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The Impact of Climate Change and Environmental Degradation on Agricultural Credit Usage: Evidence from Türkiye with Fourier Approximations

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ABSTRACT

This study aims to examine the impact of climate change and environmental degradation on agricultural credit utilization using annual data for the period 1988-2023 in Türkiye. In this paper, stationarity is tested using the Fourier KPSS stationarity test, long-run relationships are analyzed using the Fourier Shin cointegration method, and long-run coefficients are estimated using the Fourier FMOLS method. Finally, the Fourier Toda-Yamamoto causality test is used to explore causal relationships between variables. The findings show that increases in climate change and environmental degradation reduce agricultural credit utilization. On the other hand, agricultural value added, arable agricultural area, and population growth are found to increase agricultural credit utilization. According to the causality analysis results, a unidirectional causality relationship was found from agricultural credit utilization to climate change, while bidirectional causality relationships were found between agricultural credit utilization and agricultural value added and population growth. The results obtained emphasize the importance of restructuring financial policies for the agricultural sector in consideration of environmental and climatic risks and provide an important contribution to the very limited literature by addressing this interaction with Fourier-based econometric analyses.

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İklim Değişikliği ve Çevresel Bozulmanın Tarımsal Kredi Kullanımına Etkisi: Fourier Yaklaşımlar ile Türkiye'den Kanıtlar

ÖZET

Bu çalışmanın amacı, Türkiye'de 1988-2023 dönemine ait yıllık veriler kullanılarak iklim değişikliği ve çevresel bozulmanın tarımsal kredi kullanımına etkisini incelemektir. Araştırmada, değişkenlerin durağanlık özellikleri Fourier KPSS durağanlık testi ile belirlenmiş, uzun dönem ilişkiler Fourier Shin eşbütünleşme yöntemi ile analiz edilmiş ve uzun dönem katsayı tahminleri ise Fourier FMOLS yöntemiyle yapılmıştır. Son olarak, değişkenler arasındaki nedensellik ilişkileri keşfetmek için Fourier Toda-Yamamoto nedensellik testi kullanılmıştır. Bulgular, iklim değişikliği ve çevresel bozulmadaki artışların tarımsal kredi kullanımını azalttığını göstermektedir. Öte yandan, tarımsal katma değer, ekilebilir tarımsal alan ve nüfus artışının tarımsal kredi kullanımını artırdığı bulunmuştur. Nedensellik analizi sonuçlarına göre, tarımsal kredi kullanımından iklim değişikliğine doğru tek yönlü bir nedensellik ilişkisi bulunurken, tarımsal kredi kullanımı ile tarımsal katma değer ve nüfus artışı arasında çift yönlü nedensellik ilişkileri tespit edilmiştir. Elde edilen sonuçlar, tarım sektörüne yönelik finansal politikaların çevresel ve iklimsel riskler göz önünde bulundurularak yeniden yapılandırılmasının önemini vurgulamakta ve bu etkileşimi Fourier tabanlı ekonometrik analizlerle ele alarak çok sınırlı olan literatüre önemli bir katkı sağlanmaktadır.

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INTRODUCTION

Climate refers to the average of meteorological events such as temperature, humidity, atmospheric pressure, wind, and precipitation over a specific period, reflecting the general trends of a region's weather conditions. Climate change, on the other hand, is the result of both natural climate variations and the effects of global warming due to rising emissions of greenhouse gases caused by human activities (Republic of Türkiye Ministry of Environment, Urbanization and Climate Change, Climate Change Directorate, 2025). In the last few years, research on the natural and human-induced factors of climate change, the characteristics and scope of these changes, their effects on human life and ecosystems, as well as possible mitigation and adaptation strategies, has increased. As a result, the understanding of the complex relationships between the climate system, its interactions with ecosystems, and human responses to climate change has deepened (Mertz et al., 2009). These changes become more pronounced with the disruption of atmospheric composition, leading to long-term impacts on weather conditions, ecosystems, and ways of life worldwide. The Intergovernmental Panel on Climate Change (IPCC) has defined climate change as climate change in climate caused by both natural and human activities (IPCC, 2007).

Along with the increase in temperature, changes in precipitation patterns, the rise in the frequency and intensity of extreme weather events, and the increasing levels of carbon dioxide (CO_2) are the main driving forces of climate change (Nastis et al., 2012; Mahato, 2014). These changes are expected to have serious impacts in many areas such as agriculture, forests, water resources, sea levels, energy, human health, and biodiversity. Moreover, it is also possible that these changes will trigger cascading effects in social and economic life (Doğan & Tüzer, 2011). Climate change has restricted the global growth of agricultural productivity over the past century. Although many of its negative impacts on agricultural productivity have yet to be fully felt, the threats to agricultural production and food insecurity have become even more critical as the world's population grows and living standards rise (IPCC, 2014; Akalın, 2014).

Figure 1 illustrates the impacts of climate change on agriculture under three main headings: crop production, livestock production, and socio-economic aspects. As seen here, climate change and environmental factors adversely affect agriculture, animal husbandry, and food security. Losses in productivity during agricultural production processes, changes in product quality, and an increase in diseases pose serious threats to the food supply. This situation not only increases food security risks but also creates socio-economic difficulties for producers and people in rural areas. Similarly, rising feed costs and increased livestock mortality further complicate production processes in animal husbandry. Moreover, losses in productivity in pastures and grazing lands can lead to declines in the production of animal products. This may result in shortages in food supply and price increases. From a socio-economic perspective, production losses in agriculture-based industries can lead to income losses and rising unemployment rates. The decrease in population in rural areas further complicates living conditions in these regions, while restrictions on agricultural financing cause producers to face even more financial problems. Research has also demonstrated the negative impact of climate change on the agricultural industry. For example, Lobell and Field (2007) noted that global climatic fluctuations have led to losses of up to 30% in agricultural products. Climate change not only negatively affects agricultural production worldwide but also creates much deeper and more pronounced impacts in countries like Türkiye, which are heavily dependent on the agricultural sector. In these countries, since agriculture is critically important for economic development and the standard of living, the adverse conditions brought about by climate change directly threaten production processes and food security. Indeed, climate change is transforming agricultural production methods. This transformation reduces the productivity of agricultural products, putting pressure on the global food supply (Akalın, 2014). In conclusion, the increasing challenges of climate change and environmental issues are forcing countries to undertake more comprehensive research and develop effective policies.

