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Nevşehir İlinde Kuraklık Analizi ve Kuraklığın Tarımsal Ürün Verimi Üzerine Etkileri

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Öz

Türkiye, iklim değişikliğine karşı en hassas bölgelerden birisidir. İklim değişikliğinin tetiklediği kuraklık olayları bölgede sıklıkla meydana gelmekte ve önemli çevre sorunlarına neden olmaktadır. Tarım sektörü ve mahsul verimi kuraklıktan olumsuz etkilenen alanlar arasındadır. Bu çalışmada, Nevşehir Merkez ve Ürgüp istasyonları kullanılarak SPI ve SPEI yöntemleri ile meteorolojik ve hidrolojik kuraklık durumu ve yağış eğilimi incelenmiştir. Ayrıca bölgede uzun süreli kuvvetli kuraklıkların şiddeti ve süresi araştırılmıştır. Kuraklık olaylarının en önemli olumsuz etkileri tarım sektöründe bitkisel üretim üzerinde görülmektedir. Bu etkiyi analiz etmek için bölgede yetiştirilen tarım ürünlerinin verim değerleri Türkiye İstatistik Kurumu'ndan (TÜİK) alınmış ve Z-Skor yöntemi ile standardize edilmiştir. Ardından kuraklık olaylarının bölgede yetiştirilen tarım ürünlerinin verimi üzerine etkisi incelenmiştir.

Anahtar Kelimeler: Kuraklık analizi; veri standartlaştırma; kuraklığın tarıma etkileri; Nevşehir bölgesi.

Drought Analysis and Impact of Drought on Crop Yield in Nevşehir City[1]

Abstract

Türkiye is one of the most sensitive regions to climate change. Drought events triggered by climate change occur frequently in the region and cause important environmental problems. The agricultural sector and crop yield are among the areas that are adversely affected by drought. In this study, meteorological and hydrological drought situation and precipitation trend are studied with SPI and SPEI methods by using Nevşehir Center and Ürgüp stations. Besides, the severity and duration of long-lasting strong droughts in the region are studied. The most important negative effects of drought events are seen in the agricultural sector on crop production. In order to analyze this effect, the yield values of agricultural products grown in the region were obtained from Turkish Statistical Institute (TUIK) and standardized with Z-Score method. Afterwards, the impact of drought events on the yield of agricultural products grown in the region are examined.

Keywords: Drought analysis; data standardization; effect of drought on agriculture; Nevşehir region.

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1. Introduction

Drought, which is directly related to climate change, is increasing day by day all over the world and causes significant environmental problems. This effect may be even more critical for the sensitive regions to the effects of climate change such as Türkiye. Drought is an event that can have different effects over regions depending on the impact process. It is classified as meteorological, agricultural, hydrological and socioeconomic in terms of its effects. While meteorological drought occurs when precipitation falls below the average, agricultural drought occurs as a result of the inability of the plant to meet the water it needs from the soil in a certain period of time. Hydrological drought occurs as a result of the lack of underground and surface water resources. Socioeconomic drought occurs with the food crisis after other droughts [1].

The most important negative effects of the drought event are seen on agriculture and plant production. Drought is one of the abiotic stress factors that negatively affect the growth and development of the plant in its living environment, causing a decrease in product quality, quantity and yield, and preventing it from reaching the optimum product potential. The reason for the yield losses in agricultural production is based on abiotic stress factors at a rate of 71% and biotic stress factors at a rate of 29% [2]. Besides, drought has several negative effects on crop plants evolution. Drought causes low number of plants per acre, low quality and quantity of harvested yield and lower seed germination rate in next generation (Figure 1).

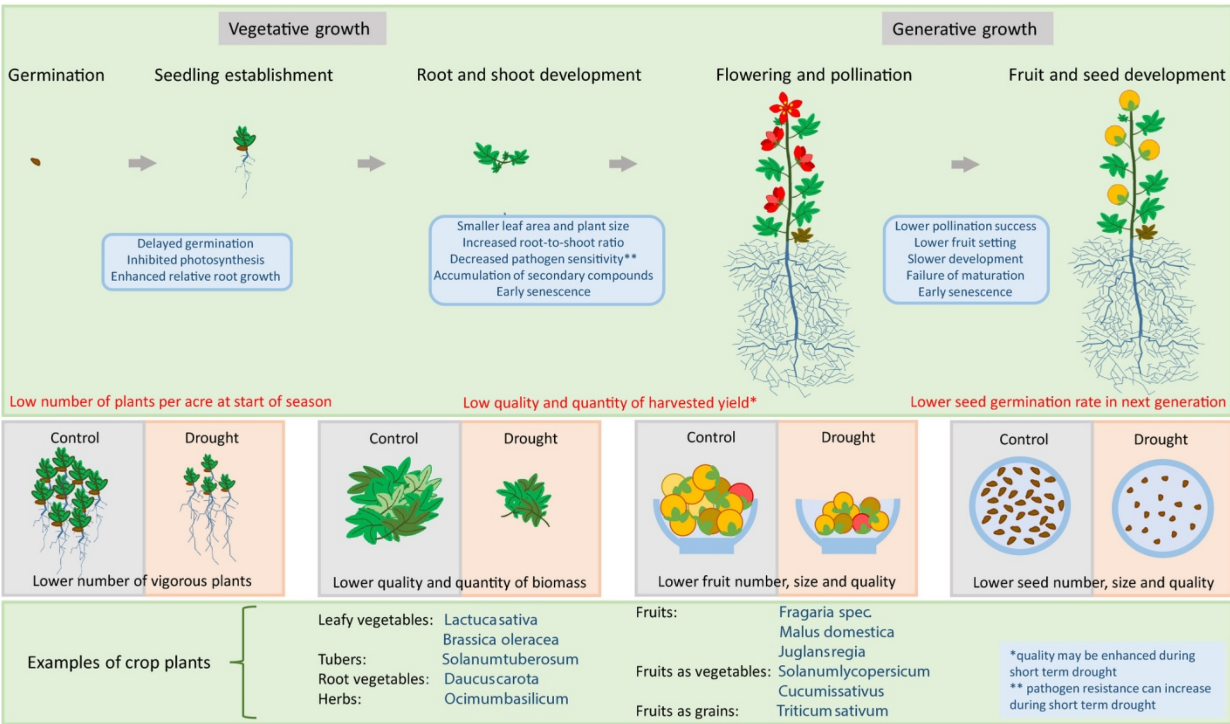

Figure 1. A scheme showing effects of drought on crop plants evolution [3].

