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EFFECTS OF TEMPERATURE AND PRECIPITATION ON TEA YIELD IN TURKEY

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Abstract: The study aims to determine the changes in annual tea yield in Turkey between 1975 and 2019 and analyse the yield relationship with temperature and precipitation conditions. Within the scope of the study, statistical relationships between monthly temperature and precipitation data and annual tea yield were examined. In addition, the annual changes and trends in the yearly tea yield were revealed. As a result of the study, a statistically significant positive relationship was determined between annual average, maximum and minimum temperatures and annual tea yield. On the other hand, the relationship between total yearly precipitation and annual tea yield was insignificant. Relationships between temperature and yield are more substantial in summer. A statistically significant increasing trend was defined in tea yield during the 1975-2019 period in the research area. There was a considerable increase in annual average temperatures in the same period but an insignificant increase in precipitation. In the light of these, an increase in tea yield due to temperature rises can be expected in the region by looking at climate change scenarios.

Keywords: Turkey, Climate change, Tea yield, Temperature, Precipitation

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1. Introduction

Known as the second most consumed beverage in the world, tea "*Camellia sinensis* (L.)" is a plant made from the young leaves and buds of the tea plant belonging to the Theaceae family (Üstün and Demirci, 2013). India, China, Sri Lanka, Kenya, Turkey, Indonesia, Bangladesh, Argentina, Malawi are the countries that produce the most tea in the world (Koday, 2014). According to FAO statistics, tea farming areas in the world reached 4193 thousand hectares in 2018; dry tea production was 6338 thousand tons in 2018 and Turkey, which ranks 7th in terms of the breadth of tea agricultural lands, ranked 5th in dry tea production. According to the 2017-2018 data of the Indian Tea Board, Turkey ranks first in the world in tea consumption per capita with 3.2 kilograms per year (FAOSTAT, 2018; ÇAY-KUR, 2019). On the other hand, Turkey ranks 31st in world tea exports and 25th in world tea imports (Republic of Turkey Ministry of Agriculture and Forestry, 2020). In Turkey, the tea plant is grown in the Eastern Black Sea Region, starting from the Soviet Union border and extending to Fatsa in the west (Horuz and Korkmaz, 2006).

Bhagat et al. (2010) discuss that climate has always been considered important in crop production. The tea plant, which has a vast ecological amplitude, can be grown in various climate conditions. The tea plant, which requires plenty of precipitation, can grow in acidic soils and have a tree's appearance. It is also an evergreen plant that can grow from 1 meter to 18 meters depending on its type. The yield of the tea plant, which has an economic life of 50-60 years, varies depending on climatic conditions and pruning-care conditions. (Kurt and Hacıoğlu, 2013). Micro-climatic conditions influence tea cultivation even for optimum development (Rahman et al., 2017). It shows that temperature is the main environmental variable affecting shoot extension; low temperatures significantly reduce yields, especially in the cold season (Tanton, 1982).

As stated in RCP4.5 and RCP8.5 scenarios, prepared by Akçakaya et al. (2015), for the geography of MGM including Turkey, according to the climate projections made using the GFDLESM2M global model data, it is predicted that the temperatures will increase in all of Turkey and the precipitation will decrease for Turkey in the period of 2016-2099. Although many effects of global climate change are expected, one of the most important effects is agriculture (Mendelsohn, 2008). Global climate variability could explain more than 30% of the inter-annual variability of crop yields (Ray et al., 2015; An et al., 2020). The variability in temperature has a decisive role specifically in the yield of horticultural crops (Wheeler et al., 2000; Ustaoğlu and Karaca, 2010), and the beginning, end and length of the growing period are related to temperature (Chmielewski, 1992). The effects of climate change on agriculture due to the increase in greenhouse gases in the atmosphere are expected to differ on a regional basis depending on the type of product, temperature rise and changes in precipitation regime (Rosenzweig and Hillel, 1995; McCarl at al., 2001; Tubiello at al., 2002).

It is very important to examine the spatial and temporal differences in tea yield and determine the effects of temperature and precipitation conditions on yield, due to its importance for the economy of the region and Turkey, and the fondness of Turkish people for its consumption. In this context, the aim of the study: 1) Is to reveal the statistical relationships between temperature and precipitation conditions and tea yield in the 1975-2019 period. 2) To determine the inter-year changes and trends in tea yield for 1975-2019. 3) To make inferences about the effects of possible temperature and precipitation changes on yield according to climate change scenarios by analysing the changes observed in temperature and precipitation conditions during the 1975-2019 period.

2. Material and Methods

2.1. Materials

The field of study covers Giresun, Trabzon, Rize, and Artvin provinces, which meet 99.9% of Turkey's tea production according to 2019 agricultural statistics published by TURKSTAT (Table 1 and Figure 1). Since the tea production in Ordu, where very little production is made and the fluctuation from year to year is very high, was included in Giresun in the data sources before 2004, it was also included in the Giresun data in this study.

Table 1. General information about agricultural land and tea production (HGM, 2014; TURKSTAT, 2020)*

Provinces	TF (decare)	AA (decare)	TPA (decare)	AA/ PA (%)	TPA/AA (%)	TPA/PTA (%)	TP in 2019 (ton)
Ordu	5861000	2528301	95	43.1	0.1	0.0	41
Giresun	7025000	1418759	20312	20.2	0.3	1.4	30710
Trabzon	4628000	944251	186069	20.4	4.0	19.7	325031
Rize	3835000	560847	552866	14.6	14.4	98.6	905650
Artvin	7393000	300466	89459	4.1	1.2	29.8	146016

*TURKSTAT (2020) and HGM (2014).

