lowest and highest values recorded at 477 mm in 1988 and 803 mm in 2001, respectively. The standard deviation for growing period precipitation, ETo, ETc, and net irrigation water requirements were found to be 49.2, 38.9, 39.9, and 67 mm, respectively (Table 7). Variability in precipitation, ETo, ETc has increased the variability in net irrigation water requirements.

TAGEM-DSİ (2017) reported that sugar beet is sown during the first 10 days of April in the Central Anatolia Region, with a growing period of 185 days. Accordingly, the ETo was given as 781.3 mm, and sugar beet water consumption as 898 mm during the growing period. Using Climwat 2.0 data and the Cropwat 8.0 program, sugar beet water consumption was estimated at 798 mm, with a net irrigation water requirement of 649 mm. Therefore, the average water consumption of 798 mm is 100 mm lower than the estimate by TAGEM-DSİ (2017) and is the same as that determined using Climwat 2.0 data and the Cropwat 8.0 program. Sugar beet water consumption varied between 704-883 mm and 813-866 mm for two consecutive years in an experiment conducted under Kayseri conditions (Ünlükara, 2019). Irik et al. (2024) determined sugar beet water consumption to be 785 mm for complete irrigation treatment in Kayseri.

Table 7. Sugar beet irrigation requirements in the conditions of Kayseri and the variation of influencing factors

	Mean	**Minimum**	**Maximum**	**S.error**	**S.deviation**
T (day)	178	-	-	-	-
R (mm)	143.4	59.6	282.3	7.98	49.2
ETo (mm)	800.6	721.4	880.5	6.31	38.9
ETc (mm)	797.7	719.7	884.1	6.47	39.9
I_{net} (mm)	664.4	477.0	803.1	10.88	67.1

T: Duration of plant growing period (day), P: Precipitation (mm), ETo: Reference evapotranspiration (mm), ETc: Crop evapotranspiration (mm), I_{net}: Net irrigation requirement.

Snack pumpkin

In Kayseri conditions, the growing period for snack pumpkin, which is harvested in 142 days, varies between 110 and 184 days depending on the year. The harvest date is determined based on the principle that snack pumpkins are sown on May 1 and harvested after accumulating 1250°C above 10°C. Accordingly, the earliest harvest date is August 18, and the latest is October 31. Ünlükara and Bakır (2018) recommended harvesting snack pumpkin after accumulating 1230°C above 10°C for the Develi population. During the growing period, the average rainfall for snack pumpkins is 111.5 mm, ranging from a minimum of 29.6 mm to a maximum of 235.7 mm. The average evapotranspiration (ETo) during the growing period is 686.3 mm, with the lowest recorded in 2010 at 598 mm and the highest in 1990 at 784.7 mm. The average crop evapotranspiration (ETc) is 557.3 mm, the lowest at 483 mm in 2010 and the highest at 618.8 mm in 1990. The net irrigation water requirement averages 454 mm, with the lowest and highest values recorded at 349.8 mm in 1988 and 533.5 mm in 1875, respectively. The standard deviations for growing period rainfall, ETo, ETc, and net irrigation water requirements were found to be 44.5, 46.1, 35.2, and 45.1 mm, respectively (Table 8). Variability in rainfall, ETo, and ETc has increased the variability in net irrigation water requirements.

TAGEM-DSİ (2017) reported that the sowing of snack pumpkin in the Central Anatolia Region takes place during the first 10 days of May, with a growing period of 142 days. According to this, the ETo during the growth period was given as 713 mm, and the water consumption for the pumpkin crop was 525 mm. Using Climwat 2.0 data and the Cropwat 8.0 program, water consumption for snack pumpkin was estimated at 555 mm, and the net irrigation water requirement at 444 mm. Therefore, the estimated average water consumption of 557 mm was 32.3 mm higher than the estimate by TAGEM-DSİ (2017). Various studies conducted under Kayseri conditions determined water consumption values for fully irrigated snack pumpkin as 479-626 mm (Kirnak et al., 2019), 421.4-502.1 mm (Ünlükara and Bakır, 2018), 526 mm (Ünlükara et al., 2019), and 511 mm (Sekendur, 2017).