There have been some studies around the world examining the effects of drought on agricultural crops. [4] investigated effects of drought on crop production and cultivation areas over 10 climate zones in Texas from 2008 to 2016. They found that drought had a greater impact on winter wheat and corn and lesser impact on cotton and sorghum production. [5] studied drought variability and the yield sensitivity of winter wheat, maize, sugar beet, and sunflower to drought in the Republic of Moldova. They found that agricultural production was sharply reduced by extreme drought periods. [6] investigated effects of a constructed index of degree-days, precipitation intensity, and a standardized precipitation index (SPI) on the mean yield and yield variability of three major crops in eight countries in the Sahelian region. It is found that an increase in the drought and degree-days tends to be harmful to crop yields, even though the cultivated crops are heat-tolerant. [7] analysed the interaction between temperature and drought variability in crop yield variability for the four most important crops worldwide (maize, rice, soybeans, and wheat) both at the global and country scale. They found that while there were no significant global effects of temperature for maize and soybeans yields for average SPEI, the combined effects of high temperatures and drought significantly decreased yields of maize, soybeans, and wheat by 11.6, 12.4, and 9.2%, respectively. [8] investigated the impacts and evidence of Australian droughts on agricultural crops. It is found that drought reduced various crops production in Australia up to 53% due to its intensity and duration. [9] investigated the influence of extreme weather disasters on global crop production. It is found that droughts and extreme heat significantly reduced national cereal production by 9–10%. [10] investigated the global-scale relationship between crop yield anomaly and multiscalar drought index. They found that global crop areas significantly affected by drought during the study period were around 23%, 8%, 30%, and 29% for maize, rice, soybean, and wheat, respectively, induced mainly by medium to longer drought timescale (5–12 months).

In this study, 3- and 12-month (meteorological and hydrological) drought status (with SPI and SPEI methods), and the severity and duration of long-lasting strong droughts as well as precipitation trend of the region were studied using Nevşehir Center and Ürgüp meteorological station data. Besides, yield values of agricultural products grown in the region were obtained from TUIK and standardized with the Z-Score method. Afterwards, the effects of drought events on the yield of agricultural products grown in the region were examined.

2. Materials and Methods

2.1. Study Location

Nevşehir province is located between 38.137° and 39.637° North latitudes and 33.616° and 35.733° East longitudes of the Central Anatolia Region. It has typical continental climate characteristics with hot and dry summers and cold and rainy winters. The annual average temperature is 10.7°C, and the total annual precipitation is 420.1 mm. Steppe plants are seen throughout the province. Forest areas make up approximately 1.3% of the province's surface area [11, 12].

In this study, we used precipitation data of Nevşehir Center and Ürgüp stations operated by Turkish State Meteorological Service. These stations were preferred because the data set is regular and uninterrupted. The locations of the meteorological stations are shown in Figure 2. We used Excel program for calculations.

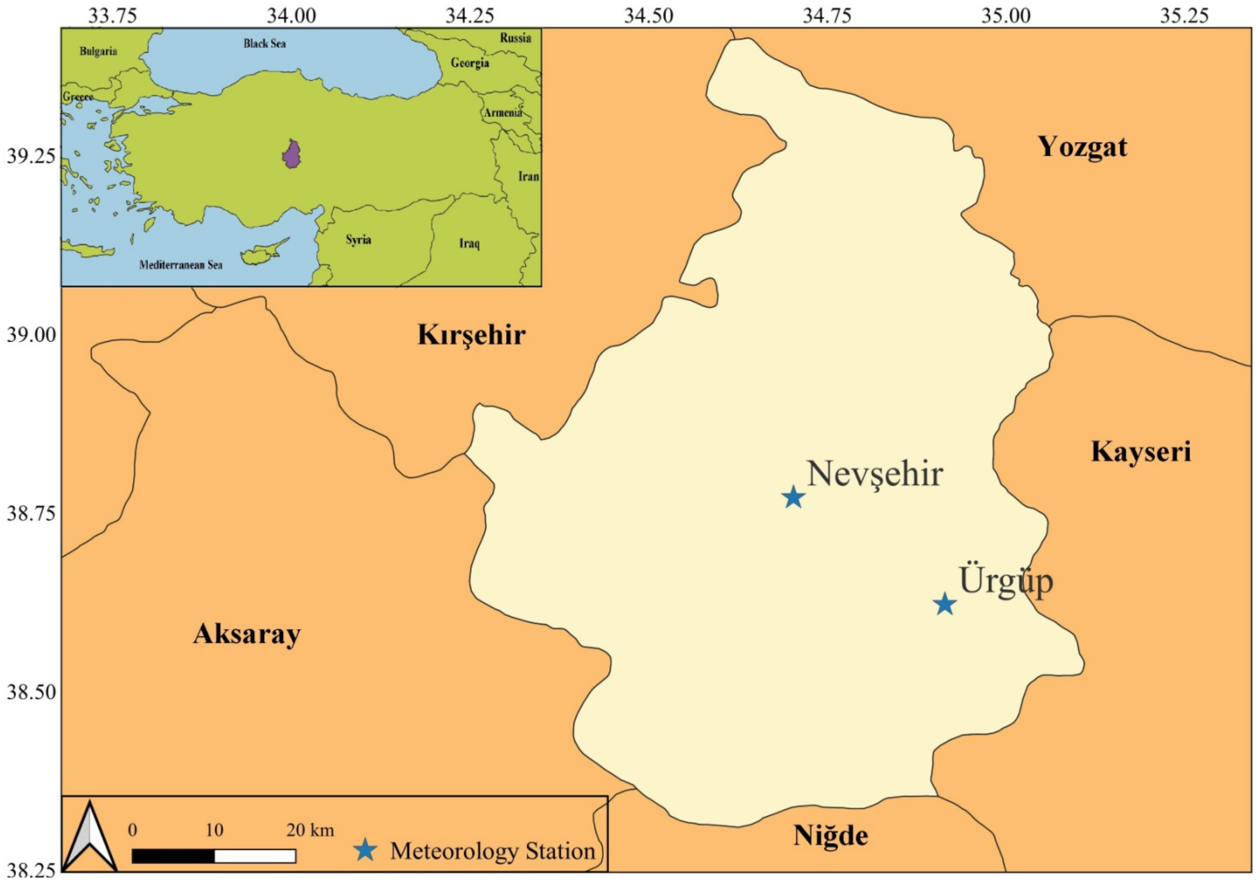

Figure 2. Locations of meteorological stations used in the study

2.2. The Standardised Precipitation Index (SPI)

SPI is a method developed by [13] for the identification and monitoring of drought. It provides the determination of the drought in a certain time scale with the precipitation data measured at any precipitation station. Negative values of SPI indicate drought, while positive values indicate humidity. The SPI is calculated by equation 1:

$$\mathrm{SPI} = (\mathrm{Xi} - \mathrm{Xort})/\sigma \qquad \text{(Equation 1)}$$

Here, Xi: is the measured precipitation data, Xort: is the precipitation mean and σ: is the standard deviation [14].

2.3. The Standardised Precipitation-Evapotranspiration Index (SPEI)

Based on calculation principles similar to SPI, SPEI uses precipitation and temperature data as input. Unlike SPI, the evapotranspiration effect is also taken into account in the calculation of SPEI. Therefore, SPEI can explain effects beyond global warming, especially for cases of temperature variability and extremes [15, 16]. In the first step of the SPEI calculation, potential evapotranspiration is calculated. SPEI is calculated by equation 2, with W, C0, C1, C2, d1, d2, d3 constants being fixed values:

$$\mathrm{SPEI} = W - \frac{C_0 + C_1 + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \qquad \text{(Equation 2)}$$

When P ≤ 0.5, W=-2ln(P), and when P > 0.5, P is replaced by 1−P. The constants are: C0=2.515517, C1=0.802853, C2=0.010328, d1=1.432788, d2=0.189269, d3=0.001308.