TF= total field, AA= agricultural area, TPA= tea production area, PA= province area, PTA= province total area, TP= tea production (ton)

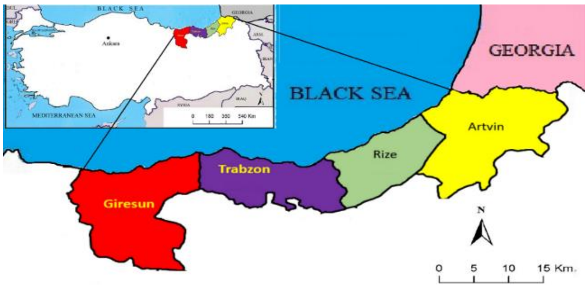

Figure 1. Location of the research area.

In the research area, the rainiest season of the year is autumn in Giresun, Trabzon and Rize, while it is winter in Artvin. The annual total precipitation for the 1975-2019 period varies between 825.3 mm (Trabzon) and 1291.3 mm (Giresun). Annual average temperatures are between 12.3 °C (Artvin) and 14.8 °C (Giresun). The annual temperature difference is the highest in Artvin (17.3 °C) and the least in Giresun (16.4 °C). While the coldest month is February in Giresun, Trabzon and Rize, it is January in Artvin. The hottest month is August in all provinces (Table 2 and Figure 2).

2.2. Data Collection

This study used monthly total precipitation, monthly average temperature, monthly average maximum temperature, and monthly average minimum temperature data of Giresun, Trabzon, Rize and Artvin meteorological stations. The data were obtained from the Turkish State Meteorological Service. Also, it was extracted monthly temperature and precipitation records from the climate dataset gridded at 0.5 intervals from KNMI Climate Explorer (http://climexp.knmi.nl) for each province. These data were found to be compatible with the data of Turkish State Meteorological Service.

The data on tea production areas and tea production amounts covering the period 1975-2003 were taken from the State Institute of Statistics agricultural statistics and the General Directorate of Tea Enterprises (ÇAY-KUR). The data for the period 2014-2109 were obtained from the website of the Turkish Statistical Institute. Since reliable data on the annual tea yield were not available on a provincial basis before 1975, the analysis included 1975 and later.

2.3. Statistical analyses

The analysis of the data was conducted in three phases. Firstly, statistical relationships between monthly temperature and precipitation data and annual tea yield were examined. Pearson Correlation Coefficient and simple linear regression analysis method were used to determine the relationships. The mathematical correlation of the relationship between two or more variables is examined by regression analysis, and the direction and degree of the relationship is questioned by correlation analysis (Ersöz and Ersöz, 2020). Linear regression tests the relationship between X and Y variables and whether a linear trend exists (Karabulut and Cosun, 2009).

Table 2. Distribution of precipitation in the period 1975-2019 (Edited from the data of the Turkish State Meteorological Service)

Station	Total annual precipitation	Seasonal precipitation totals (mm) and percentages							
		Winter		Spring		Summer		Autumn	
		mm	%	mm	%	mm	%	mm	%
Giresun	1291.3	340.4	26.4	245.3	19.0	248.9	19.3	456.8	35.4
Trabzon	825.3	222.3	26.9	172.7	20.9	136.4	16.5	293.8	35.6
Rize	2247.0	634.2	28.2	334.1	14.9	469.4	20.9	809.4	36.0
Artvin	709.4	248.9	35.1	171.9	24.2	110.4	15.6	178.3	25.1