Table 8. Snack pumpkin irrigation requirements in the conditions of Kayseri and the variation of influencing factors

	Mean	Minimum	Maximum	S.error	S.deviation
T (day)	142	110	184	3.17	19.6
R (mm)	111.5	29.6	235.7	7.2	44.5
ETo (mm)	686.3	597.7	784.7	7.5	46.1
ETc (mm)	557.3	483	618.8	5.7	35.2
I_{net} (mm)	454	350	533.5	7.3	45.1

T: Duration of plant growing period (day), P: Precipitation (mm), ETo: Reference evapotranspiration (mm), ETc: Crop evapotranspiration (mm), I_{net}: Net irrigation requirement.

Tomato

In Kayseri conditions, the growing period for tomatoes, which is harvested in 140 days, varies between 108 and 168 days depending on the year. The harvest date is determined based on the principle that tomatoes are sown on May 15 and harvested after accumulating 1665°C above 7°C. Accordingly, the earliest harvest date is August 30, and the latest is October 29. During the growing period, the average rainfall for tomatoes is 99.3 mm, ranging from a minimum of 23.8 mm to a maximum of 249.6 mm. The average evapotranspiration (ETo) during the growing period is 669.3 mm, with the lowest recorded in 2010 at 603.9 mm and the highest in 1985 at 746.7 mm. The average crop evapotranspiration (ETc) is 632.8 mm, the lowest at 577.8 mm in 2010 and the highest at 691.3 mm in 1985. The net irrigation water requirement averages 539.3 mm, with the lowest and highest values recorded at 427.6 mm in 1988 and 635.5 mm in 2003, respectively. The standard deviations for growing period rainfall, ETo, ETc, and net irrigation water requirements were found to be 47.5, 35.7, 26.6, and 44.4 mm, respectively (Table 9). Variability in rainfall, ETo, and ETc has increased the variability in net irrigation water requirements.

Table 9. Tomato irrigation requirements in the conditions of Kayseri and the variation of influencing factors

	Mean	Minimum	Maximum	S.error	S.deviation
T (day)	140	108	168	3.2	18.6
R (mm)	99.3	23.8	249.6	8.3	47.5
ETo (mm)	669.3	603.9	746.7	6.2	35.7
ETc (mm)	632.8	577.8	691.3	4.6	26.6
I_{net} (mm)	539.3	427.6	635.5	7.7	44.4

T: Duration of plant growing period (day), P: Precipitation (mm), ETo: Reference evapotranspiration (mm), ETc: Crop evapotranspiration (mm), I_{net}: Net irrigation requirement.

TAGEM-DSİ (2017) reported that tomato sowing in the Central Anatolia Region occurs during the second 10 days of May, with a growing period of 145 days. According to this, the ETo was given as 648.9 mm, and tomato water consumption as 622 mm. Using Climwat 2.0 data and the Cropwat 8.0 program, tomato water consumption was estimated at 607 mm, with a net irrigation water requirement of 524 mm. Therefore, the estimated water consumption of 607 mm is 16 mm lower than the estimate by TAGEM-DSİ (2017).

Silage Corn

In Kayseri conditions, the growing period for silage corn, which is harvested in 132 days, varies between 104 and 178 days depending on the year. The harvest date is determined based on the principle that corn is sown on May 5 and harvested as silage after accumulating 1190°C above 10°C. Accordingly, silage corn is harvested as early as August 17 and as late as October 29. During the growing period, the average rainfall for corn is 101 mm, ranging from a minimum of 26.2 mm to a maximum of 228.6 mm. The average evapotranspiration (ETo) during the growing period is 646.7 mm, with the lowest recorded in 2010 at 564.6 mm and the highest in 1976 at 730.8 mm. The average crop evapotranspiration (ETc) is 625.7 mm, the lowest at 540.5 mm in 2010 and the highest at 718.4 mm in 1976. The net irrigation water requirement averages 536.2 mm, with the lowest and highest values recorded at 441 mm in 1988 and 624.5 mm in 1974, respectively. The standard deviations for growing period rainfall, ETo, ETc, and net irrigation water requirements were found to be 43.5, 41.6, 43, and 46.6 mm, respectively (Table 10). The variability observed in rainfall, ETo, ETc has increased the variability in net irrigation water requirements.

