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ISTANBUL GELISIM UNIVERSITY
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Department of Economics and Finance

THE IMPACT OF CLIMATE CHANGE ON THE AGRICULTURAL SECTOR IN MEDITERRANEAN COUNTRIES

Master Thesis

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DECLARATION

I hereby declare that in the preparation of this thesis, scientific ethical rules have been followed, the works of other persons have been referenced in accordance with the scientific norms if used, there is no falsification in the used data, any part of the thesis has not been submitted to this university or any other university as another thesis.

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SUMMARY

The aim of this study is to analyze the impact of climate change on the agricultural sector in the Mediterranean countries, with a focus on Egypt, Türkiye, Spain, Italy and Greece. These countries are among the most important producers of major crops. Climate change is a growing challenge for these countries, posing a real threat to agricultural production.

The research is based on past climate and agricultural data from 1980 to 2024 as a basis for future projections, as well as on the use of inductive models such as the ARIMA model and the ARIMAX model to predict the impact of climate change on past production in the period from 2025 to 2030. The research aims to clarify the relationship between climate change and agriculture in the Mediterranean region and to identify the most influential climate factors on agricultural production. The study examined the impact of temperature and precipitation variables on wheat production through the application of ARDL cointegration analysis.

The study shows the importance of adapting to the expected climate changes through some strategies such as the improvement of irrigation systems, the development of drought-resistant crops and the promotion of agricultural practices that adapt to the negative effects of climate change on agriculture in order to maintain agricultural production in Mediterranean countries.

Keywords: Climate change, Agriculture, Mediterranean, Food security, ARIMA model, ARIMAX model, ARDL, Agricultural Adaptation, Climate Forecasting.

ÖZET

Bu araştırma, iklim değişikliğinin Akdeniz ülkelerinde, özellikle Mısır, Türkiye, İspanya, İtalya ve Yunanistan'da tarım sektörü üzerindeki etkisini analiz etmeyi amaçlamaktadır. Bu ülkelerin her biri, birçok temel ürünün üreticilerinden biridir. Oysa bu ülkeler, tarımsal üretim için gerçek bir tehdit oluşturan iklim değişikliği konusunda giderek artan bir zorlukla karşı karşıyadır.

Araştırma, 2025'ten 2030'ye kadar olan dönemde iklim değişikliğinin geçmişin üretimi üzerindeki etkisini tahmin etmek için ARIMA modeli ve ARIMAX modeli gibi tümevarımsal modellerin kullanımına ek olarak, gelecek tahmini için bir temel olarak 1980'den 2024'e kadar olan önceki iklim ve tarımsal verilere dayanmaktadır. Araştırma, Akdeniz bölgesinde iklim değişikliği ve tarım arasındaki ilişkiyi aydınlatmayı ve tarımsal üretim üzerinde en etkili iklim faktörlerini belirlemeyi amaçlamaktadır. Çalışmada, ayrıca ARDL eşbütünleşme analizi uygulanarak sıcaklık ve yağış değişkenlerinin buğday üretimine etkisi incelenmiştir.

Çalışma, Akdeniz ülkelerinde tarımsal üretimin sürdürülebilmesi için sulama sistemlerinin iyileştirilmesi, kuraklığa dayanıklı mahsullerin geliştirilmesi ve tarımda olumsuz değişen iklim koşullarına uyum sağlayan tarım uygulamalarının teşvik edilmesi gibi bazı stratejiler aracılığıyla beklenen iklim değişikliklerine uyum sağlamanın önemini göstermektedir.

Anahtar kelimeler: İklim değişikliği, Tarım, Akdeniz, Gıda güvenliği, ARIMA modeli, ARIMAX modeli, ARDL, Tarımsal Uyum, İklim Tahmin.