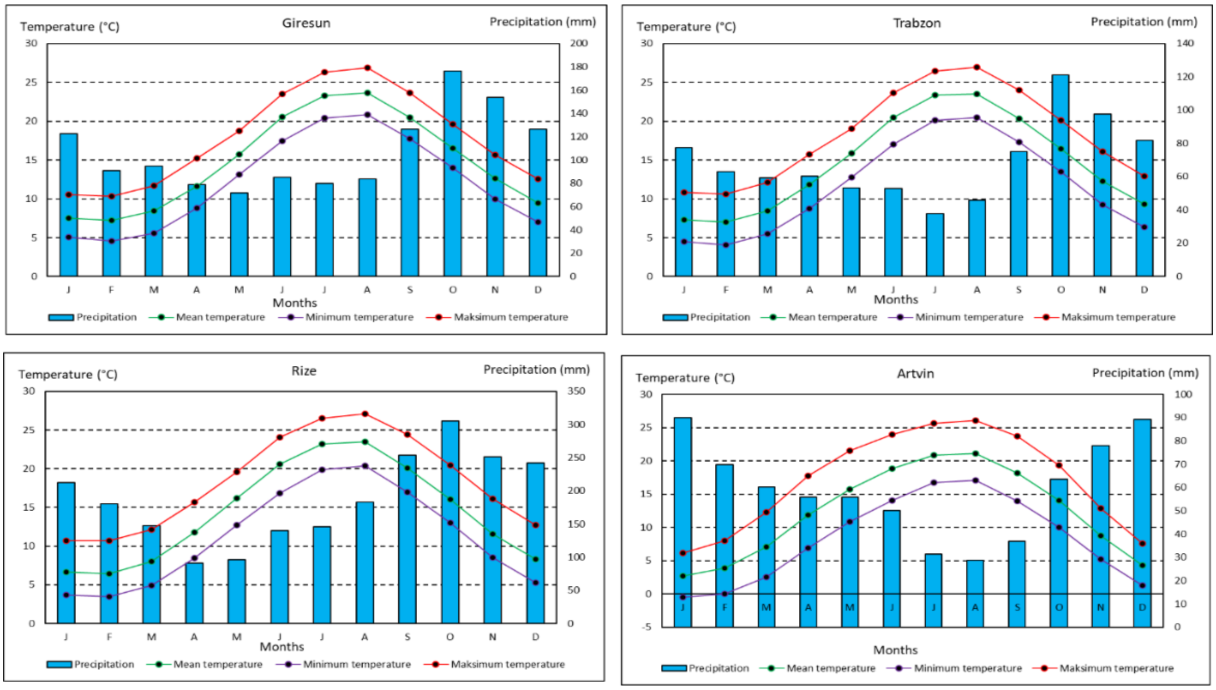

Figure 2. Temperature and Precipitation Charts for the Period 1975-2019 (From the Data of the Turkish State Meteorological Service).

The data of monthly total precipitation, monthly average temperature, monthly average minimum, and maximum temperature from October of the previous year, which is called the biological year (Fritts, 1976), to October of the year in which the tea harvest is made, is the independent variable. The data on annual yield values obtained per decare is the dependent variable. The aim is to reveal the effect of the temperature and precipitation conditions of October, November and December of the previous year on the yield in the harvest year (İrdem, 2021). The correlation coefficients obtained were significant at 0.95, 0.99 and 0.999 confidence levels. The differences between the months and provinces in the results were evaluated. The regression results were also used to explain the temperature and precipitation parameters analysis in the annual tea yield. The IBM SPSS 22.0 package program (SPSS, 2013) was used in the analysis.

In the second stage, changes, and trends in annual tea yield over the years were revealed. The annual tea yields of the provinces studied in the 1975-2019 period were calculated. The tea production amounts of each year between 1975 and 2019 were proportioned to the tea planting areas and the number of kilograms of yield per acre was calculated. While examining the temporal changes in the annual tea yield, the yield differences between the provinces were also emphasized, and the periods when the tea yield was high and low in the 1975-2019 period were determined. Trends in tea yield were demonstrated by simple linear regression testing.

The changes observed in temperature and precipitation in the research area during the 1975-2019 period were analysed in the last stage. According to possible climate change scenarios, the changes that could occur in tea production were evaluated. This study used 1971-2000 reference period and 2016-2099 future period climate change projections prepared by Akçakaya et al. (2015) and analyzed by Gürkan et al. (2016). This projection used GFDLESM2M global model data and regcm4.3.4 regional climate model according to RCP4.5 and RCP8.5 scenarios for geography, including Turkey.

3. Results and Discussion

3.1. Relationship between Average Temperatures and Tea Yield

In the field of research, strong positive relationships were determined between the average temperatures of

September of the previous year and the tea yield. The correlation coefficient is significant at the confidence level of 0.999 in all provinces. According to the regression analysis results, the change in average temperatures in September of the previous year in Giresun explains 22% of the change in tea yield in Giresun, 24% in Trabzon, 30% in Rize, and 21% in Artvin between years. In October and November of the previous year, a significant positive relationship between average temperatures and tea yields in Giresun at the confidence level of 0.99 is noted. There is no significant relationship in any of the provinces for December of the previous year (Table 3).

In the January-April period, the effect of average temperatures on tea yield is most evident in February. There is a significant positive correlation at 0.999 trust level in Artvin and 0.99 trust level in Giresun this month. The change in average temperatures in Giresun in February explains 21% of the difference in tea yield between years. April is the month with the lowest correlation. It is clear that the correlation between average temperatures and tea yields has become increasingly evident in May, and especially in the June-August period, the correlation coefficient obtained in all provinces was significant at the confidence level of 0.999. It is important that the power of the average temperatures between May and August in Rize, which meets most of the Turkey's tea production, in explaining the change in tea yield, is at the highest values among 4 provinces.

The effect of annual average temperatures on tea yield is generally more evident than the effect of monthly average temperatures. It is significant at a confidence level of 0.999 in all provinces. According to the regression analysis results, the change in average annual temperatures in Giresun explains 44% of the change in tea yield between years, 40% in Trabzon, and 49% in Rize and Artvin (Table 3).

Table 3. Correlation of average monthly mean temperatures with tea yield

Provinces	Giresun		Trabzon		Rize		Artvin	
Months	r	R^2	r	R^2	r	R^2	r	R^2
September	0.47***	0.22	0.49***	0.24	0.55***	0.30	0.46***	0.21
October	0.39**	0.16	0.24	0.06	0.40*	0.16	0.29	0.08
November	0.39**	0.15	0.20	0.04	0.31	0.10	0.30*	0.09
December	0.21	0.05	0.21	0.05	0.24	0.06	0.17	0.03
January	0.30*	0.09	0.24	0.06	0.32*	0.10	0.27	0.08
February	0.38**	0.13	0.25	0.06	0.27	0.08	0.46***	0.21
March	0.31*	0.09	0.13	0.02	0.23	0.05	0.32*	0.10
April	0.04	0.00	-0.03	0.00	-0.02	0.00	0.11	0.01
May	0.57***	0.33	0.41**	0.17	0.51***	0.26	0.36*	0.11
June	0.67***	0.45	0.52***	0.27	0.59***	0.35	0.56***	0.32
July	0.47***	0.22	0.54***	0.29	0.57***	0.33	0.42***	0.18
August	0.54***	0.29	0.68***	0.46	0.68***	0.46	0.62***	0.38
Annual	0.67***	0.44	0.63***	0.40	0.70***	0.49	0.70***	0.49

*P≤0.05, **P≤0.01, ***P≤0.001, r= correlation coefficient.