2.4. Drought Severity and Duration

A drought event is considered a period with negative SPI values, as drought is defined when SPI values fall below zero. The duration of the drought event is equal to the number of months between the beginning (inclusive) and the ending month (not included). Drought duration (D) is the length of the period starting from values where the SPI index values are negative and ending when the SPI values are positive and equal to 0 (zero) consecutively. The severity is the absolute value of the integral area between the SPI line and the horizontal axis (SPI = 0) up to the beginning month of the drought. Drought severity (S) is the cumulative SPI values obtained by adding up the remaining indices during the drought period, giving the total drought severity and expressing the magnitude of the drought [14]. The severity (S) of the drought is calculated by equation 3 and the intensity (I) by equation 4:

$$S = -\sum_{i=1}^{D} SPI_i \qquad \text{(Equation 3)}$$
$$I = S/D \qquad \text{(Equation 4)}$$

2.5. Z-Score

Z-Score (standardization) refers to the number of standard deviations above the mean for a data set. The Z-Score method is an effective transformation technique that can be used to compare two sets of data that are not of the same type. The Z-score value is calculated by equation 5:

$$Z = \frac{x - \mu}{\sigma} \qquad \text{(Equation 5)}$$

Here, x: data to be converted, μ: arithmetic mean of the data set, σ: standard deviation of the data set. Yield values of agricultural products grown in the region were obtained from TUIK and standardized with the Z-Score method. In our country, the harvest is usually done in July months. From March to the end of May, flowering occurs and the plant experiences the most active period in terms of development. Therefore, the drought index values of May and July were analyzed by correlation analysis with Z-score yield values.

3. Results and Discussion

Nevşehir province and Ürgüp district are classified as having semi-arid-less humid climates according to Thornthwaite Climate Classification [17]. The annual total precipitation average (1991-2021) of Nevşehir center meteorological station (17193) is 412 mm, and the average temperature is 11.2°C. The annual total precipitation average of Ürgüp meteorological station (17835) is 350 mm and the average temperature is 10.6°C.

There is a significant increase in the 95% confidence interval in the annual average temperature Mann-Kendall (M-K) trend analysis at both stations. It is seen that the increase has started to become evident since 2005. According to the annual total precipitation M-K trend analysis, a significant decrease and/or increase is not expected at Nevşehir Station, while a significant decrease is observed at Ürgüp station (Figure 3).

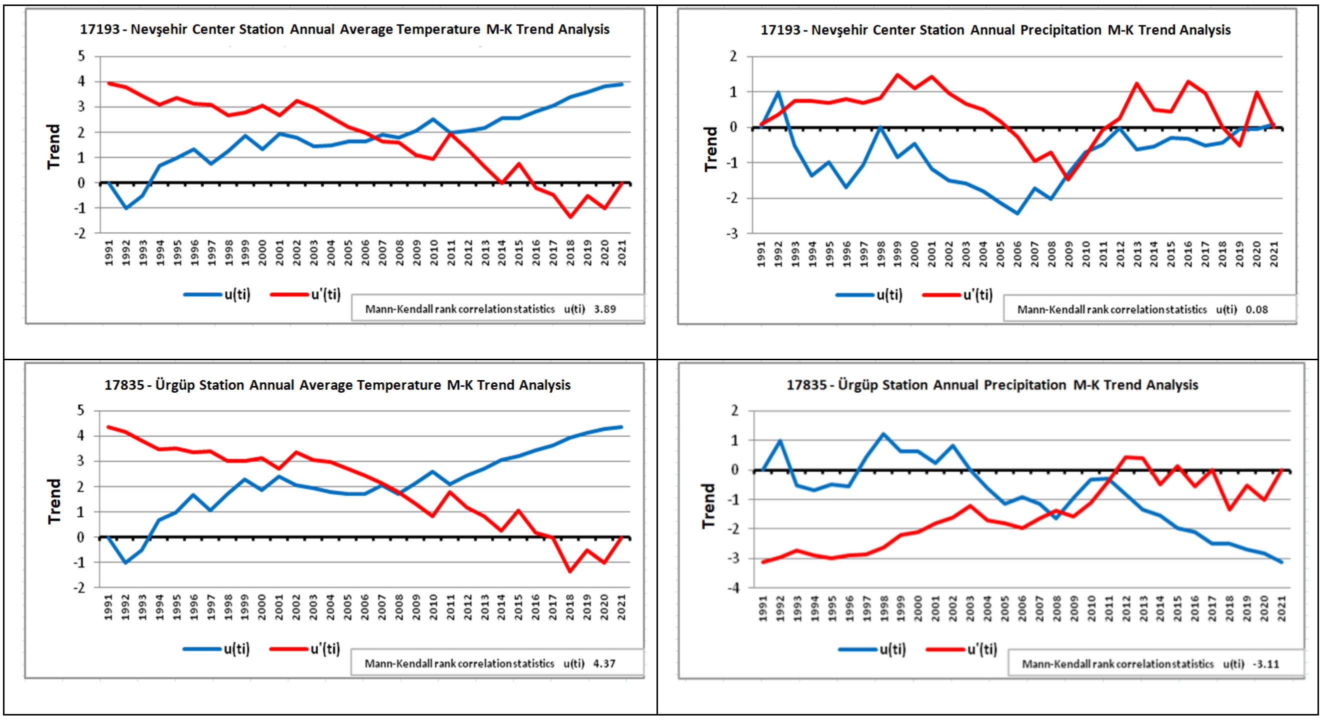

Figure 3. Mann-Kendall Trend Analysis of Nevşehir Center and Ürgüp Stations for Annual Average Temperature and Total Annual Precipitation (Blue line u(ti) indicate the forward sequential statistics and red line u(ti') indicates the backward sequential statistics).

At the 3-month scale at Nevşehir Center Station; the normal grade (slightly dry and slightly wet) is 46% in SPI while it is 44% in SPEI. The moderate dry class is 5% in SPI and 7% in SPEI. Severe dry is 5% in SPI and 4% in SPEI. The extreme dry class is 2% in SPI and 1% in SPEI.

At the 12-month scale; the normal grade is 43% in SPI and 40% in SPEI. The moderate dry class is 7% in SPI and 11% in SPEI. The extreme dry class is 1% in SPI but not in SPEI (Figure 4).

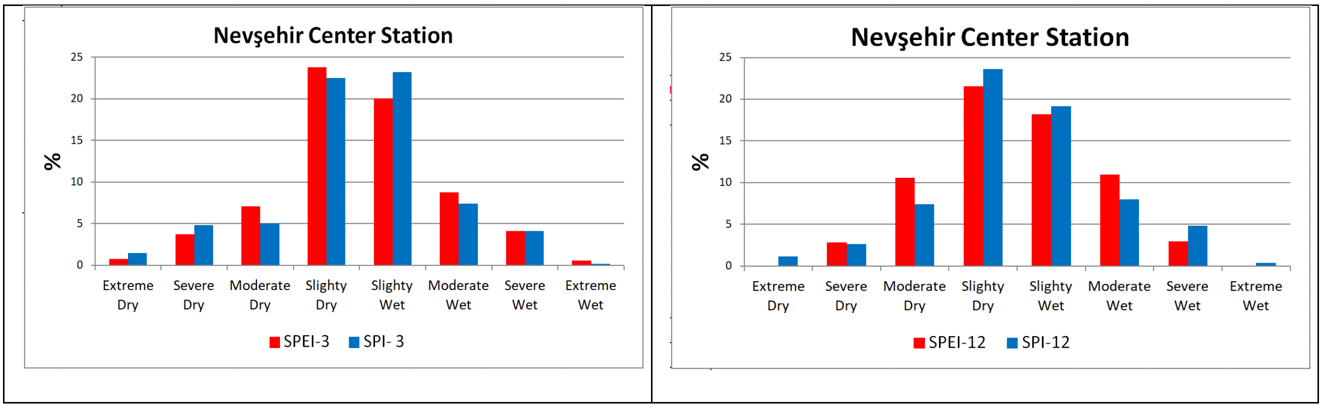

Figure 4. Occurrence Percentages of Drought Classes at Nevşehir Center Station (SPI-12 and SPEI-12)