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ABBREDIVATIONS

ACF	**:**	Autocorrelation Function
ADF	**:**	Augmented Dickey Fuller
AIC	**:**	Akaike Information Criteria
ARCH	**:**	Autoregressive Conditional Heteroskedasticity
ARDL	**:**	Auto Regressive Distributed Lag
ARIMA	**:**	Auto Regressive Integrated Moving Average
ARIMAX	**:**	Auto Regressive Integrated Moving Average with Exogenous Variables
CUSUM	**:**	Cumulative Sum of Recursive Residuals
FAO	**:**	Food and Agriculture Organization
GIS	**:**	Geographic Information System
IPPC	**:**	International Plant Protection Convention
PACF	**:**	Partial Autocorrelation Function
RESET	**:**	Regression Equation Specification Error

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PREFACE

Many challenges have arisen for the agricultural sector in the last century. The most prominent of these has been climate change, as climate change has a significant and clear impact on agriculture and food security, thus affecting the global economy, as the continuous rise in temperatures, low rainfall and some natural phenomena related to climate, gases and global warming pose a strong and serious threat to agricultural production. The Mediterranean is one of the regions most affected by climate change due to its particular geographical and climatic characteristics. These include temperatures and the negative impact on rainfall, leading to an increase in the risk of drought, which has a direct impact on harvests, soil quality and water availability. Agriculture is an important source of livelihood for this region, as rural areas are heavily dependent on agriculture as their main source of income. Given these challenges, it is necessary to understand the impact of climate change on agriculture and develop adaptation strategies to ensure future food security.

INTRODUCTION

This study analyses the impact of climate change on five of the main agricultural producing countries in the Mediterranean region (Egypt, Türkiye, Greece, Spain and Italy), which play an important role in agricultural production both in the Mediterranean region and at global level, for the different main crops that are strongly affected by climate change. For this purpose, climate data will be analyzed together with crop production over 44 years between 1980 and 2024 and projections will be made for future impacts from 2025 to 2030. The aim of this study is to develop a vision for the future of agriculture in the Mediterranean countries in the light of climate change. This study will predict the impact of climate change on crop production and identify vulnerabilities and evidence-based communication essential for sustainable planning using Auto Regressive Integrated Moving Average (ARIMA) and Auto Regressive Integrated Moving Average with Exogenous Variables (ARIMAX) modelling to show to what extent climate change in terms of temperature and precipitation increase may affect agricultural production in these countries amidst an expected challenge. These recommendations can help stakeholders to develop flexible agricultural strategies and mitigate the negative impacts of climate in the region.

The great importance of this study can be seen in addressing fundamental issues related to the impact of climate change on the agricultural sector in Mediterranean countries, as nations seek to achieve a trade-off between economic development and the environment. In view of the global challenges to world food security, the results of this study could be useful if the competent authorities take into account that they can act in advance to prevent or mitigate the negative effects of climate change.

CHAPTER ONE

BACKGROUND AND CONTEXT

1.1.Background of The Study

In recent years, the world has experienced unstable climate change, which poses a threat to the agricultural sector and therefore to food security. The agricultural sector plays an important role that goes beyond food production. Firstly, it is the linchpin of food security and crisis prevention, as it provides the vital crops for the population in a stable manner, and climate change will affect this stability. Secondly, the agricultural sector contributes to sustainability and the green economy by promoting environmentally friendly farming practices that conserve water and soil and reduce greenhouse gas emissions. Thirdly, it is the main source of employment and rural development, especially in the Mediterranean countries, as people in this region are heavily dependent on agriculture for their income and livelihood. Finally, the agricultural sector influences global food prices, as the impact of climate change on agriculture can lead to price increases. Therefore, understanding and protecting the agricultural sector from the effects of climate change will help to ensure food security, sustainable development and economic stability in the Mediterranean region.