Environmental degradation, which can be defined as the mixing of foreign substances into the air, water, and soil that threatens the health of all living beings and damages environmental factors, is fueled by multidimensional factors, including educational deficiencies, rapid urbanization, increasing population, industrial activities, agriculture, and transportation (IPCC, 2021). The combination of these factors leads to an increase in issues such as air, water, and soil pollution, seriously endangering ecosystems and human health. According to global statistics, in 2019, approximately 74% of greenhouse gas (GHG) emissions were due to CO_2 emissions, while the agriculture sector accounted for 12% of these emissions. Industrial production, the increasing energy demand, and transportation play a decisive role in intensifying environmental degradation, making it more difficult to achieve sustainable development goals (FAO, 2020; IEA, 2021; Eştürk et al., 2023). According to the 2024 greenhouse gas inventory results, Türkiye's total greenhouse gas emissions in 2022 were calculated at 558.3 million tons (Mt) CO_2 equivalent (CO_2 eq.), a decrease of 2.4% compared to the previous year. Per capita total greenhouse gas emissions were calculated as 4.1 tons CO_2 eq. in 1990, 6.8 tons CO_2 eq. in 2021, and 6.6 tons CO_2 eq. in 2022. In 2022, the largest share of total greenhouse gas emissions, amounting to 71.8% in terms of CO_2 eq., came from energy-related emissions, followed by 12.8% from agriculture, 12.5% from industrial processes and product use, and 2.9% from the waste sector. While agriculture sector emissions increased by 37.9% compared to 1990, they decreased by 5.1% compared to the previous year, and were calculated at 71.5 Mt CO_2 eq. In 2022, 32.6% of total CO_2 emissions were from electricity and heat production, meaning that 86.6% of emissions came from the energy sector, 13.1% from industrial processes and product use, and 0.3% from the agriculture and waste sectors. Of the methane (CH_4) emissions, 60.5% originated from agriculture, 19.9% from energy, 19.6% from waste, and 0.02% from industrial processes and product use; while 77.9% of nitrous oxide (N_2O) emissions originated from agriculture, 11.2% from energy, 6.2% from waste, and 4.6% from industrial processes and product use (TURKSTAT, 2024).

Crop Production	Animal Production	Socio-economic
• Changes in productivity	• Increasing feed costs or difficulties in finding feed materials	• Revenue losses
• Decrease in production quantity	• Increase in animal mortality	• Losses in agriculture-based industrial production
• Product quality changes	• Reproductive cycle change	• Decrease in land prices
• Production pattern changes	• Increases in miscarriages	• Increase in unemployment
• Changes in the production period	• Loss of productivity in pastures and grasslands	• Constraints in agricultural financing
• Decrease in soil fertility	• Decrease in production of animal products	• Decline in producers
• Increase in plant diseases and pests	• Increased water costs for animal production	• Decrease in rural population
• Increased irrigation costs	• Cost increases realised in irrigation investments	
• Increase in irrigation investments	• Increase in fires in meadows, pastures and grasslands	

Figure 1. Reflections of Climate Change on Agriculture
Şekil 1. İklim Değişikliğinin Tarıma Yansımaları
Source: (Dellal, 2021).

Agriculture is one of the fundamental building blocks for a country's economy, supporting economic development by improving food production and public health. The contributions provided by agriculture are critical in enhancing the nation's overall well-being (Erdinç & Aydınbaş, 2021). According to data from the United Nations Food and Agriculture Organization (FAO), over the past twenty years, global agricultural value has increased significantly, growing by 89% in real terms and reaching 3.8 trillion dollars in 2022. Worldwide primary production increased by 56% compared to the year 2000, reaching 9.6 billion tons as of 2022 (FAO, 2024). Türkiye, with its fertile lands and diverse climate, ranks among the top ten economies in agricultural production and holds a prominent position as an important producer and exporter of many agricultural products. For the continuity of agricultural production and the financing of technological investments, producers require financial resources. In addition to agricultural supports, agricultural credits provided by public and private banks are essential to enhance agricultural productivity, adopt modern technologies, and improve the overall sustainability of agricultural systems. Access to credit plays a critical role by enabling farmers to secure necessary inputs such as seeds, fertilizers, pesticides, and agricultural equipment, thereby increasing productivity and providing resilience against risks associated with climate change (Terin et al., 2014; Baysa & Cihangir, 2021; Sabasi et al., 2021; Önder, 2023). Climate changes—

including rising temperatures, alterations in precipitation patterns, and extreme weather events—can affect crop yields and animal health. These uncertainties and risks in agriculture arise from the adverse impacts of unpredictable weather conditions on production. This not only complicates crop yield and quality but also increases uncertainty due to the lengthy time required for biological processes. Climate change leads to greater uncertainty in agricultural productivity, thereby affecting farmers' demand for credit. For example, in Ethiopia, rainfall uncertainty has reduced agricultural credit demand, as farmers fear potential crop losses and subsequent credit defaults. Consequently, farmers are forced to adopt new technologies, diversify their products, or turn to sustainable methods to maintain productivity—changes that require additional financial resources. Agricultural lenders assess risks by evaluating the impact of climate change on borrowers' repayment capacity, and they support sustainable agricultural practices. Thus, the processes related to climate uncertainties can directly and indirectly affect credit conditions and credit risk management (Abay et al., 2018; Céu & Gaspar, 2024). On the other hand, environmental degradation can significantly influence the use of credit in the agricultural sector through credit constraints and green credit policies (Abay et al., 2018). Perceived risks associated with climate impacts may lead to credit constraints; in such cases, lenders may hesitate to provide credit due to concerns about borrowers' repayment capacity under adverse conditions (Olagunju et al., 2023). Green credit policies have been associated with increased investment efficiency in sectors that damage the environment, and similar policies are argued to potentially increase credit usage in agriculture by encouraging sustainable practices (Qi, 2021). In this context, financial institutions are encouraged to incorporate climate factors into their lending practices, thereby providing better access to credit for producers adopting sustainable methods (Céu & Gaspar, 2024). Credit constraints can limit farmers' ability to invest in technologies that reduce environmental impact. Reducing these constraints could boost production and lead to lower emissions per unit of output. All these aspects illustrate the existence of a complex relationship between credit access and environmental sustainability (Andersen, 2016).