3.2. Relationship of tea Yield with Average Minimum Temperatures

In the research area, strong positive relations were found between the average minimum temperatures of September of the previous year and the tea yield in all provinces except Giresun. Although the correlation value obtained for Giresun is significant at the confidence level of 0.95, the correlation coefficient obtained for this month in other provinces is significant at the confidence level of 0.999. According to the regression analysis results, while the change in average minimum temperatures in September of the previous year in Giresun explains 11% of the change in tea yield between years, it explains 23% of it in Trabzon, 24% in Rize, and 27% in Artvin. In October of the previous year, there was a significant positive correlation at the confidence level of 0.95 in Giresun and Artvin, and 0.99 in Rize. There is no significant relationship between the average minimum temperatures and tea yield in provinces other than Artvin for November and December of the previous year. The correlation value obtained for November in Artvin is significant at the confidence level of 0.95 (Table 4).

The province where the effect of average minimum temperatures on tea yield in the January-April period is most evident is Artvin. In Artvin, a significant positive correlation is observed at the level of 0.95 in January and March, and at 0.999 in February.

Table 4. Correlation of average monthly minimum temperatures with tea yield

Provinces	Giresun		Trabzon		Rize		Artvin	
Months	r	R^2	r	R^2	r	R^2	r	R^2
September	0.33*	0.11	0.48***	0.23	0.49***	0.24	0.52***	0.27
October	0.33*	0.11	0.28	0.08	0.43**	0.18	0.39*	0.15
November	0.25	0.07	0.14	0.02	0.27	0.07	0.40*	0.16
December	0.24	0.06	0.19	0.04	0.20	0.04	0.30	0.09
January	0.32*	0.10	0.25	0.06	0.29	0.08	0.40*	0.16
February	0.27	0.07	0.15	0.02	0.22	0.05	0.45***	0.20
March	0.13	0.02	0.07	0.01	0.19	0.04	0.35*	0.13
April	-0.06	0.00	-0.05	0.00	0.02	0.01	0.15	0.02
May	0.47***	0.22	0.29	0.08	0.51***	0.26	0.46***	0.21
June	0.53***	0.28	0.44**	0.19	0.57***	0.33	0.58***	0.33
July	0.38*	0.15	0.49***	0.24	0.52***	0.27	0.46***	0.21
August	0.50***	0.25	0.71***	0.50	0.68***	0.46	0.63***	0.40
Annual	0.53***	0.28	0.59***	0.34	0.68***	0.46	0.74***	0.54

*P≤0.05, **P≤0.01, ***P≤0.001, r= correlation coefficient.

April is the month with the lowest correlation for average minimum temperatures and average temperatures. Similarly, for the average minimum temperatures, it is observed that the correlation becomes more evident with May. Although the correlation value obtained for all provinces in the May-August period is significant at different confidence levels, it is examined that the relationship is even stronger especially in Artvin and Rize.

The effect of annual average minimum temperatures on tea yield is quite consistent with average temperatures. The correlation value obtained in all provinces is significant at the confidence level of 0.999. According to the regression analysis results, the change in annual average minimum temperatures in Giresun explains 28% of the variation in tea yield between years, 34% in Trabzon, 46 in Rize and 54% in Artvin (Table 4).

3.3. Relationship of Tea Yield with Average Maximum Temperatures

In the research area, significant positive relations were found between the average maximum temperatures of September of the previous year and tea yield except Giresun. Especially in Trabzon and Rize, correlations are very prominent. The change in average maximum temperatures in September of the last year in Trabzon explains 23% of the difference in tea yield over the years, while in Rize, it explains 38%. In October of the previous year, the significant relationship was only in Rize at the confidence level of 0.99. There is no significant correlation between average maximum temperatures and tea yield in November and December of the previous year (Table 5).

Rize is the province where the effect of average maximum temperatures on tea yield in the January-April period is most evident. In Rize, there was a significant positive correlation at 0.95 confidence levels in January, February, and March. There is almost no correlation between tea yield and average maximum temperatures in April. Although it is seen that the correlation becomes more evident in May, there are not as strong correlations as in average temperatures and average minimum temperatures. It is seen that the relationship is even stronger in May-August, especially in Trabzon and Rize, compared to other provinces (Table 5).

Although the effect of average annual maximum temperatures on tea yields is significant at 0.95 confidence level in Giresun, the correlation value is much more remarkable in other provinces. The correlation value obtained for other provinces is significant at the confidence level of 0.999. According to the regression analysis results, the change in average annual maximum temperatures in Giresun explains 16% of tea yield variation between years. In Trabzon, it explains 39%, 52% in Rize, and 29% in Artvin (Table 5).