At the 3-month scale at Ürgüp Station; the normal class is 46% in SPI and 45% in SPEI. Moderate dry class is 7% in SPI and 7% in SPEI. Severe dry is 3% in SPI and 4% in SPEI. Extreme dry class is 2% in SPI and 1% in SPEI. On the 12-month scale; the normal class is 44% in SPI and 41% in SPEI. Moderate dry class is 8% in SPI and 10% in SPEI. Severe dry is 3% in SPI and 3% in SPEI. The extreme dry class is 2% in SPI but not in SPEI (Figure 5).

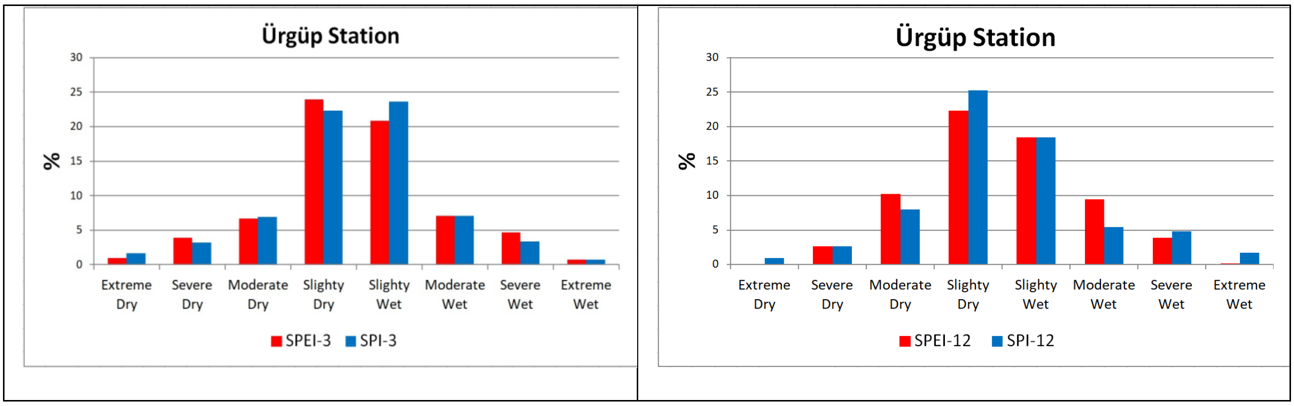

Figure 5. Occurrence Percentages of Drought Classes at Ürgüp Station (SPI-12 and SPEI-12)

At the 3-month scale, temporal variations between wet and dry periods are high in frequency, making it difficult to define distinct dry/wet periods during the analysis period. On the other hand, at the 12-month scale; As the frequency decreases, the duration of the drought increases. In addition, it was observed that the severity of drought differed on the time scale in some dry periods (Figure 6 and Figure 7).