The agricultural sector is of strategic importance for economic development and sustainability. In countries like Türkiye, where agricultural production plays a critical role in the economic and social structure, the financing of the agricultural sector is a decisive factor for the continuity and productivity of production. However, climate change and environmental degradation are increasingly affecting agricultural production processes and placing significant pressure on their economic aspects. Although the impacts of climate change and environmental degradation on agricultural indicators such as agricultural value added and agricultural productivity have been extensively studied in the literature, there has been no econometric analysis of their impacts on agricultural finance, particularly on agricultural credit use in the case of Türkiye. In this context, this study aims to investigate the impact of climate change and environmental degradation on agricultural credit usage in Türkiye using annual data from 1988 to 2023. Within the scope of the study, four hypotheses have been formulated as presented below, and these hypotheses have been tested.

Relationship between climate change and agricultural credit usage:

H_0: Climate change does not have a significant impact on agricultural credit usage.

H_1: Climate change has a significant impact on agricultural credit usage.

Relationship between environmental degradation and agricultural credit usage:

H_0: Environmental degradation does not have a significant impact on agricultural credit usage.

H_1: Environmental degradation has a significant impact on agricultural credit usage.

The subsequent phases of the study have been designed as follows: a literature review, materials and methods, findings, and finally, a section on conclusions, discussion, and recommendations, thereby completing the research.

LITERATURE REVIEW

In the literature, the relationships between climate change, environmental degradation, and agricultural sector indicators have been addressed through numerous econometric analyses conducted for different countries and regional groups. However, studies specifically examining the impact of climate change and environmental degradation on the credits provided to the agricultural sector, which is the focus of this study, are quite limited. In this literature review, studies addressing the impact of environmental degradation and climate change on the agricultural sector are first examined, followed by evaluations focusing on credits provided to the agricultural sector.

Among the research examples dealing with the impact of climate change on the agricultural sector, Başoğlu and Telatar (2013), in a regression analysis conducted in Türkiye for the period 1973-2011, revealed that an increase in precipitation positively affected the share of agriculture in GDP, while temperature changes decreased this share. Acharya and Bhatta (2013), in the case of Nepal (1975-2010), detected the enhancing effect of precipitation on value added in agriculture. Belloumi (2014), in a panel data analysis covering 11 East and South African countries for the period 1961-2011, demonstrated that in South Africa, particularly an increase in precipitation had positive effects on agricultural production, whereas the annual average temperature increase had negative effects. Iqbal and Siddique (2014), in Bangladesh for the period 1975-2008, showed that long-term changes in the means and standard deviations of climate variables had varying effects on rice production, emphasizing the uncertainty of the overall impact of climate change on agriculture. In his study, Uslu (2021) employed panel data analysis for Türkiye's Southeastern Anatolia Region for the period 1995-2019 and found that the production area of garden plants was positively influenced by changes in average temperature and precipitation, while the production quantity was negatively affected by seasonal fluctuations in precipitation. Khalid et al. (2016), by examining the effects of climate change indicators on agricultural value added and economic growth in 10 countries for the period 1990-2014 using separate models, determined that although climate change hurt overall GDP, it did not have a significant impact on agricultural value added. Hayaloğlu (2018), on the other hand, conducted a panel analysis using data from the ten countries most affected by global climate change (Bangladesh, the Philippines, Guatemala, Haiti, Honduras, Myanmar, Nicaragua, Pakistan, Thailand, and Vietnam) for the period 1990-2016 and demonstrated that climate change had long-term negative effects on both economic growth and agricultural value added. He et al. (2022) investigated the effects of global climate change on grain yield in a sample from Sichuan Province, China, for the period 1978-2018 and if agricultural loans, together with technological development, could mitigate these effects. There was a long run cointegration relationship between the variables in the analysis using the ARDL model. Results indicate that temperature hurt grain production, while precipitation had a positive effect. Eştürk and Mert (2022) examined the impact of global climate change on Ardahan's agricultural indicators using ARDL boundary and Toda-Yamamoto causality tests with data from the 1990-2020 period. The analysis results showed that there was no long-term relationship in the established model, while in the short term, precipitation had an impact on forage and feed crops, whereas temperature had no significant effect. Özkurt (2024) analyzed the impact of climate change indicators on agricultural production in Türkiye using variance decomposition, impulse-response function and Toda-Yamamoto causality analysis. The findings show that a causal relationship exists between greenhouse gas emissions and agricultural production and emphasize the need to control emissions to mitigate the effects of climate change.

Among the studies addressing the impact of environmental degradation on the agricultural sector, Ben Jebli and Ben Youssef (2017) conducted an econometric analysis for the Tunisian economy for the period 1980-2011, examining the relationships among real GDP, energy consumption, trade openness, agricultural value added, and carbon emissions. In their long-term analysis, they found that agricultural value added had an increasing effect on carbon emissions. Doğan (2019) used Chinese data for the period 1971-2010 to analyze the long-term relationship between agriculture and carbon emissions using the Granger causality method, concluding that agriculture increased emissions. Anwar et al. (2020), employing the Pooled Mean Group (PMG) estimator for a sample of 33 BRI countries over the period 1986–2017, showed that per capita industrial value-added raised emissions, whereas agricultural value added played a reducing role. Raihan and Tuspekova (2022), using Dynamic Ordinary Least Squares (DOLS) for Türkiye with data from 1990-2020, demonstrated that industrialization increased carbon emissions while agriculture had a mitigating effect on emissions. Eştürk et al. (2023), in their panel data analysis of selected OECD countries for the period 2000-2019, and Ülger (2024), using the panel ARDL method for the E-7 countries, both examined the effects of economic growth, agriculture, and industrial value added on environmental degradation, highlighting the significant roles of these sectors in carbon emissions. Özbek and Özbek (2024) analyzed the relationships among agricultural production, environmental degradation, climate change, agricultural labor, and growth in the Turkish economy over the 1990-2020 period by using the ARDL bounds testing method. Their findings revealed that, in the long run, temperature increases led to an increase in agricultural production, whereas rises in CO_2 emissions, growth in the economy, and agricultural labor led to a decrease in agricultural production; furthermore, the interaction between climate change and environmental degradation was shown to be more detrimental.