TAGEM-DSİ (2017) reported that silage corn planting in the Central Anatolia Region occurs during the first 10 days of May, with a growing period of 122 days. Accordingly, the ETo was given as 681.9 mm, and the water consumption for silage corn was reported as 533 mm for the growing period. Using Climwat 2.0 data and the Cropwat 8.0 program, water consumption for grain corn is estimated at 641 mm, with a net irrigation water requirement of 541.6 mm. Therefore, the average water consumption of 626 mm is 93 mm higher than the estimate by TAGEM-DSİ (2017).

Table 10. Corn irrigation requirements in the conditions of Kayseri and the variation of influencing factors

	Mean	**Minimum**	**Maximum**	**S.error**	**S.deviation**
T (day)	132	104	178	2.8	17.2
R (mm)	101	26.2	228.6	7.1	43.5
ETo (mm)	646.7	564.5	730.8	6.8	41.6
ETc (mm)	625.7	540.5	718.4	6.9	43.1
I_{net} (mm)	536.2	441	624.5	7.6	46.6

T: Duration of plant growing period (day), P: Precipitation (mm), ETo: Reference evapotranspiration (mm), ETc: Crop evapotranspiration (mm), I_{net}: Net irrigation requirement.

Potato

In Kayseri conditions, the growing period for potato plants, which are harvested in 146 days, varies between 126 and 175 days depending on the year. The harvest date is determined based on the principle that potatoes are sown on April 15 and harvested after accumulating 1630°C above 7°C. Accordingly, potatoes are harvested as early as August 18 and October 6. During the growing period, the average rainfall for potatoes is 132 mm, ranging from a minimum of 48 mm to a maximum of 251.8 mm. The average evapotranspiration (ETo) during the growing period is 699.5 mm, with the lowest recorded in 2010 at 641 mm and the highest in 1994 at 756 mm. The average crop evapotranspiration (ETc) is 667.6 mm, the lowest at 611 mm in 2010 and the highest at 738 mm in 1994. The net irrigation water requirement averages 547 mm, with the lowest and highest values recorded at 428 mm in 1988 and 690 mm in 1994, respectively. The standard deviations for growing period, rainfall, ETo, ETc, and net irrigation water requirements were 12.4 days, 49.5, 29.1, 28.9, and 53.7 mm, respectively (Table 11). The variability observed in rainfall, ETo, and ETc has increased the variability in net irrigation water requirements.

TAGEM-DSİ (2017) stated that potato planting in the Central Anatolia Region occurs during the second ten days of April, with a growing period of 140 days. Accordingly, the ETo is reported as 660 mm, and the water consumption for potato plants is given as 597 mm for the growing period. Using Climwat 2.0 data and the Cropwat 8.0 program, water consumption for potatoes is estimated to be 652.2 mm, with a

net irrigation water requirement of 523.7 mm. Therefore, the average water consumption of 667.6 mm is found to be 71 mm higher than the estimate provided by TAGEM-DSİ (2017).

Table 11. Potato irrigation requirements in the conditions of Kayseri and the variation of influencing factors

	Mean	Minimum	Maximum	S.error	S.deviation
T (day)	146	126	175	2	12.4
R (mm)	132	48	251.8	8	49.5
ETo (mm)	699.5	640.9	756.2	4.7	29.1
ETc (mm)	667.6	611.3	738.0	4.7	28.9
I_{net} (mm)	547.0	428.3	690.3	8.7	53.7

T: Duration of plant growing period (day), P: Precipitation (mm), ETo: Reference evapotranspiration (mm), ETc: Crop evapotranspiration (mm), I_{net}: Net irrigation requirement.

Alfalfa

In Kayseri, it is assumed that the alfalfa growth period begins on April 1 and is harvested after every 550° of accumulated temperature above a base temperature of 5°C (Doorenbos and Kassam, 1986). In the conditions of Kayseri, there are usually four harvests, and rarely 5 can be obtained. Under these conditions, the growth period of alfalfa varies between 160 and 235 days, with an average duration of 183 days. During the alfalfa growth period, the average rainfall is 171.3 mm, ranging from a minimum of 72.4 mm to a maximum of 297.4 mm. The average ETo during the growth period is 825.6 mm, with a minimum of 764.3 mm in 1999 and a maximum of 950.4 mm in 2012. The average ETc is 794 mm, with a minimum of 720 mm in 2011 and a maximum of 962 mm in 1994. The average net irrigation water requirement is 630.3 mm, with a minimum of 513.4 mm in 1985 and a maximum of 875 mm in 1994. In 1994, when the net irrigation water requirement was highest, it was observed that the second growth period was the longest, with the least rainfall, the highest second ETo, and the highest first ETc. The standard deviations for the duration of the growth period, rainfall, ETo, ETc, and net irrigation water requirement were 16.7 days, 61.9 mm, 46.4 mm, 49.2 mm, and 78.7 mm, respectively (Table 12). The most tremendous variability is observed in the net irrigation water requirement of the plant. The variability observed in the growth period, rainfall, ETo, and ETc has increased the variability in the net irrigation water requirement.