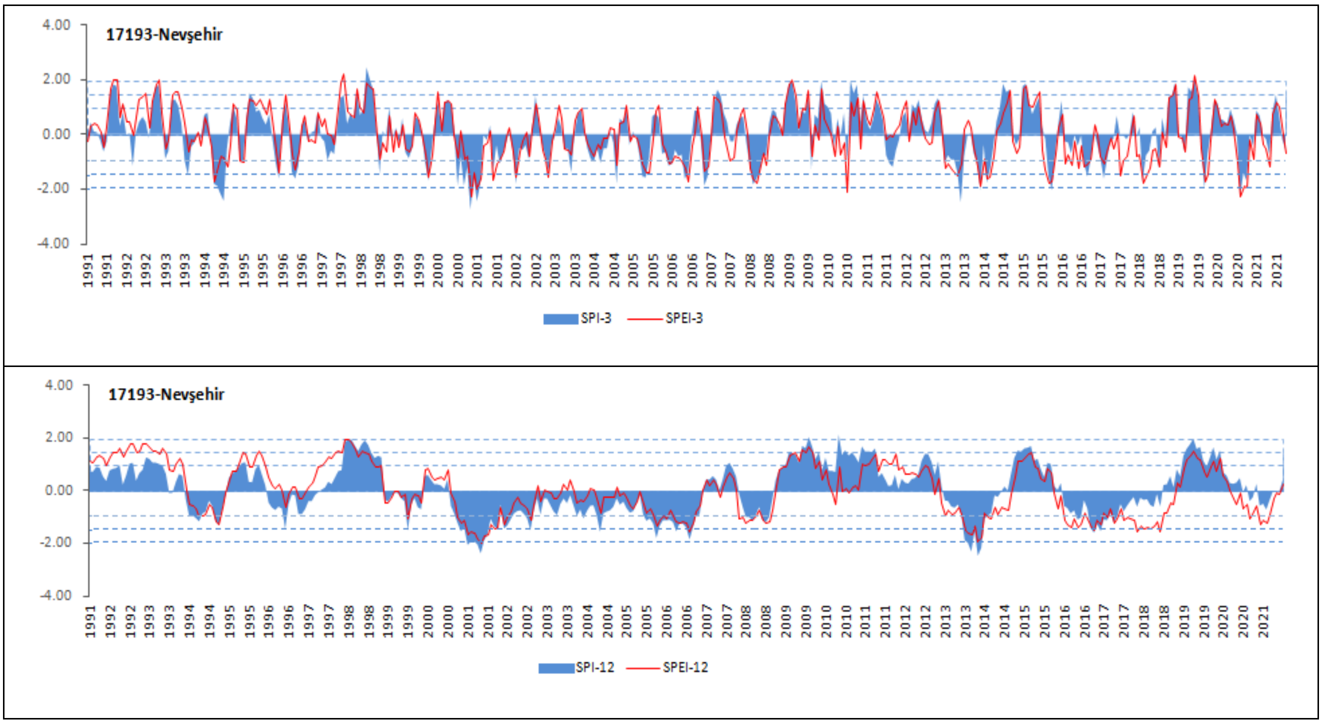

Figure 6. 3-12 months SPI and SPEI values of Nevşehir center station

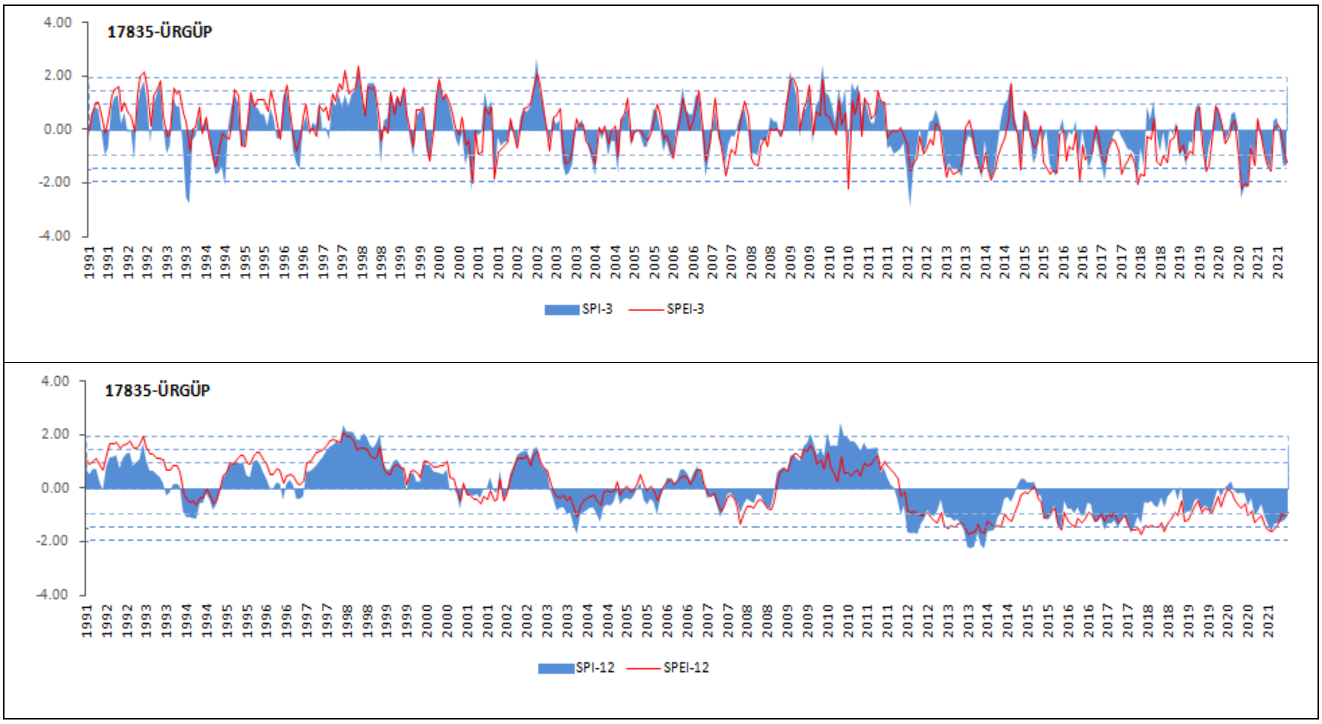

Figure 7. 3-12 months SPI and SPEI values of Ürgüp station

SPEI-12 and SPI-12 dry periods of both stations are patterned in Figure 8. The main drought periods at Nevşehir center and Ürgüp stations were determined according to whether they were abnormally dry (SPI-SPEI<= -1) at SPEI-12 and SPI-12 time scales.

At Nevşehir center station; the main drought periods are 1994-1995, 1999, 2001-2008, 2013-2014, 2016-2017 at SPI-12 time scale and 1995, 1999, 2001-2003, 2006-2008, 2013-2014, 2016-2018 and 2021 at SPEI-12 time scale. Drought periods of 1995, 2001-2003, 2006-2008, 2014, and 2016-2018 are well detected by both indexes at Nevşehir center station. SPI showed higher drought severity compared to SPEI. While SPI-12 in 1994 showed an earlier onset in the dry period, it was higher than SPEI-12 in terms of severity. 2016-2018 and 2021 droughts were seen at SPEI-12 with higher intensity and longer duration than SPI-12.

At Ürgüp station; the main drought periods are 1994, 2004, 2007, 2012-2018, and 2021 at SPI-12 and 2004, 2008, 2012-2019, and 2021 at SPEI-12 (Figure 8). Drought periods that occurred between 2012-2021 are well detected by both indexes at Ürgüp station. While the summer months of 1994 were moderately dry in SPI-12, it was slightly dry in SPEI-12. SPI showed higher drought severity compared to SPEI in 2012 and 2014. On the other hand, drought severity experienced in SPEI-12 in 2016, 2018, and 2019 is higher than in SPI-12.

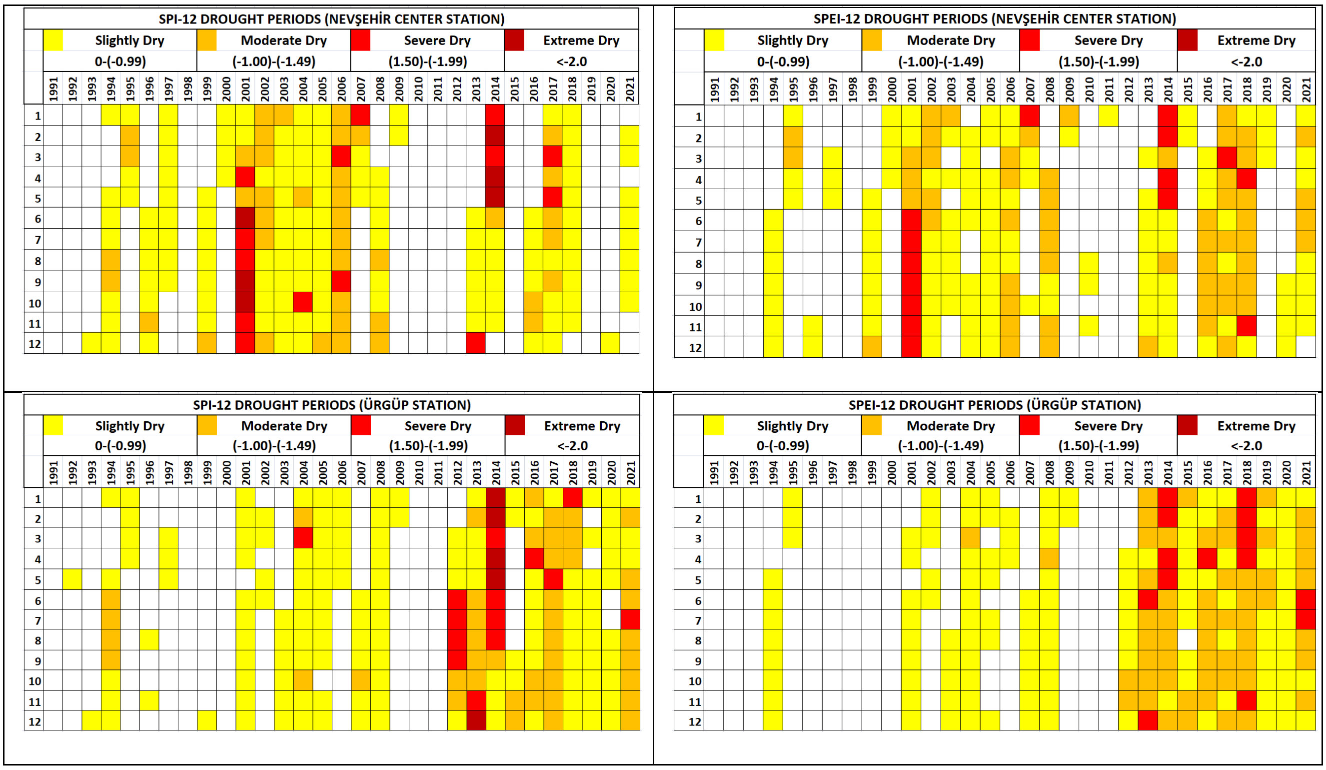

Figure 8. SPI-12 and SPEI-12 Droughts Periods at Nevşehir Center and Ürgüp Stations

The correlation between the two indices on a 3-month scale is 0.90 at Nevşehir center station and 0.87 at Ürgüp station. It is 0.87 at Nevşehir center station and 0.90 at Ürgüp station on a 12-month scale. The high correlation between the two indices indicates that the effect of temperature through evaporative water demand plays a role in determining droughts, while the lack of precipitation is a clear indication that drought is a dominant driver.