Among the few studies focusing on agricultural sector credits, Abay et al. (2018) investigated the effect of rainfall uncertainty on the agricultural credit demand of rural households in Ethiopia. The study examined the impacts of rainfall variability between 2010 and 2020 using household data covering smallholder farmers. The findings indicate that rainfall uncertainty leads to credit risk-based constraints, thereby reducing the demand for agricultural credit. Moreover, rainfall uncertainty was found to contribute to low take-up of yield-enhancing agricultural technologies such as fertilizers, whereas it encourages investment in protective agricultural products like herbicides, pesticides, and fungicides. Wahab et al. (2024) analyzed whether climate change had any effect on the repayment of agricultural credits in urban areas by using panel data from 82 cities in Pakistan over the period 2000-2020. The results showed that the effect of climate change on the repayment of agricultural credits is asymmetric, with negative sensitivities leading to lower repayments and positive sensitivities resulting in higher credit repayments. Liu (2024) looked at how climate change would affect access to credit for US farms post-2010.

The study utilized nonlinear econometric methods with credit and temperature anomaly data at both the district and bank levels. The effects, which varied according to factors such as farm size, income level, and bank type, demonstrated that climate change reduces bank lending, with small farms experiencing greater difficulties in accessing credit. Islam and Singh (2024) investigated the impact of climate change on agricultural credits using regression models and a dataset covering the period 1997–2017, gathering information at the district and bank levels in the United States. According to the study's findings, as climate risk increases, geographically dispersed banks tend to provide less credit to small farms.

The studies in the literature analyze the effects of climate change and environmental degradation on the agricultural sector while also highlighting the limited number of research studies focused on agricultural credit usage, which is the central focus of this study. Therefore, due to the lack of econometric analyses examining the impact of climate change and environmental degradation on agricultural credit usage in the case of Türkiye, this study aims to fill this gap in the literature. In this context, considering the direct and indirect linkages of agriculture within Türkiye's economy, addressing the sensitivity of agricultural credit usage to climate and environmental effects is of great importance. The limited number of studies specifically related to agricultural credits in Türkiye has also served as an additional motivation for the authors.

MATERIAL and METHOD

This study aims to analyze how agricultural credit usage in Türkiye is affected by climate change and environmental degradation. The selected period of 1988-2023 encompasses a phase in which the impacts of climate change became more pronounced globally, the Turkish agricultural sector underwent structural transformations, and significant changes in agricultural credit usage were observed. During this period, environmental pressures increased, agricultural production techniques modernized, and agricultural input costs fluctuated. At the same time, economic crises, changes in population dynamics, and agricultural policies reshaped the financial needs of the agricultural sector and the conditions for access to financing. In this context, understanding the relationship between agricultural credit usage and climate change/environmental degradation is crucial for assessing the financial sustainability of the sector. In the study, average temperature change is considered an indicator of climate change, while CO_2 emissions are used as an indicator of environmental degradation. To better analyze the financial dynamics of the agricultural sector, agricultural value-added, arable land, and population dynamics are included as control variables in the model. Within this scope, the following model has been constructed in the study:

$$ACU_i = \alpha_0 + \alpha_1 ATC_i + \alpha_2 CO2_i + \alpha_3 AVA_i + \alpha_4 AAA_i + \alpha_5 PG_i + \varepsilon_i \quad (1)$$

The detailed explanations of the variables used in this model and the descriptive statistics are presented in Table 1.

Table 1. Variable Information and Descriptive Statistics
Çizelge 1. Değişken Bilgileri ve Tanımlayıcı İstatistikler

Notation	Variable	Source	Mean	Std. Dev.	Skewness	Kurtosis	Jarque-Bera
ACU	Agricultural specialized credit volume/Total credit volume (%)	BAT	7.540	5.792	0.817	1.937	5.698 (0.058)
ATC	Average temperature change (°C)	FAO	0.852	0.830	-0.156	3.173	0.191 (0.909)
$CO2$	Carbon dioxide (CO_2) emissions excluding LULUCF per capita (t CO_2 e/capita)	World Bank	3.904	1.003	0.228	1.774	2.568 (0.277)
AVA	Agriculture, forestry, and fishing, value added (% of GDP)	World Bank	10.135	3.976	0.653	1.896	4.389 (0.111)
AAA	Agricultural land (% of land area)	World Bank	51.122	1.383	0.176	1.921	1.932 (0.381)
PG	Population growth (annual %)	World Bank	1.331	0.375	-0.888	4.840	9.810 (0.007)

Note: BAT (Banks Association of Türkiye); Food and Agriculture Organization of the United Nations (FAO).

When examining the descriptive statistics, the ACU variable has the highest standard deviation at 5.792, indicating significant fluctuations in agricultural credit usage. In contrast, the AAA variable has the lowest standard deviation at 1.383, suggesting that agricultural arable land is more stable. In terms of skewness, the PG variable exhibits the most pronounced negative skewness at -0.888, while the ACU and AVA variables display a right-skewed distribution. Regarding kurtosis values, the PG variable has the highest kurtosis at 4.840, making it more sensitive to extreme values. The other variables generally exhibit kurtosis values close to a normal distribution. According to the Jarque-Bera test results, only the PG variable shows a significant deviation from normality, while the other variables follow a normal distribution.

Structural breaks in time series indicate sudden and significant changes in the intrinsic structure of the series within a specific period. These breaks typically appear in deterministic components, causing the series to exhibit behavior different from previous periods. Fourier transformation converts the time-domain information of a time series into the frequency domain, revealing the periodic structure and frequency components within the series. This transformation method allows for modelling by adding trigonometric terms to detect potential breaks in the time series structure. Therefore, Fourier methods were preferred in this study, as they help accurately analyze structural changes in time series. In this context, the stationarity properties of the variables were first assessed using the Fourier KPSS (FKPSS) unit root test developed by Becker et al. (2006). Then, long-term relationships were examined using the Fourier-Shin cointegration analysis proposed by Tsong et al. (2016). For estimating long-term coefficients, parameter estimates were obtained using the Fourier Fully Modified Ordinary Least Squares (FFMOLS) estimator. Finally, the causal relationships between the variables were analyzed using the Fourier Toda-Yamamoto (FTY) causality analysis developed by Nazlıoğlu et al. (2016).