Table 12. Alfalfa irrigation requirements in the conditions of Kayseri and the variation of influencing factors

	Mean	Minimum	Maximum	S.error	S.deviation
T (day)	182.9	160	235	3.0	16.7
R (mm)	171.3	72.4	297.4	11.1	61.9
ETo (mm)	825.6	764.3	950.4	8.3	46.4
ETc (mm)	794.2	719.5	962.2	8.8	49.2
I_{net} (mm)	630.3	513.4	874.9	14.1	78.7

T: Duration of plant growing period (day), P: Precipitation (mm), ETo: Reference evapotranspiration (mm), ETc: Crop evapotranspiration (mm), I_{net}: Net irrigation requirement.

Considering the average growth period of 183 days (from April 1 to October 1), the reference evapotranspiration is 865 mm (TAGEM-DSİ, 2017). According to TAGEM-DSİ (2017), alfalfa is reported to be harvested 6 times in the Central Anatolia Region, with a plant water consumption of 668 mm. Therefore, the average plant water consumption of 794 mm is found to be 126 mm higher than the estimate by TAGEM-DSİ (2017). While it has been concluded that alfalfa can be harvested 4 times, and rarely 5 times under Kayseri conditions during the considered years, TAGEM-DSİ (2017) suggests that 6 harvests can be achieved. In a two-year study conducted in Kayseri with 12 alfalfa varieties by Varol et al. (2024), 840 mm and 811 mm were implemented for full irrigation treatments. While the reference plant water consumption was determined to be 943 mm in the first year and 885 mm in the second year,

the plant water consumption for full irrigation treatments was found to be 1021 mm in the first year and 969 mm in the second year. In both years, alfalfa was harvested 4 times.

Variability in Net Irrigation Water Requirements

Figure 2 depicts rainfall and the plants' net irrigation water requirements. The net irrigation water requirement decreases during rainy periods and increases during low rainfall. The net irrigation water requirement and rainfall are closely intertwined and show an inverse relationship for wheat and barley. As seen in Figure 2, rain during the plants' growing periods only met a small portion of the net irrigation requirements except for wheat and barley.

The percentage of net irrigation water relative to crop water consumption was determined as 34.6%-77.2% for wheat, 31.4%-74.4% for barley, 57.1%-90.1% for safflower, 63.7%-93.7% for sunflower, 65.0%-92.8% for sugar beet, 63.3%-95.0% for pumpkin (for seeds), 68.7%-96.4% for tomato, 71.9%-95.9% for silage corn, 63.0%-93.5% for potato, and 64.4%-91.3% for alfalfa. The percentage of crop water consumption met by precipitation during the crop growth period over the years was found to be 29.0%-87.5% for wheat, 35.1%-98.5% for barley, 9.9%-42.9% for safflower, 6.6%-40.4% for sunflower, 7.1%-38.5% for sugar beet, 5.3%-42.6% for pumpkin (for seeds), 3.6%-40.1% for tomato, 4.2%-37.3% for silage corn, 6.5%-31.1% for potato, and 8.9%-36.3% for alfalfa. During the crop growth period, precipitation met slightly more than half of the water consumption for wheat and barley (54% and 52%, respectively), reducing the net water requirement. Therefore, wheat and barley cultivation in Kayseri provides an advantage regarding water resource utilization.

CONCLUSIONS

To determine the effects of inter-annual variability in weather conditions on crop water consumption and net irrigation water requirements, 10 crops that are most grown under Kayseri conditions were selected. Using the Cropwat 8.0 program, the crop water consumption was calculated each year, and the net irrigation requirements were determined. Changes in air temperatures, which define the duration and speed of crop growth, led to variations in the crop growth period. Reference evapotranspiration, calculated with data on solar radiation, air temperature, humidity, and wind speed factors that influence crop water consumption also exhibited variations over the years. Changes in the crop growth period and reference evapotranspiration resulted in fluctuations in crop water consumption. The highest variability during the crop growth period was observed in precipitation. The crop's net irrigation water requirement is determined by subtracting effective rainfall from the total crop water demand during the crop growth. The significant precipitation and crop water consumption variability over the years has led to considerable variation in net irrigation water requirements.