Although precipitation is an important indicator of water availability, the temperature is also an important factor that can affect water availability as it controls evapotranspiration rates. Whereas SPI only uses monthly precipitation data as input, SPEI uses different data between precipitation and PET. SPEI uses data on the difference between precipitation and PET. At both stations, both indices recorded similar patterns, but there were some notable differences in temporal evolutions. In cases where these differences occurred, SPI overestimated the severity of the drought, especially during the dry spring months at Nevşehir center station, and during the dry winter and spring months at Ürgüp Station.

This is because both indices mainly respond to precipitation variability in climatic conditions where inter-year temperature variability is suppressed and irregular precipitation changes are observed throughout the year. The intensity, duration, and intensities of consecutive maximum droughts in the SPEI and SPI series of Nevşehir center and Ürgüp stations at 3- and 12-month scales are shown in Table 1 and Table 2. The strongest and longest drought experienced in Nevşehir center station at the SPI-12 monthly scale was higher and longer than SPEI-12 recorded with a temporal difference. While the extreme maximum drought intensity experienced at Nevşehir center station at SPEI-12 scale was recorded as -1.98 in October 2001, SPI-12 was recorded as -2.45 in April 2014.

The strongest and longest drought at Ürgüp station on SPI-12 monthly scale was shorter and lower than that recorded in SPEI-12. The extreme maximum drought intensity experienced at Ürgüp station at SPEI-12 scale was recorded as -1.71 in December 2013, while it was recorded at SPI-12 as -2.25 in May 2014. It was observed that the drought events overlapped throughout the study area and in some cases they differed only in duration and magnitude.

Table 1. Start and End Dates of Long Lasting Strong Droughts in SPEI and SPI Series of Nevşehir Center Station at 3-month and 12-month scales

			The Strongest			The Longest			The Highest				
	NAME	NO	S Severity	Start-End Year/Month		D Duration	Start-End Year/Month		I Intensity	Start-End Year/Month		S Severity	Start Year/Mont
SPEI-3	Nevşehir	17193	-9,77	2000 /11	2001 /06	10	2005 /12	2006 /09	-1,37	2020 /09	2021 /02	-2,27	2001 /01
SPI-3	Nevşehir	17193	-14,52	2000 /09	2001 /06	10	2000 /09	2001 /06	-1,50	1994 /05	1994 /10	-2,74	2001 /01
SPEI-12	Nevşehir	17193	-39,70	2016 /03	2019 /03	37	2016 /03	2019 /03	-1,08	2001 /01	2003 /02	-1,98	2001 /10
SPI-12	Nevşehir	17193	-76,10	2001 /01	2007 /04	76	2001 /01	2007 /04	-1,05	2013 /06	2014 /11	-2,45	2014 /04

Table 2. Start and End Dates of Long Lasting Strong Droughts in SPEI and SPI Series of Ürgüp Station at 3-month and 12-month scales

			The Strongest			The Longest			The Highest				
	NAME	NO	S Severity	Start-End Year/Month		D Duration	Start-End Year/Month		I Intensity	Start-End Year/Month		S Severity	Start Year/Mont
SPEI-3	Ürgüp	17835	-17,26	2017 /02	2018 /06	17	2017 /02	2018 /06	-2,22	2010 /09	2010 /09	-2,24	2020 /10
SPI-3	Ürgüp	17835	-19,78	2013 /02	2014 /07	18	2013 /02	2014 /07	-1,68	2020 /10	2021 /02	-2,88	2012 /04
SPEI-12	Ürgüp	17835	-79,45	2015 /09	2021 /12	76	2015 /09	2021 /12	-1,08	2012 /04	2015 /07	-1,71	2013 /12
SPI-12	Ürgüp	17835	-44,67	2012 /03	2015 /02	41	2015 /09	2019 /01	-1,24	2012 /03	2015 /02	-2,25	2014 /05

The droughts experienced in both indices at Ürgüp station between 2001 and 2008 were not as high as the droughts experienced at Nevşehir center station. It was experienced in a slightly dry manner. On the other hand, the droughts experienced at Ürgüp station between 2012-2021 were more uninterrupted and severe especially in SPEI-12 compared to Nevşehir center station. At Nevşehir center station, SPI-12 was interrupted in 2015, 2019-2020, and the first months were slightly dry in SPEI-12. It was observed that both indices can detect historical drought disaster events [18].

The dry periods experienced in Nevşehir and Ürgüp stations and the low yield of agricultural products grown in the region correspond to almost the same periods (Figure 9-10).