Fourier KPSS Unit Root Test

The stationarity test developed by Kwiatkowski et al. (1992), known as the KPSS test, is based on the hypothesis that time series are stationary. Becker et al. (2006) extended this test to incorporate structural changes, enhancing its ability to detect changes in time series more accurately by using Fourier functions (Kızılkaya & Konat, 2019). Fourier functions provide reliable results even when the nature, location, and number of changes in the series are unknown. The greatest advantage of this test is that it accounts not only for distinct structural changes but also for more gradual transitions (Gündüz, 2020). The data generation process for the unit root test developed by Becker et al. (2006) is presented in Equation (2).

$$y_t = X_t'\beta + Z_t'\gamma + r_t + \varepsilon_t$$
$$r_t = r_{t-1} + u_t$$
$$Z_t = [sin(2\pi kt/T), cos(2\pi kt/T)]' \quad (2)$$

In Equation (2), ε_t represents a stationary process, u_t denotes a process with constant variance, T indicates the number of observations, and k represents the frequency. The Fourier structure of $\alpha(t)$ is as follows:

$$\alpha(t) = a_0 + \sum_{k=1}^{n} a_k \, sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} b_k \, cos\left(\frac{2\pi kt}{T}\right); \qquad n < T/2 \quad (3)$$

In the Fourier structure, n indicates the number of all possible frequencies. However, Becker et al. (2006) set n=1 to make the problem more manageable. In this context, they proposed a single-frequency Fourier structure.

$$\alpha(t) \cong Z_t'\gamma = \gamma_1 sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 cos\left(\frac{2\pi kt}{T}\right) \quad (4)$$

To determine the appropriate number of frequencies, frequency values ranging from 1 to 5 are applied to the single-frequency Fourier structure. The appropriate frequency is the frequency value with the smallest sum of squares of the residuals (Fendoğlu & Canpolat Gökçe, 2019). The FKPSS test statistic is as follows:

$$\tau_\tau(k) = \frac{1}{T^2}\frac{\sum_{t=1}^{T}\tilde{S}_t(k)^2}{\tilde{\sigma}^2}$$
$$\tilde{S}_t(k) = \sum_{j=1}^{t}\tilde{e}_j$$
$$\tilde{\sigma}^2 = \tilde{\gamma}_0 + 2\sum w_j\,\tilde{\gamma}_j \quad (5)$$

In Equation (5), $\tilde{e}_j$ is the error term of the Fourier function model, $\tilde{\gamma}_j$ represents the j. autocovariances of the residuals, and $\tilde{\sigma}^2$ denotes the non-parametric estimate of the long-term variance. The F-test statistic used to test the significance of the Fourier function is defined as shown in Equation (6) (Becker et al., 2006):

$$F_i(k) = \frac{(KKT_0 - KKT_1(k))/2}{KKT_1(k)/(T-q)}, \; i = \mu, \tau \quad (6)$$

$KKT_1(k)$represents the sum of squared residuals obtained from the Fourier structure, q denotes the number of independent variables, and KKT_0 refers to the sum of squared residuals from the model without the inclusion of trigonometric terms.

Fourier Shin Cointegration Test

To determine the cointegration relationship between series, Shin (1994) developed a method based on the KPSS unit root test. Arai and Kurozumi (2007) adapted this test to allow for structural breaks. Since long-term relationships between series can be affected by abrupt or gradual structural breaks, Tsong et al. (2016) added Fourier functions to Shin's test and developed a new Fourier-Shin cointegration test. The data generation process for this test is given in Equation (7).

$$y_t = d_t + X_t'\beta + \eta_t \quad (7)$$

$\eta_t = \gamma_t + \vartheta_{1t}$, where $\gamma_0 = 0$, and $\gamma_t = y_{t-1} + u_t$, $x_t = x_{t-1} + \vartheta_{2t}$. ϑ_{1t}. Since ϑ_{1t} and ϑ_{2t} are stationary, x_t and y_t are stationary in first differences. $d_t = \delta_0 + f_t$ or $d_t = \delta_0 + \delta_1 t + f_t$. When the deterministic components are m = 0, only the constant term is included, and when m = 1, both the constant term and the trend are included (Tsong et al., 2016).

f_t is the Fourier function as shown in Equation (8).

$$f_t = \alpha_k sin\left(\frac{2\pi kt}{T}\right) + \beta_k cos\left(\frac{2\pi kt}{T}\right) \quad (8)$$

As in the FKPSS stationarity test by Becker et al. (2006), the significance of the trigonometric terms is tested using the F statistic. The Fourier-Shin test statistic is expressed as in Equation (9) by Tsong et al. (2016).

$$CI_f^m = T^{-2}\widehat{\omega}_1^{-2}\sum_{t=1}^{T} S_t^2 \quad (9)$$

In Equation (9), $S_t = \sum_{t=1}^{T}\hat{v}_{1t}$, represents the partial sum of the error terms, and $\widehat{\omega}_1$ denotes the estimator of the long-run variance of $\hat{v}_{1t}$.

Fourier Toda-Yamamoto Causality Test

Introduced by Nazlıoğlu et al. (2016), Fourier Toda-Yamamoto (FTY) causality testing specifically addresses the limitations of traditional Granger causality testing when working with integrated variables and structural breaks. This test combines the advantages of the Toda-Yamamoto (TY) approach, which eliminates the need for differencing for integrated variables and preserves long-term information, with the flexibility of the Fourier function used to account for structural changes. The FTY test is based on the following vector autoregressive model:

$$Y_t = \beta_0 + \beta_1 \sin(2\pi kt/T) + \beta_2 \cos(2\pi kt/T) + \sum_{i=1}^{p+dmax}\theta_i Y_{t-i} + \sum_{i=1}^{p+dmax}\phi_i X_{t-i} + u_t$$

$$Y_t = \delta_0 + \delta_1 \sin(2\pi kt/T) + \delta_2 \cos(2\pi kt/T) + \sum_{i=1}^{p+dmax}\varphi_i Y_{t-i} + \sum_{i=1}^{p+dmax}\theta_i X_{t-i} + v_t \quad (10)$$

In Equation (10), Y_t and X_t represent the variables of interest, p is the optimal lag length, and dmax indicates the maximum integration order of the variables. sin and cos are the trigonometric terms of the Fourier function and are used to calculate the impact of structural changes. k determines the optimal frequency and is identified by minimizing the sum of squared errors. Finally, t refers to the trend term, and T represents the sample size.

RESULTS

In this study, the Zivot-Andrews (ZA) unit root test was applied to examine the effects of structural breaks. However, to reduce the complexity of the study, tables containing the results of the ZA unit root test were not included. Instead, to visually present the effects of structural breaks during the period, graphs showing the break dates obtained from the ZA (1992) structural break unit root test have been added. These graphs help in understanding the significant structural changes and fluctuations in specific periods, making it easier to comprehend the changes in agricultural credit usage. The graphs, which aim to visually illustrate the effects of climate change and environmental degradation on agricultural credit usage, are presented in Figure 2. The year 1994 marks a significant break in terms of average temperature change and CO_2 emissions; the 1998-1999 period represents a break regarding agricultural credit and agricultural value-added; and the 2007-2009 period contains notable breaks in terms of arable land and annual population growth, highlighting the periods of significant structural changes.