3.4. Relationship between Total Precipitation and Tea Yield

The relations between total monthly precipitation and tea yield remain extremely low compared to temperature-yield relationship. The correlation coefficient obtained only in March in Trabzon is statistically significant at the confidence level of 0.95. The change in total precipitation in Trabzon in March explains 12% of tea yield changes between years. None of the correlation values found in other provinces and months are statistically significant. While there was a positive correlation between tea yield and monthly total precipitation for some months in some provinces, negative correlations were also found in another province for the same month. For example, while there is a positive correlation between the total precipitation in April and tea yield in Trabzon and Rize, there is a negative correlation in Giresun and Artvin. Although the positive effect of annual total precipitation is not statistically significant in provinces except Artvin, the obtained correlation values are close to the significance limit for a confidence level of 0.95. The change in annual total precipitation in Giresun explains 7% of the variation in tea yield between years, 6% in Trabzon, and 9 in Rize. In Artvin, on the other hand, a negative correlation was found between annual total precipitation and tea yield. However, the point to be noted here is that the negative correlation between annual total precipitation and tea yield in 2010 and 2011 also reduced the long-term average correlation. While the correlation value between the annual total precipitation and tea yield in Artvin for the 1975-2019 period was -0.14, this value was found to be 0.40 for the 1975-2009 period, which corresponds to a significant positive relationship at the confidence level of 0.95. For other provinces, the 1975-2009 is stronger than the 1975-2019 period correlation (see Table 6).

3.5. Changes and Trends in Tea Yield over the Years

When the areal distribution of annual tea yield is examined, it has been determined that the highest yield on decare basis is Rize with 1187 kilograms and the lowest yield is Giresun with 798 kilograms, according to the average of 1975-2019 period (Figure 3).

Table 5. Correlation of average monthly maximum temperatures with tea yield

Provinces	Giresun		Trabzon		Rize		Artvin	
Months	r	R^2	r	R^2	r	R^2	r	R^2
September	0.20	0.04	0.48***	0.23	0.62***	0.38	0.33*	0.11
October	0.13	0.02	0.22	0.05	0.41**	0.16	0.13	0.02
November	0.14	0.02	0.25	0.06	0.29	0.08	0.24	0.06
December	0.17	0.03	0.28	0.08	0.30	0.09	0.17	0.03
January	0.22	0.05	0.25	0.06	0.38*	0.14	0.21	0.05
February	0.27	0.07	0.35*	0.12	0.37*	0.14	0.37*	0.14
March	0.15	0.02	0.20	0.04	0.32*	0.10	0.17	0.03
April	-0.10	0.01	-0.05	0.00	0.07	0.01	0.02	0.00
May	0.43**	0.18	0.42**	0.18	0.49***	0.24	0.22	0.05
June	0.40*	0.16	0.55***	0.30	0.65***	0.42	0.32*	0.10
July	0.36*	0.13	0.50***	0.25	0.62***	0.38	0.32*	0.10
August	0.37*	0.14	0.62***	0.39	0.69**	0.48	0.52**	0.27
Annual	0.40*	0.16	0.62***	0.39	0.72***	0.52	0.54***	0.29

*P≤0.05, **P≤0.01, ***P≤0.001, r= correlation coefficient.

Table 6. Correlation of total monthly precipitation with tea yield

Provinces	Giresun		Trabzon		Rize		Artvin	
Months	r	R^2	r	R^2	r	R^2	r	R^2
September	0.24	0.06	0.04	0.00	0.29	0.09	0.28	0.08
October	0.05	0.00	0.23	0.05	0.12	0.02	0.07	0.01
November	-0.03	0.00	-0.12	0.02	0.01	0.00	-0.02	0.00
December	0.28	0.08	-0.03	0.00	-0.10	0.01	-0.10	0.01
January	0.24	0.06	0.14	0.02	-0.06	0.00	-0.17	0.03
February	-0.19	0.04	-0.04	0.00	0.00	0.00	-0.22	0.05
March	0.27	0.07	0.35*	0.12	0.27	0.07	0.08	0.01
April	-0.23	0.05	0.21	0.04	0.06	0.00	-0.19	0.04
May	0.07	0.01	0.17	0.03	-0.03	0.00	0.09	0.01
June	0.10	0.01	-0.05	0.00	0.10	0.01	0.14	0.02
July	0.14	0.02	-0.13	0.02	0.23	0.05	-0.08	0.01
August	-0.25	0.06	0.04	0.00	0.06	0.00	-0.04	0.00
Annual	0.27	0.07	0.25	0.06	0.30	0.09	-0.14	0.02

*P≤0.05, r= correlation coefficient.