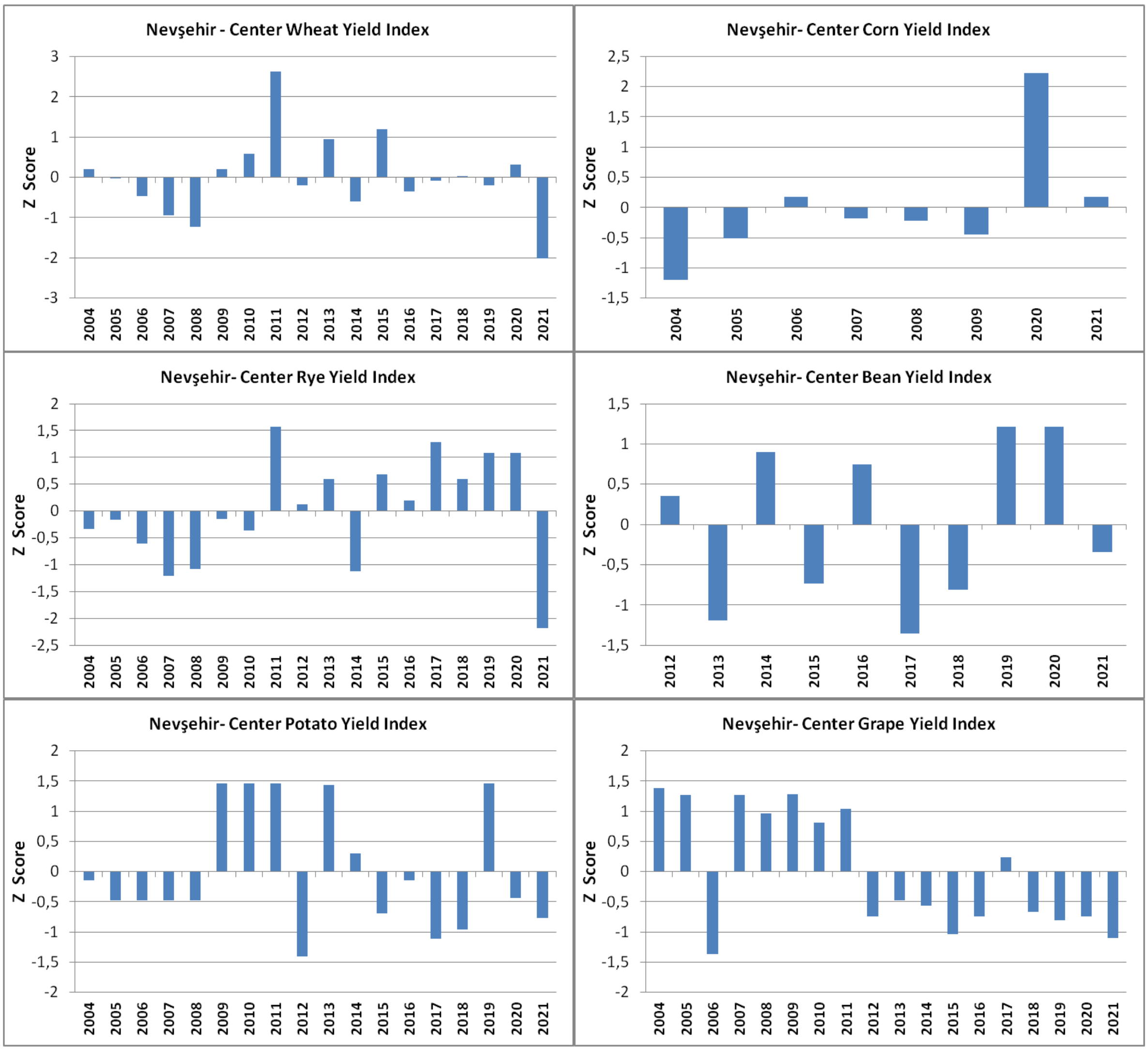

Figure 9. Z-Score index of yields of some agricultural products grown in Nevşehir Center

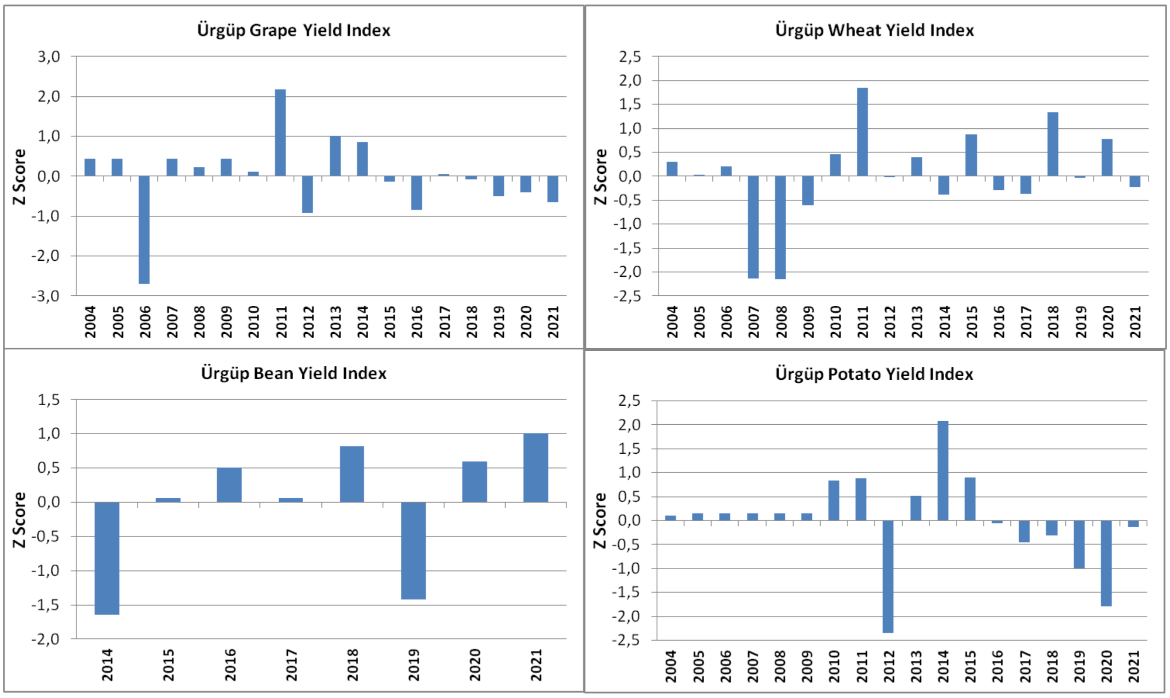

Figure 10. Z-Score index of yields of some agricultural products grown in Ürgüp

The correlations between yield index values and drought index values are given in Tables 3 and 4.

Table 3. Correlations between SPI and crop yield (Nevşehir Center station)

Index	Crop	Pearson's r
SPEI-12	Wheat	0.54*
SPEI-12	Potato	0.41
SPEI-12	Rye	0.39
SPEI-12	Bean	0.31
SPEI-12	Grape	0.20
SPEI-12	Corn	0.04
SPEI-3	Wheat	0.32
SPEI-3	Grape	0.21
SPEI-3	Rye	0.18
SPEI-3	Corn	0.15
SPEI-3	Bean	0.13
SPEI-3	Potato	0.02
SPI-12	Wheat	0.56*
SPI-12	Potato	0.50*
SPI-12	Rye	0.44
SPI-12	Bean	0.30
SPI-12	Corn	0.24
SPI-12	Grape	0.10
SPI-3	Corn	0.26
SPI-3	Wheat	0.21
SPI-3	Bean	0.12
SPI-3	Rye	0.09
SPI-3	Grape	0.05
SPI-3	Potato	-0.04

* p < .05, ** p < .01, *** p < .001

Table 4. Correlations between SPI and crop yield (Ürgüp station)

Index	Crop	Pearson's r
SPEI-12	Wheat	0.19
SPEI-12	Potato	0.17
SPEI-12	Grape	0.14
SPEI-12	Bean	0.01
SPEI-3	Bean	0.77*
SPEI-3	Wheat	0.24
SPEI-3	Potato	0.07
SPEI-3	Grape	0.01
SPI-12	Wheat	0.30
SPI-12	Bean	0.29
SPI-12	Potato	0.24
SPI-12	Grape	0.19
SPI-3	Bean	0.82*
SPI-3	Wheat	0.25
SPI-3	Potato	0.09
SPI-3	Grape	-0.13

* p < .05, ** p < .01, *** p < .001

Statistically significant ($p < .05$) correlations were found between Wheat and SPI-12 (r=0.56) and SPEI-12 (r=0.54) and Potato and SPI-12 (r=0.50) in Nevşehir Center. On the other hand, a statistically insignificant but relatively high correlation was obtained between potato and SPEI-12 (r=0.41) and between rye and SPI-12 (r=0.44). In Ürgüp, a statistically significant ($p < .05$) correlation was obtained between bean and SPEI-3 (r=0.77) and SPI-3 (r=0.82). Another important finding in the table is that the correlation of grape, which is a perennial plant, is quite low. This may be since perennial plants are often grown by irrigation. On the other hand, the correlations of wheat and rye plants grown with dry farming are higher than expected. It can be concluded that these plants are more sensitive to drought.