The results of the Fourier KPSS (FKPSS) stationarity test are reported in Table 2.

According to the findings of the Fourier KPSS test, the first differences test for stationarity of the variables analyzed is valid. This finding reveals that the variables do not have long-run stationarity properties at their levels, but their first differences become stationary.

Following the stationarity finding in the first-order differences of the variables, the Fourier-Shin cointegration test was applied to determine the long-term relation between the variables. The findings of the test are shown in Table 3.

There is a long-run relationship in the model analyzed according to the results of the Fourier-Shin cointegration test. This finding indicates that the variables tend to be in equilibrium with each other in the long run. To estimate the long-run coefficient, the Fourier FMOLS estimator was used. Table 4 shows the results obtained.

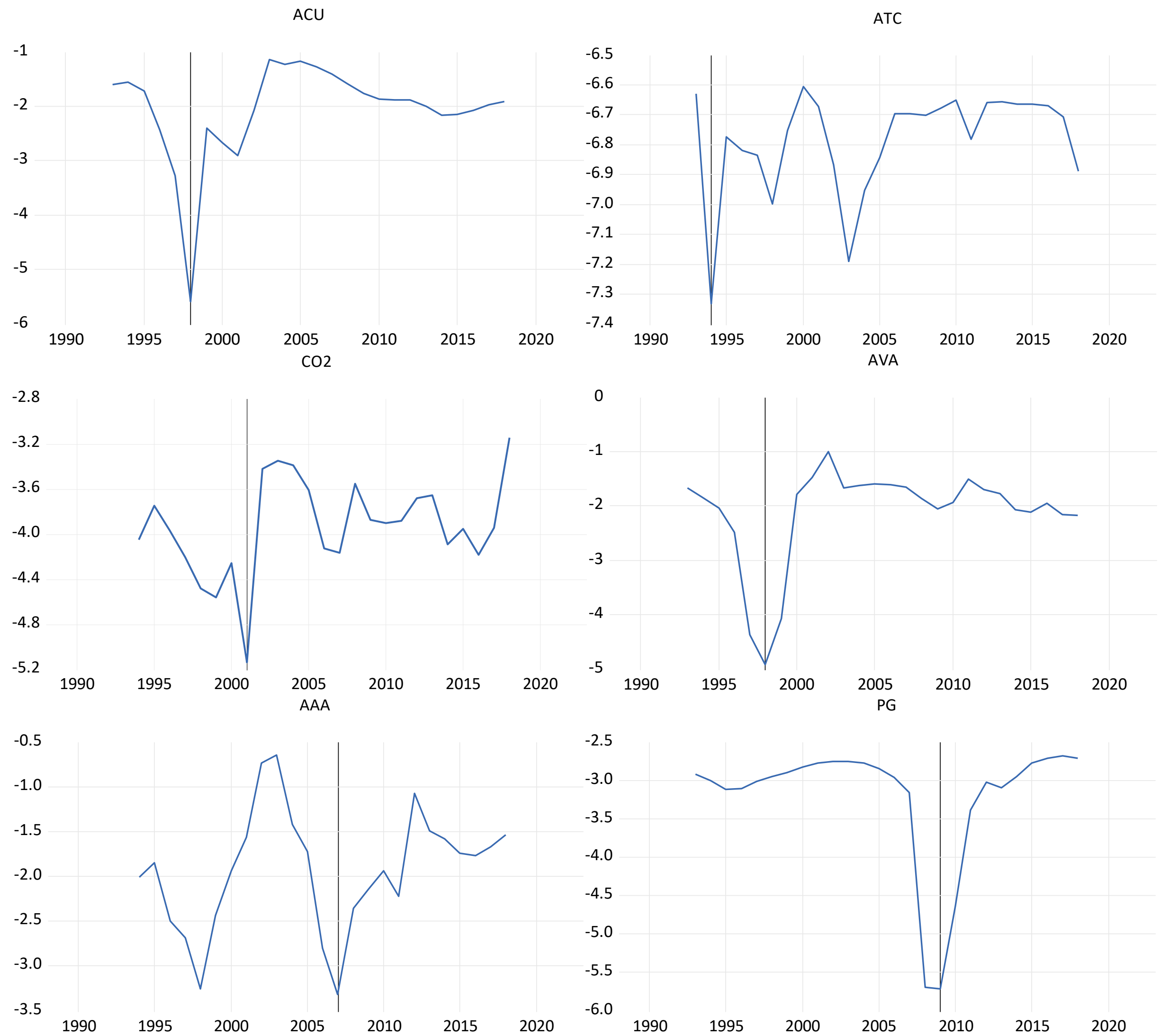

Figure 2. Breaks of Variables Included in the Model
Şekil 2. Modele Dahil Edilen Değişkenlere Ait Kırılmalar

Table 2. FKPSS Stationarity Test Results
Çizelge 2. FKPSS Durağanlık Test Sonuçları

Variable	Frequency	Min. KKT	F Test Statistic	FKPSS Test Statistic	Critical Values		
					1%	5%	10%
ACU	1	307.306	46.538*	0.498	0.269	0.172	0.131
ΔACU	1	124.392	21.176*	0.124*	0.269	0.172	0.131
ATC	1	17.783	35.885*	0.496	0.269	0.172	0.131
ΔATC	4	25.908	30.164*	0.112*	0.722	0.459	0.347
$CO2$	1	13.049	27.989*	0.485	0.269	0.172	0.131
$\Delta CO2$	4	1.091	31.695*	0.193*	0.722	0.459	0.347
AVA	1	197.082	29.828*	0.449	0.269	0.172	0.131
ΔAVA	5	23.782	24.385*	0.107*	0.738	0.462	0.351
AAA	1	17.0302	48.401*	0.398	0.269	0.172	0.131
ΔAAA	3	7.806	33.369*	0.117*	0.718	0.448	0.339
PG	2	3.798	34.827*	0.87	0.667	0.415	0.315
ΔPG	4	2.495	30.785*	0.132*	0.722	0.459	0.347

Note: The * symbol indicates 1% significance level. In Becker et al. (2006), the critical values for the F test statistic are given as 6.73 at the 1% level, 4.29 at the 5% level and 4.133 at the 10% level.

