Chapter 9

The Impact of Climate Variables on Wheat Yield in Turkey

Melike Tekin[1]

Gülistan Erdal[2]

Abstract

In recent years, global warming and climate change have been affecting agricultural production both directly and indirectly. Rising temperatures, changing precipitation patterns, and extreme weather events have significant impacts on the yield of many crops. In Turkey, which is located in a semi-arid climate zone, this variability becomes even more pronounced. Staple cereal crops such as wheat are particularly sensitive to fluctuations in temperature and precipitation, and climatic anomalies occurring during critical growth stages can lead to substantial yield losses.This study aims to examine the effects of climate variables on wheat yield in Turkey. The dataset covers the period from 2004 to 2024. Wheat yield (Y, kg/ha) was used as the dependent variable, while climate-related independent variables (Xi) included temperature (°C), average precipitation (mm), the Southern Oscillation Index (SOI), and the Oceanic Niño Index (ONI). The SOI and ONI indicators employed in the study provide important parameters for understanding the impact of large-scale climatic oscillations on crop yields. In this context, ocean-atmosphere interactions such as the El Niño–Southern Oscillation (ENSO), which operate on a global scale, create significant regional and temporal variability in agricultural production.The results of the multiple linear regression analysis show that the model is statistically significant, with a high coefficient of determination (R^2 = 64.3%). Among the climate variables, temperature and SOI were found to be statistically significant. In particular, SOI was determined to have a strong and positive effect on wheat yield. The analysis results reveal that climate indicators play a critical role

1 Tokat Gaziosmanpaşa University, Faculty of Agriculture, Department of Agricultural Economics, Turkey

2 Tokat Gaziosmanpaşa University, Faculty of Agriculture, Department of Agricultural Economics, Turkey

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in wheat productivity. The findings of this study offer valuable insights for the development of sustainable agricultural policies and the formulation of adaptation strategies in response to climate change.

Introduction

Wheat is both a fundamental food staple and a strategic agricultural commodity. It forms the basis of food security, especially in developing countries. Beyond being merely a food product, wheat holds a critical position in countries' agricultural policies, trade balances, and rural development strategies. Globally, wheat production in 2024 reached approximately 785 million tons, with an average yield of 3.7 tons per hectare (FAO, 2025). In Turkey, wheat production in 2024 was about 20.8 million tons, with a yield of 2.4 tons/ha. Wheat production is highly sensitive to climatic conditions. In particular, increases in temperature, drought, frost events, and changes in precipitation patterns directly affect both yield and quality. Turkey, located in a semi-arid climate zone, is among the countries with a high potential to be affected by climate change, a situation that becomes especially apparent in the production of strategically important cereal crops such as wheat. Wheat not only constitutes one of the fundamental elements of Turkey's food security but also plays a critical role in the sustainability of rural economies. However, this crop is very sensitive to climatic variables such as temperature and precipitation during its growth and development stages (İm et al., 2020). Indeed, studies have shown that increases in temperature and irregular precipitation patterns can negatively impact wheat yields (Asseng et al., 2015; Zampieri et al., 2017). Moreover, not only local climatic variables but also large-scale ocean-atmosphere interactions can affect agricultural production. Large-scale climatic oscillations such as the El Niño–Southern Oscillation (ENSO) alter precipitation and temperature regimes, indirectly influencing regional productivity (Rosenzweig et al., 2001).

Global warming and climate change have recently become one of the most significant environmental issues directly and indirectly affecting the agricultural sector. Rising temperatures, changing precipitation patterns, and the increasing frequency of extreme weather events pose serious threats to the productivity of climate-sensitive crops (Lobell et al., 2011; Wheeler & von Braun, 2013). This study focuses on examining the impacts of climatic variables on wheat yield in Turkey. Specifically, the roles of temperature, precipitation, the Southern Oscillation Index (SOI), and the Oceanic Niño Index (ONI) on wheat yield between 2004 and 2024 have been analyzed using a multiple linear regression model. The primary aim of the study is to analyze the relationship between wheat yield and selected climatic variables in Turkey during the 2004–2024 period. The research seeks to reveal the effects of both local and global climatic indicators such as temperature, precipitation, SOI, and ONI on wheat productivity. The findings are expected to contribute to more accurate assessments of climate risks in agricultural production planning, the development of adaptation policies for climate change, and sustainable agricultural strategies. The conceptual framework of the study revolves around core concepts such as climate change, agricultural production, productivity, climatic variability, and large-scale climatic oscillations.In this context, productivity (kg/ha) represents the amount of product obtained per unit area, with climatic factors such as temperature, precipitation amount and distribution, and extreme weather events being the primary components affecting this value. Furthermore, large-scale ocean-atmosphere interactions at the global level, particularly phenomena such as the El Niño–Southern Oscillation (ENSO), indirectly affect regional climate conditions, causing significant fluctuations in agricultural production. The two main indicators of ENSO—the Southern Oscillation Index (SOI) and the Oceanic Niño Index (ONI)—are standard climatic indices used to analyze the direction and intensity of these oscillations. This study empirically evaluates the effects of these concepts, integrating both local climatic variables and global climate indices, on wheat yield.