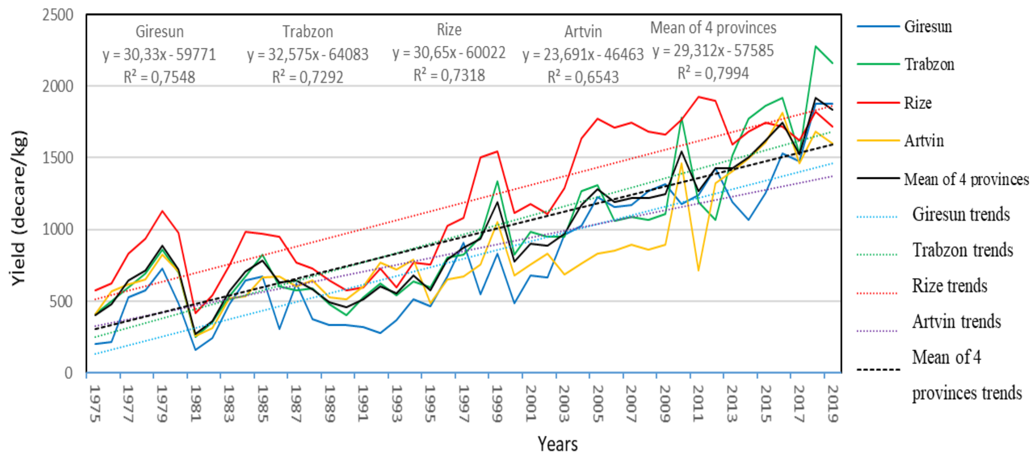

Figure 3. Changes and trends in tea yield in the research area between years (State Institute of Statistics agricultural statistics; ÇAY-KUR Annual Activity Reports; TURKSTAT, 2020).

Table 7. Results of the linear trend test applied to tea yield

	Provinces	a	b	t	r (β)	R^2	Results
Tea yield	Giresun	99.958	30.330	11.505	0.87***	0.755	Increasing trend.
	Trabzon	219.75	32.575	10.761	0.85***	0.729	Increasing trend.
	Rize	481.84	30.65	10.833	0.86***	0.732	Increasing trend.
	Artvin	302.87	23.691	9.021	0.81***	0.654	Increasing trend.

**P≤0.001, r= correlation coefficient.

The average yield of the four provinces in the field of study for 1975-2019 is 950 kg. The highest average yield was achieved in 2018 with 1916 kilograms, while the lowest average was obtained in 1981 with 272 kilograms. In 2018, the total tea production of these four provinces was 1480534 tons, while in 1981, production decreased to 192218 tons. In the period 2004-2019, the yield was over 1000 kg. On the other hand, in the 1975-2004 period, it is seen that the yield exceeded 1000 kilograms only in 1999. It is also noteworthy that since 2014, the yield has exceeded 1500 kilograms. In contrast, in 1975, 1976, 1981, 1982, 1989, and 1990, the average yield of four provinces decreased to 500 kg (Figure 3). When the temporal changes observed in tea yield are evaluated, a fluctuating course draws attention, but an increasing trend is also observed. According to linear trend analysis, the increases are significant at the confidence level of 0.999 in all provinces. When the analyzed 45-year period is divided into 15-year slices, the average yield in the 1975-1989 period as 593.1 kg, the average yield in the 1990-2004 period as 792.4 kg, and the average yield in the 2005-2019 period as 1465.3 kg reveals the extent of the yield increase (Table 7 and Figure 3).

Tea yield generally increases in years when the annual average temperatures increase. Especially in 1979 and 2010, the positive relationship between the increase in yield and temperature is quite evident. However, although the temperature has increased, it has been observed that the yield has decreased in some years. In 1981, for example, tea yields dropped significantly despite increasing average annual temperatures (Figure 4). When the relationship of this extreme decrease in yield with temperature and precipitation parameters is examined in detail, it is seen that the winter temperatures in the mentioned year, especially in January, are well above the average, and the actual precipitation is well below the average. For example, while the long-term average of January precipitation in Rize was 212 mm, only 130 mm precipitation fell in 1981. In January, the average temperature was 6.6 °C for many years, while in 1981, the average temperature was 8.5 °C. The long-term average of winter precipitation was 633 mm for many years.

In contrast, 439 mm precipitation fell in the winter of 1981. The average winter temperature was 7.1 °C. On the contrary, in 1981, the average winter temperature was 9.3 °C. In addition, the total precipitation for the June-July period of 1981 was only about half of the long-term average (while the long-term average was 289 mm, in 1981 it was 150 mm). All these adverse conditions may influence the sudden decrease in tea yield. It is seen that tea yields are generally high when the total annual rainfall increases in the field of study. However, in 2010 and 2011, there is a situation contrary to this generalization. The average yield of 4 provinces increased in 2010. As opposed to this, the annual total precipitation of these 4 provinces decreased. In 2011, however, while the average yield of 4 provinces decreased, the annual total precipitation of these 4 provinces increased. Figure 4 shows that the strong correlation between temperature conditions and tea yield eliminates precipitation's positive or negative effect in these two years.