Table 3. Fourier Shin Cointegration Test Results
Çizelge 3. Fourier Shin Eşbütünleşme Testi Sonuçları

Model	Frequency	Min. KKT	F Test Statistic	FSHIN Test Statistic	Critical Values		
					1%	5%	10%
$ACU_i = f(ATC_i, CO2_i, AVA_i, AAA_i, PG_i)$	3	43.849	12.486***	0.084***	0.25	0.146	0.112

Note: * symbol indicates 1% significance level. In Becker et al. (2006), the critical values for the F test statistic are given as 6.73 at the 1% level, 4.29 at the 5% level and 4.133 at the 10% level.

Table 4. Fourier FMOLS Coefficient Estimation Results
Çizelge 4. Fourier FMOLS Katsayı Tahmin Sonuçları

Dependent Variable: ACU	Coefficient	Std. Error	t-Statistic	Prob.
ATC	-0.509	0.301	-3.689*	0.003
$CO2$	-1.368	0.881	-5.553*	0.000
AVA	0.708	0.183	-3.876*	0.001
AAA	1.544	0.341	-4.522*	0.000
PG	0.923	0.842	1.096	0.283
SIN	-3.359	0.559	-6.005*	0.000
COS	-0.597	0.422	-4.415*	0.000
C	-3.763	21.437	-3.907*	0.001

Note: * symbol indicates 1% significance level.

According to the Fourier FMOLS results, a 1-unit change in average temperature reduces agricultural credit usage by 0.509 units. In other words, increases in climate change reduce agricultural credit usage, highlighting the restrictive effect of climate change on financing and investment in the agricultural sector. Similarly, a 1-unit increase in CO_2 emissions reduces agricultural credit usage by 1.368 units, indicating that environmental degradation decreases agricultural credit usage, and this suggests that environmental degradation increases risks for the agricultural sector, limiting investment and financing demand. On the other hand, a 1-unit increase in agricultural value-added increases credit usage by 0.708 units, indicating that as the sector's income-generating capacity strengthens, investability increases and access to financing becomes easier. The expansion of agricultural arable land increases credit usage by 1.544 units, confirming the effect of economies of scale and the increased financing need due to the expansion of production capacity. Additionally, a 1-unit change in population growth increases agricultural credit usage by 0.923 units, which can be interpreted as the rising food demand stimulating agricultural production leading agricultural producers to require more financing.

The results of the Fourier Toda-Yamamoto causality analysis applied to determine the causal relationships between the variables are presented in Table 5.

Table 5. Fourier Toda-Yamamoto Causality Analysis Results
Çizelge 5. Fourier Toda-Yamamoto Nedensellik Analizi Sonuçları

H_0	Optimal Lags	Optimal Frequency	Wald Stat.	Asymptotic p-value	Bootstrap p-value
$ACU \nrightarrow ATC$	1	2	-13.245***	0.000	0.000
$ATC \nrightarrow ACU$	1	2	-1.755	0.185	0.197
$ACU \nrightarrow CO2$	1	1	-0.785	0.376	0.381
$CO2 \nrightarrow ACU$	1	1	-0.021	0.885	0.892
$ACU \nrightarrow AVA$	1	1	-6.869***	0.009	0.015
$AVA \nrightarrow ACU$	1	1	-12.108***	0.000	0.000
$ACU \nrightarrow AAA$	2	1	-1.500	0.472	0.486
$AAA \nrightarrow ACU$	2	1	-0.651	0.722	0.730
$ACU \nrightarrow PG$	1	1	-11.116***	0.000	0.000
$PG \nrightarrow ACU$	1	1	-11.652***	0.000	0.000

Note: * symbol indicates 1% significance level.

There is a one-way causality from the use of agricultural credit to the change in average temperature, according to the results of the Fourier Toda-Yamamoto causality analysis. This finding suggests that agricultural finance may have indirect effects on climate variables through production scale, input usage, and the intensity of agricultural activities. The provision of credit to the agricultural sector may contribute to the widespread mechanization of production processes, the use of chemical products in agriculture, increased energy consumption, and changes in land use, which could play a decisive role in climate systems in the long term. The causal relationship between the use of agricultural credit and agricultural value added is two-way. This indicates that agricultural finance promotes sectoral growth by increasing production capacity, while the rise in agricultural value-added strengthens the demand for financing. In terms of the sustainable development of the agricultural sector, increasing the effectiveness of financial support mechanisms is expected to not only expand producers' investments but also sustainably increase agricultural productivity. Finally, the causality test results also revealed a bidirectional causality relationship between agricultural credit usage and population growth. Population growth increases food demand, which strengthens agricultural production and the need for financing, while the expansion of agricultural credit plays a critical role in supporting production processes and ensuring food security.