The graph of the products with statistically significant correlations is shown in Figures 11 and 12.

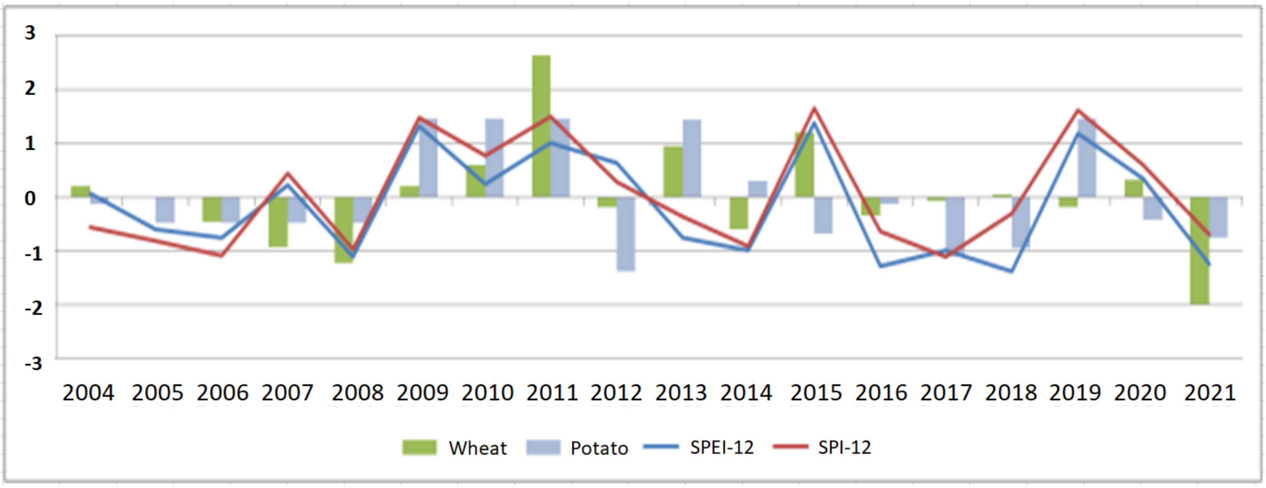

Figure 11. Nevşehir Center Station wheat yield index and drought index graph

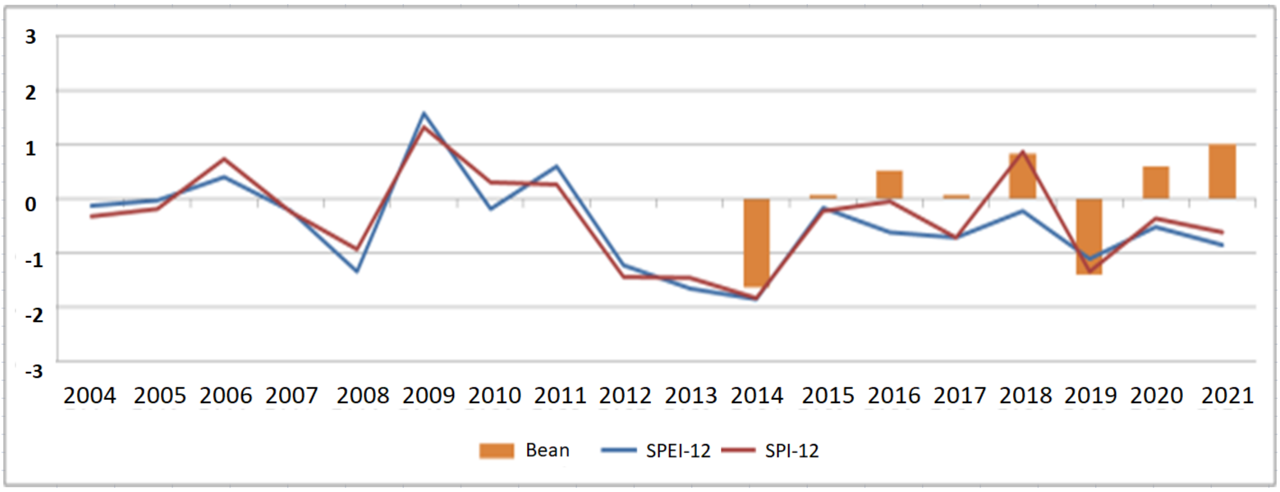

Figure 12. Nevşehir Center Station bean yield index and drought index graph

Only climatic conditions alone cannot determine plant yield. Plant breeding studies and culture-technical practices have a significant effect on plant yield. However, since it is not possible to control climatic conditions, it is the most important source of problems that can be encountered during aquaculture. Drought is one of these problems.

The fact that temperature increase experienced in the region since 2005 has caused higher water demand on PET and has been effective on the severity of droughts, especially at Nevşehir center station in 2016-2018 and 2021, along with other stress factors, the stress created by the dry conditions on the yield of agricultural products grown in the region. Droughts experienced during these periods were seen at a higher intensity in SPEI-12.

Plants with a high correlation between drought and plant yield (especially wheat, and potato) should not be deprived of irrigation in periods when drought is effective. It would be beneficial to irrigate more frequently and intensely for dry periods by closely monitoring the periods when drought is effective in the region. The results of this study constitute an important base for the prevention of drought-indexed crop yield loss, diversification of crop production, and future adaptations according to drought severity in the Nevşehir region.

As a result, drought, which has been experienced in recent years with global warming, poses significant dangers to plant production. Especially in the 21st century, when there is strong evidence of global temperature increase and the severity of drought is predicted to increase in the same way, it becomes more and more necessary to use indices containing temperature (SPEI, etc.) to describe drought characteristics.

A better understanding of the effects of drought characteristics such as severity, impact, and duration of drought on agricultural product yield will guide countries on the right decisions and investments for agriculture under long-term strategic planning against expected climate change.

This study can be extended to cover wider areas where agricultural production is widespread.

4. Conclusions

In this section, the results obtained from the study are compared with other studies in the literature. [7] found that combined effects of high temperatures and drought significantly decreased yields of maize, soybeans, and wheat by 11.6, 12.4, and 9.2%, respectively. [8] found that drought reduced various crop production in Australia by up to 53% due to its intensity and duration. [9] found that droughts and extreme heat significantly reduced national cereal production by 9–10%.[10] found that global crop areas significantly affected by drought during the study period were around 23%, 8%, 30%, and 29% for maize, rice, soybean, and wheat, respectively. In this study, the relationship (correlation) of crop yields with drought was studied. As a result, the relationship of wheat and potato products with drought (SPI) in Nevşehir Center was found to be r=0.56 and r=0.54, respectively. In Ürgüp, this relationship was found to be r=0.82 for beans.

Along with drought, other factors such as soil nutrients, soil water holding capacity, soil water condition, surface runoff, and soil inorganic matter content also affect crop yield. These conditions also affect the differences in regional reductions in crop yields. However, the general conclusion in the findings is that the correlations (yield loss) with drought are higher for plants grown with dry farming.

5. Statement of contrubition

KO (%33), GC (%34), and MAP (%33) design of the study. KO (%33), GC (%34), and MAP (%33) data acquisition and analysis. KO (%33), GC (%34), and MAP (%33) writing up. KO (%34), GC (%33), and MAP (%33) submission and revision.

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