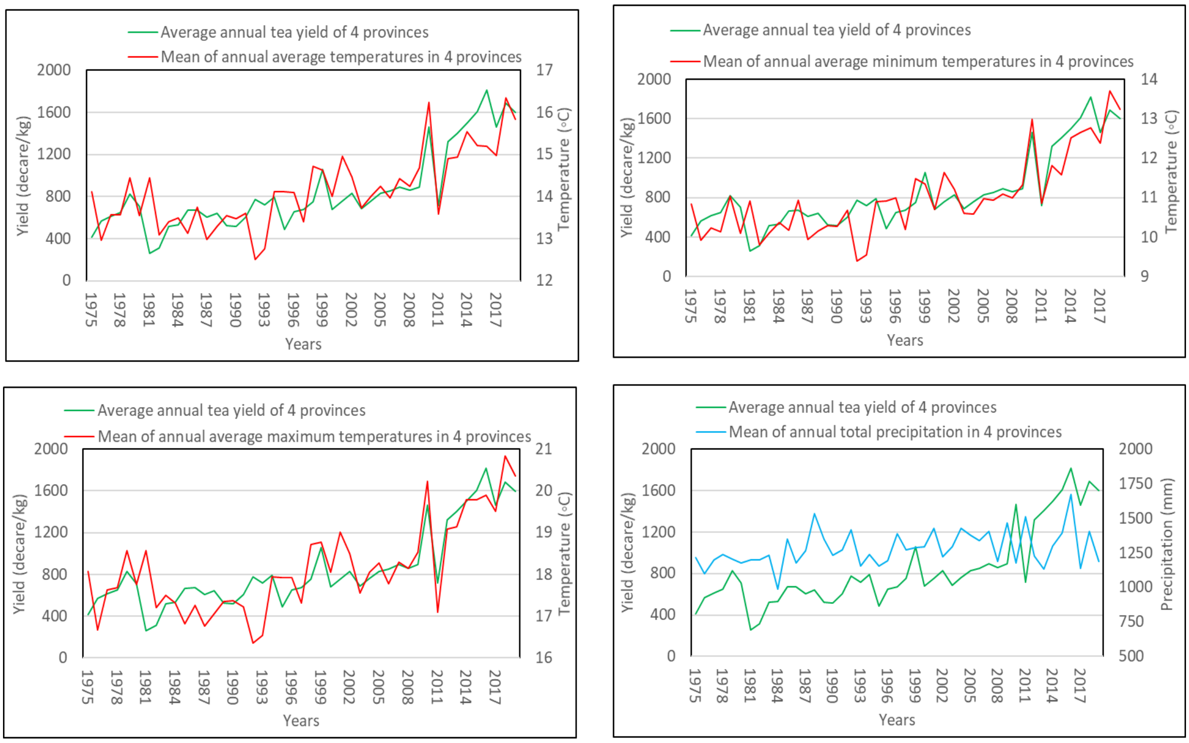

Figure 4. Harmony of trends in temperature and precipitation with trends in yield (Climate data is obtained from the Turkish State Meteorological Service).

3.6. Possible Yield Changes Based on Climate Change Scenarios

Turkish State Meteorological Service has created climate projections for Turkey and its region. According to the RCP4.5 and RCP8.5 scenarios for the geography, including Turkey, projections for the 1971-2000 reference period and the future 2016-2099 were produced using GFDLESM2M global model data. From the regional climate model data with a resolution of 20 km, projection outputs of temperature and precipitation parameters for the periods 2016-2040, 2041-2070, 2071-2099 were viewed seasonally. (Gürkan et al., 2016). According to the projection results prepared by (Akçakaya et al., 2015) and analysed in the study conducted by Gürkan et al. (2016), in both scenarios (RCP4.5 and RCP8.5), increases in temperatures are expected in all basins, thus also in the Eastern Black Sea Region, throughout the entire period (2016-2099). According to the RCP4.5 scenario; it is predicted that the increase in the Eastern Black Sea basin will generally be around 0.5°C-1°C in the first period and will increase to 1.5°C-2°C in the 2041-2070 and 2071-2099 periods. According to the RCP8.5 scenario, average temperatures in the Eastern Black Sea Region are generally around 0.5°C-1°C in the first period, 1.5°C-2°C in the 2041-2070 period and is predicted to increase over 2.5°C in the 2071-2099 period. While a decrease is foreseen in total precipitation in all periods in Turkey, an increase of 5-10% is expected in the first two periods in the Eastern Black Sea basin based on RCP4.5 scenario. A decrease of 5-10% is predicted in the third period. When RCP8.5 scenario is considered, a decrease is expected in total precipitation in all periods throughout Turkey. In the first period, an increase of 5-10% is expected in the Eastern Black Sea Region. However, a decrease of 5-10% is anticipated in the second period and a decrease of 15%-20% in the third period.

According to the linear trend model, there was a significant increase in the research area in 1975-2019 at the average, average maximum, and average minimum temperatures of 0.999 confidence level (Table 8).

On the other hand, the increase in tea yield in the years when temperatures increase is also noted (see Figure 4). In this respect, the rise in tea yield likely continues due to the temperature increases predicted by climate change scenarios. Yet, as in 1981, extreme hot winters or other possible temperature extremes will harm yield.

In the period 1975-2019, there is a significant increase in the total annual rainfall at the level of 0.95 confidence in Rize and Trabzon. The rise in Giresun is also at the confidence level limit of 0.95, although in Artvin, a trend has not been detected (see Table 8). Considering the relationship between tea yield and total annual rainfall, it is also essential to reveal the effect of changes in precipitation on tea yield. Although climate change scenarios related to precipitation are not as regular as temperature, the expected reductions in the post-2040 period according to the RCP8.5 scenario may adversely affect the yield. The tea plant will inevitably be negatively affected, primarily due to the expected decrease in summer precipitation.