Materials and Methods

Data

This study aims to investigate the climatic and structural factors affecting wheat yield in Turkey. Annual data from the period 2004–2024 were used in the analysis. The dependent variable considered was wheat yield per hectare (kg/ha). The independent variables were defined as follows:

- Average temperature (°C),
- Annual average precipitation (mm),
- Southern Oscillation Index (SOI),
- Oceanic Niño Index (ONI),
- Number of tractors (units),
- Number of combine harvesters (units).

Wheat yield, tractor, and combine harvester data were obtained from the Turkish Statistical Institute (TurkStat), while climate variables were sourced from the General Directorate of Meteorology (MGM) and the National

Oceanic and Atmospheric Administration (NOAA). The number of tractors and combine harvesters represent the level of mechanization in agricultural production and were included in the model as structural indicators that may affect production capacity. The SOI and ONI indices were used to analyze the effects of the global El Niño–Southern Oscillation (ENSO) events on agricultural production in Turkey.

Method

The effects of climatic and structural factors on wheat yield were evaluated using multiple linear regression analysis. The analyses were conducted using the SPSS 26.0 software package (Field, 2013). The overall significance of the model was assessed by the F-test, while the individual contributions of the variables were tested with t-tests. The explanatory power of the model was measured by the coefficient of determination (R^2), which was calculated as 64.3%. The dependent variable in the regression model was wheat yield, and the independent variables included:

- Temperature (°C)
- Average precipitation (mm)
- Southern Oscillation Index (SOI)
- Oceanic Niño Index (ONI)
- Number of tractors (units)
- Number of combine harvesters (units)

The model tests the combined effect of climatic conditions and the level of agricultural mechanization on yield. In the regression table, the overall significance of the model is checked with the F-test. If the p-value is less than 0.05, the model is considered significant. The R^2 value indicates how much of the variation in the dependent variable is explained by the independent variables (Gujarati & Porter, 2009). The coefficients (B) of the independent variables explain their effect on yield. Variables with positive coefficients increase yield, while those with negative coefficients decrease it. Variables with a p-value less than 0.05 are statistically significant (Wooldridge, 2016). The regression model is defined as follows:

$$Yt=\beta0+\beta1\cdot Temperature_t +\beta2\cdot Precıpıtıon_t,+\beta3\cdot SOIt +\beta4\cdot ONIt +\beta5\cdot Tractor_t +\beta6 Harvester_t+\varepsilon t$$

Where:

- Yt = wheat yield in year (kg/ha),

- βi= coefficients estimated by the model,
- εt = error term.

The assumptions of regression, including normality of data, multicollinearity, autocorrelation, and homoscedasticity, were tested. Variable transformations and outlier analyses were performed when necessary.

RESULTS

Table 1. Wheat Production and Yield Development in the World and Turkey Between 2004 and 2024

Year	World Production (million tons)	World Yield (tons/ha)	Turkey Production (million tons)	Turkey Yield (tons/ha)
2004	596	2.7	21.0	2.4
2005	621	2.8	20.5	2.3
2006	589	2.7	20.0	2.2
2007	610	2.8	17.2	2.0
2008	683	3.0	17.8	2.1
2009	681	3.0	20.06	2.4
2010	651	2.9	19.7	2.3
2011	697	3.1	21.8	2.5
2012	655	3.0	20.1	2.3
2013	717	3.2	22.1	2.6
2014	728	3.3	19.0	2.2
2015	736	3.4	22.6	2.7
2016	757	3.4	20.6	2.5
2017	762	3.3	21.5	2.6
2018	731	3.4	20.0	2.4
2019	759	3.5	20.5	2.5
2020	773	3.6	20.5	2.5
2021	780	3.7	17.7	2.2
2022	789	3.7	19.8	2.4
2023	785	3.7	21.0	2.5
2024	791	3.7	20.8	2.4

Between 2004 and 2024, a continuous increase in global wheat production and productivity has been observed. World wheat production rose from 596 million tons in 2004 to 791 million tons in 2024, while yield increased from 2.7 tons per hectare to 3.7 tons per hectare during the same period. This indicates significant advancements worldwide in areas such as agricultural technologies, irrigation systems, climate adaptation, and seed quality.