CONCLUSIONS, DISCUSSION and RECOMMENDATIONS

Using annual data from 1988 to 2023, this study examines the impact of climate change and environmental degradation on agricultural credit use in Türkiye. The results show that a 1-unit increase in average temperature reduces agricultural credit usage by 0.509 units, while a 1-unit increase in CO_2 emissions decreases agricultural credit usage by 1.368 units. These findings highlight that climate and environmental degradation increase financial risks in the agricultural sector, limiting investment and credit demand. On the other hand, the 1-unit increase in agricultural value-added and expansion of arable land increases credit usage by 0.708 and 1.544 units, respectively, showing that the sector's income-generating capacity and economies of scale are reflected in financial opportunities. A 1-unit change in population growth increases agricultural credit usage by 0.923 units, which can be interpreted because of the increased demand for food, stimulating agricultural production, and increasing the need for financing. Causality analysis revealed a one-way causality from agricultural credit usage to average temperature change, and bidirectional causality between credit usage and agricultural value-added, as well as population growth. These results suggest that agricultural finance affects not only production processes but also climate variables through demographic and structural economic interactions. The fact that agricultural credit usage causes changes in average temperature reflects the environmental impacts of how credit is utilized as a financial resource in agricultural activities. For example, increased environmentally harmful practices-such as energy consumption, the development of agricultural activities and techniques, chemical fertilizer and pesticide use, or excessive exploitation of water resources-can be linked to credit usage. This suggests that when credits support unsustainable agricultural models, they exert pressure on the climate. The finding that agricultural credit usage increases agricultural value-added implies that financial resources are likely used for productivity improvements, technology investments, or diversification of production. Conversely, rising value-added may incentivize financial institutions to extend more credit to the sector. This bidirectional relationship highlights that while financial support can drive agricultural growth, the environmental costs of such growth must not be overlooked. The bidirectional causality between agricultural credit usage and population growth can be attributed to population growth increasing the demand for agricultural credit due to rising food needs. Population growth stimulates agricultural production by boosting food demand, thereby elevating financing requirements. At the same time, increased credit usage can expand production capacity, enhancing food supply. Additionally, the potential of credit usage to drive population growth may be explained by its role in boosting agricultural employment or rural welfare. These dynamics underscore the intertwined nature of the agricultural sector with socioeconomic and demographic structures. In the literature, studies on climate change and environmental degradation's impact on agricultural sector credit are quite limited, and the results of this study are largely consistent with the findings of Abay et al. (2018), Wahab et al. (2024), Liu (2024), and Islam and Singh (2024). However, there are some differences in terms of sample, methodology, and variables used. When evaluating the findings, both this study and other studies in the literature highlight that climate change makes access to agricultural credit more difficult. For example, Abay et al. (2018) show that rainfall uncertainty reduces credit demand in Ethiopia, while Liu (2024) finds that small farmers in the U.S. face more difficulties in accessing credit. Similarly, this study identifies that increases in environmental degradation and climate change reduce agricultural credit usage in Türkiye. However, the study by Wahab et al. (2024) emphasizes the asymmetric effects of climate change on credit repayments, whereas this study examines its impact on credit usage. In terms of sample, this study analyses the long-term effects of climate change in Türkiye over an extended period (1988-2023). In contrast, Abay et al. (2018) used micro-level household data in Ethiopia, Wahab et al. (2024) worked with panel data from 82 cities in Pakistan, and Liu (2024) and Islam and Singh (2024) focused on bank credit policies using county- and bank-level data in the U.S. This study, conducted specifically in Türkiye, offers a broad perspective on agricultural credit dynamics due to its longer-term and macro-level nature. Methodologically, this study uses Fourier-based econometric tests to conduct stationarity, cointegration, and causality analyses. This method is more capable of capturing the nonlinear behavior of variables compared to traditional econometric approaches. Most other studies have used regression models and panel data analysis. For instance, Islam and Singh (2024) assessed climate risks at the bank level using regression models in the U.S., while Liu (2024) preferred nonlinear econometric methods. In this context, this study, conducted using Fourier methods, offers a more flexible analysis of the relationship between climate change and agricultural credit. As a result, while this study reaches findings that are largely consistent with other research in the literature, it makes a significant contribution by providing a long-term analysis specific to Türkiye. The use of Fourier methods and the analysis with a broad set of variables at the macro level allow for a deeper understanding of the relationship between climate change and agricultural credit usage.

Research shows that both climate change and environmental degradation significantly and negatively impact agricultural credit use. H_0 (no significant impact of climate change on agricultural credit use) is rejected, while H_1 (significant impact of climate change) is accepted. Similarly, the hypothesis H_0 regarding the effect of environmental degradation (environmental degradation does not have a significant effect on agricultural credit usage) is also rejected, and the alternative hypothesis H_1 (environmental degradation has a significant effect) is confirmed. In summary, for both cases, the alternative hypotheses are found to be valid, demonstrating that climate and environmental changes hurt agricultural credit usage. These findings emphasize the need to consider environmental factors in the development of credit policies in the agricultural sector.

In light of the research findings, comprehensive policy recommendations can be developed to address the factors of climate change and environmental degradation affecting agricultural credit usage in Türkiye. Firstly, financial institutions providing credit should establish credit evaluation systems that take climate risks into account. Based on the results, the reduction in agricultural credit usage due to the increase in average temperature highlights the decisive effect of climate risks on financial decisions. Therefore, considering climate change adaptation strategies, sustainable agricultural practices, and environmental risk management plans in credit applications will enable more realistic risk modelling. Secondly, considering that environmental degradation significantly reduces agricultural credit usage, support programs that promote environmental sustainability should be implemented. The government and relevant institutions can develop interest rate reductions, tax incentives, and grant programs for farmers who adopt environmentally friendly agricultural technologies or implement sustainable production methods. These incentives will increase producers' compliance with environmental standards, thus facilitating access to finance. Thirdly, the findings that agricultural added value and the expansion of arable land increase credit usage indicate the need to support investments that enhance production capacity and efficiency. Within the scope of rural development projects, the promotion of modernization, mechanization, infrastructure improvements, and digital agriculture applications will strengthen production processes and increase the effectiveness of agricultural finance. Fourthly, considering that population growth increases the demand for agricultural credit, inclusive agricultural financing policies should be developed to ensure food security. Institutions that develop and support small and medium-sized enterprises should design low-interest, long-term credit programmers for farmers. In addition, financing models tailored to regional needs should be offered to support the sustainability of agricultural production. It is expected that the findings of this study, approached holistically, will make a significant contribution to aligning the agricultural sector's financial structure with environmental and climate risks and provide a solid foundation for similar future studies.

This study, which analyses Turkish agriculture in the context of climate-environment-finance interaction at the macro level with annual data for the period 1988-2023, has some limitations and strengths. Firstly, data availability problems regarding agricultural credits and the inability of annual data to reflect seasonal or short-term shocks may limit the dynamics of the analyses. Another limitation is that the study does not include the credit behavior of farmers, regional differences, and the direct effects of agricultural policies at the micro level since it deals with Turkish agriculture at the macro level. Considering the strengths of the study, it offers an innovative perspective by analyzing the climate-environment-agricultural credit interaction, which has not been addressed in the Turkish sample. Thanks to Fourier-based econometric approaches, complex structural changes in time series can be modelled more precisely compared to traditional models, increasing the validity of the results. The comprehensive 35-year dataset enables the analysis of long-term dynamics and supports the robustness of the findings. Moreover, quantifying the impact of climatic and environmental risks on agricultural credit demand provides concrete evidence for Turkish agricultural sector stakeholders. This unique topic choice and methodological approach are among the key elements that make this study stand out in its field and contribute to filling an important gap in the literature.

Contribution Rate Statement Summary of Researchers

The authors declare that they have contributed equally to the article.

Conflict of Interest

The authors declare that there is no conflict of interest between them.

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