Table 8. Results of the linear trend test applied to temperature and precipitation

	Provinces	a	b	t	r	R^2	Results
Total annual precipitation	Giresun	100.46	0.311	2.012	0.29	0.086	no trend
	Trabzon	64.213	0.243	2.523	0.36*	0.129	increasing trend
	Rize	177.5	0.496	2.023	0.30*	0.087	increasing trend
	Artvin	58.946	0.009	0.070	0.01	0.001	no trend
Annual mean temperature	Giresun	13.790	0.043	5.679	0.66***	0.429	increasing trend
	Trabzon	13.884	0.045	6.361	0.70***	0.485	increasing trend
	Rize	13.199	0.061	8.162	0.78***	0.608	increasing trend
	Artvin	11.277	0.043	5.289	0.63***	0.394	increasing trend
Annual mean max. temperature	Giresun	17.096	0.045	4.462	0.56***	0.316	increasing trend
	Trabzon	17.073	0.064	6.924	0.726***	0.527	increasing trend
	Rize	16.935	0.072	8.847	0.80***	0.645	increasing trend
	Artvin	16.196	0.047	4.227	0.54***	0.294	increasing trend
Annual mean min. temperature	Giresun	10.994	0.056	6.939	0.73***	0.528	increasing trend
	Trabzon	10.719	0.053	6.995	0.73***	0.532	increasing trend
	Rize	10.115	0.056	7.695	0.76***	0.579	increasing trend
	Artvin	6.867	0.067	8.224	078***	0.611	increasing trend

*P≤0.05, **P≤0.01, ***P≤0.001, r= correlation coefficient.

4. Discussion

This study determined that changes in temperature conditions were much more effective on tea yield than changes in precipitation.

Similarly, Lobell et al. (2011) found that temperature change was more effective than the change in rainfall in their study, which investigated the impact of climate trends on corn, rice, wheat, and soybean production globally for 1980-2008. Eaqually, İrdem (2021) examined the effects of temperature and precipitation on hazelnut yield in Turkey during 1993-2019 and observed that temperature change affected the yield more than the change in precipitation.

Ali et al. (2014) state that temperature is the most critical microclimatic parameter for tea leaf production. Despite this, the relationship between temperature and tea leaf production was not detected as significant. There is also a moderately positive relationship between tea leaf production and precipitation. While substantial positive relationships between temperature and yield were found in this study, positive relationships between precipitation and yield were not significant.

It is examined that the correlation of tea yield with average maximum temperatures was positively significant. However, Carr and Stephens (1992) note that it is difficult to distinguish the effects of maximum temperatures on tea yield from other factors, whereas air or leaf temperatures often exceeding 35 °C are likely to reduce shoot growth rates and even photosynthesis.

Long rainy periods negatively affect tea yield due to the decrease in sunlight and the reduction of photosynthesis of the leaves (Wijeratne et al., 2007; Esham and Garforth, 2013; Duncan et al., 2016). Similarly, Rahman et al. (2017) put forward that there may be a decrease in yield due to lack of sunlight in years when the annual total precipitation is too high. It is also suggested that excessive water may adversely affect tea production due to increased soil saturation and failure of absorption. The year with the least annual total precipitation of the four provinces analyzed in this study was 1674 mm in 2016, and the average yield of four areas in this year was 1747 kg. The year with the least annual precipitation was 985 mm in 1984, while the yield was 710 kg.

There was an increase in temperatures and precipitation in the research area from 1975-2019. It is also observed that tea yields increased in parallel during the same period. Gürkan et al. (2016) present that temperature and precipitation will continue to rise in the Eastern Black Sea basin from 2016-2040. Yet, one could not claim that tea yields will continue to increase in the future. According to Nowogrodzki (2019), climate change reduces the yield of tea plants by changing precipitation levels, rising temperatures, changing the timing of seasons, encouraging insect pests, and causing soil erosion and puddles, especially with heavy rains.

Biggs et al. (2018) state that increased crop stress caused by changes in precipitation and temperature conditions affects harvest quality and timing. In contrast to this, Yurt (1991) argues that high temperature increases the rate of tea. Based on this, tea quality can be expected to increase in the future depending on the increase in average temperatures.

In the studies conducted on a day-to-day basis, Bütüner (2019) determined that the fruits' growth, development and maturation are fast in the periods when the number of sunny days is high. For instance, he argues that the most extended harvest period in the 2003-2016 period was in 2008, which is also related to temperature. However, the study determined that the yield in 2008 was lower than in 2007 and 2009 when the harvest time was shorter. In that case, climate change may cause changes in harvest times, but at this point, the effect of summer temperature and precipitation on yield is more remarkable.

5. Conclusion

As a result of the study, a significant positive relationship was found between annual average, maximum and minimum temperatures, and annual tea yield. Still, no significant correlation with total yearly precipitation was detected. The relations between temperature and yield are more substantial in summer, and relationships between the monthly precipitation and its yield are more irregular. In 1975-2019, a significant increase in tea yield was determined, more vital in the last 15 years.

There was a significant increase in annual average temperatures and no significant increase in precipitation in research between 1975 and 2019. According to climate change scenarios, it can be expected that the temperature and precipitation increases predicted for the 2016-2040 period in the Eastern Black Sea basin will lead to increases in tea yield. However, when the damage to the tea shoots from heavy rains and the expected increases in harmful insects due to the temperature rise is taken into account, there may even be decreases in yield and quality.

In the following stages, the results of this study can be supported by the analyses considering the factors affecting tea yield other than temperature and precipitation (climatic parameters such as wind, humidity, sunbathing times, and the effects of methods and techniques used in agriculture, etc.).

Author Contributions

All task made by single author and the author reviewed and approved the manuscript.

Conflict of Interest

The author declared that there is no conflict of interest.

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