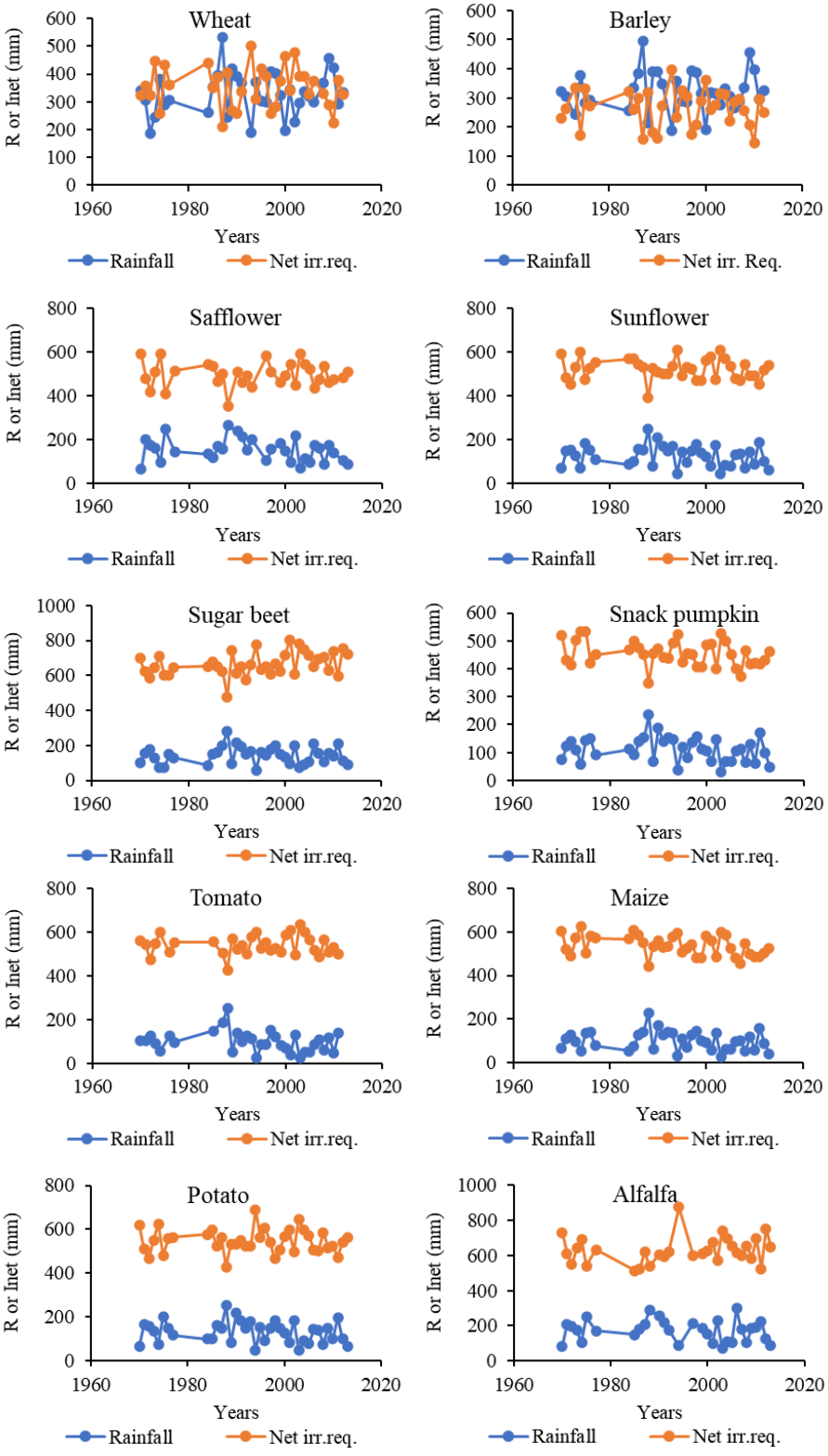


Figure 2. Variability in net irrigation water requirements and rainfall for the widely cultivated crops in Kayseri

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