In Turkey, however, there have been considerable fluctuations in production volumes during the same period. Especially in 2007 and 2021, production significantly declined to 17.2 million tons and 17.7 million tons, respectively. Turkey's wheat yield remained stagnant at 2.4 tons/ha in both 2004 and 2024. This situation reveals that agricultural productivity in Turkey lags behind the world average and needs to be supported by more sustainable, technology-based policies. Compared to the world, Turkey has experienced slow growth in yield and appears to be more sensitive to external factors such as climate conditions in terms of production. This picture also highlights the need for modernization in Turkish agriculture and its vulnerability to climate change.

Table 2. Summary of Regression Model Results

Variables	B	Std. Hata	Beta	t	p	Sig.
Turkey Average Temperature (°C)	-270.63	102.89	-0.507	-2.630	.020*	,020
SOI (Southern Oscillation Index)	260.20	113.04	0.433	2.302	.037*	,037
Number of Combine Harvesters (units)	0.099	0.030	0.948	3.325	.005**	,005

Model Statistics:

$R = .802$, $R^2 = .643$, Adjusted $R^2 = .490$,

$F(6, 14) = 4.20$, $p = .013$

Note: *$p < .05$, **$p < .01$. Dependent variable: Wheat yield in Turkey (kg/ha).

The R value (0.802) indicates a strong linear relationship between the dependent variable and the independent variables.

R Square (0.643) shows that the model explains 64.3% of the total variance, indicating that approximately two-thirds of the variability in wheat yield is explained by the model.

Adjusted R Square (0.490) accounts for the number of independent variables and shows that the explanatory power of the model decreases to 49.0%. This suggests that some variables may have limited contribution to the model.

Standard Error of the Estimate (198.823) represents the average size of the prediction errors.

Average Temperature in Turkey: The result is negative and significant, indicating that with a 1°C increase, yield decreases by 270 units, showing that temperature negatively affects yield.

SOI: Positive and significant, meaning that as the SOI (La Niña) effect increases, yield also increases.

Number of Combine Harvesters: Positive and strong result, indicating that as mechanization increases, yield significantly improves.

Results

his study examines the climatic and mechanical factors affecting agricultural productivity in Turkey through regression analysis. The findings reveal that agricultural productivity is significantly influenced by temperature, atmospheric circulation indices, and agricultural mechanization elements.

The first significant variable in the model is the average temperature in Turkey. The results indicate that increases in average temperature have a negative and statistically significant effect on agricultural productivity. This finding demonstrates that rising temperatures associated with climate change threaten agricultural production, and this threat is measurable in concrete terms. Accordingly, agricultural policies should focus on developing heat-resistant seed varieties, enhancing microclimatic measures, and strengthening irrigation infrastructure.Secondly, the positive and significant effect of global atmospheric variables such as the Southern Oscillation Index (SOI) is noteworthy. This suggests that Turkey's agricultural production is influenced by large-scale climate cycles. In this context, it is important to develop early warning systems for predicting global climate events such as El Niño and La Niña in agricultural production planning.

One of the most striking findings is the strong and positive impact of the number of combine harvesters on agricultural productivity. This indicates that increasing mechanization directly supports productivity. Facilitating access to harvesting machinery like combine harvesters reduces time loss during the production process and minimizes crop losses. Therefore, the widespread implementation of low-interest loan programs for agricultural machinery procurement, shared machinery parks, and regional equipment support programs is necessary.

Conversely, the lack of a significant effect of the number of tractors and precipitation on agricultural productivity suggests that considering these variables only quantitatively is insufficient. Particularly, including qualitative features such as tractor usage intensity, technological equipment, and maintenance status in the analysis, rather than merely the number of tractors, will yield more accurate results.

In conclusion, this study highlights the critical importance of developing climate change-adaptive agricultural strategies and strengthening mechanization infrastructure to increase agricultural productivity in Turkey. Future studies should include additional agricultural inputs such as soil fertility, fertilizer and pesticide use, and cropping patterns in the model, which will broaden the scope of policy recommendations.

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Conflict of Interest

The authors have declared that there is no conflict of interest.

Author Contributions

The authors contributed equally.