One of the regions threatened by this danger is the Mediterranean basin, as it is affected by climate change through rising temperatures, decreasing rainfall and also some extreme weather events such as floods and droughts. These impacts naturally extend to the agricultural sector, as it is primarily dependent on climate variability and therefore threatens food security in the area. For this reason, it is important to analyze the impact of climate change on the agricultural sector in the Mediterranean region, and five countries from this region were selected for the study. These countries were selected due to their geographical and climatic diversity in order to gain a comprehensive understanding of the Mediterranean region. These countries are (Türkiye, Egypt, Italy, Spain and Greece), and these countries selected because of these countries are considered some of the main producers or importers of wheat in the Mediterranean region and share the same climatic challenges, Türkiye is one of the largest wheat-producing countries in the area owing to its importance in wheat production, while Egypt is the largest wheat-importing country and also produces it despite its limited water resources. Spain and Italy are the largest wheat producers in

Europe; however, Greece, despite its limited wheat production, is important in this study because of its sensitivity to climate. By studying these countries, a comparative analysis can be conducted to understand how climatic conditions and different policies affect adaptation strategies in the agricultural sector.

Also to observe the effects of climate change on the agricultural sector under different climatic conditions in the region, as these countries face similar challenges manifested in climate change and scarcity of water resources, which leads to a decline in agricultural productivity, and this diversity of conditions and challenges faced by these countries helps in comparing experiences and analyzing data for each country and dealing with the effects of climate change.

In the agricultural sector, wheat was selected as the main crop for the study, as these countries are among the leading wheat producers in the Mediterranean region. This is also due to the importance of wheat for food security, as it is considered a staple food in the region and is also one of the crops affected by climate change, which in turn has an impact on food security.

Practically, these countries have a wealth of climate and agricultural data, as the availability of reliable data is essential for the accurate application of statistical forecasting models. In the study, Auto Regressive Integrated Moving Average (ARIMA) and Auto Regressive Integrated Moving Average with Exogenous Variables (ARIMAX) time series models are used to predict future changes in agricultural production.

1.2 Problem Statement

Mediterranean countries are increasingly affected by climate change, which has a direct impact on the agricultural sector, as high temperatures, limited rainfall and periodic weather extremes will lead to soil degradation and a reduction in irrigation resources. These factors affect crop yields, which in turn threatens food security and ultimately the economies of these countries. Against this background, the problem of the study is to analyze the impact of climate change on agriculture in five Mediterranean countries: Egypt, Türkiye, Spain, Italy and Greece, and to determine the strategies that can be pursued to adapt to these challenges in order to ensure the continuity of the agricultural sector and achieve food security in the future.

1.3 Purpose of the Study

The aim of this study is to analyses the impact of climate change on agriculture and crop production in the Mediterranean countries, particularly in Egypt, Türkiye, Spain, Italy and Greece. It also aims to identify the main climate factors affecting the agricultural sector, such as high temperatures, changes in precipitation and the frequency of extreme weather events.

The study uses inductive models such as the ARIMA and ARIMAX models to predict future changes between 2025 and 2030 based on past climate and agricultural data, and works as far as possible to provide farmers and decision-makers with recommendations for adaptation strategies to mitigate the effects of climate change on agriculture and maintain food security in the region.

1.4 Significance of Study

The importance of this study is emphasized in view of the increasing challenges for agriculture and the economy in relation to the impacts of climate change in the Mediterranean region, by providing an understanding of the relationship between climate change and the agricultural sector in Mediterranean countries, which helps to identify the risks to which the agricultural sector may be exposed. It also aims to make recommendations, based on climate projections, to help farmers and professionals in the sector adapt to the expected climate changes. This study aims to offer solutions to improve crop productivity in Mediterranean countries.

1.5 Research Questions

The study focuses on answering these questions as a basis for analyzing the impact of climate on the agricultural sector

1) How do changes in temperature, precipitation and extreme weather events affect the agricultural sector and the productivity of the wheat production?

2) What future impacts of climate change on the agricultural sector in Mediterranean countries are expected between 2025 and 2030?

3) What adaptation strategies should Mediterranean countries adopt to mitigate the impact of climate change on the wheat production?

4) Can time-series forecasting using the ARIMA model provide reliable estimates of wheat yield between 2025 and 2030 in the Mediterranean region?

1.6 Research Hypotheses

Hypothesis 1: The existence of a statistically significant negative impact of climate change on the production of agricultural crops in the Mediterranean countries "Egypt, Türkiye, Italy, Spain and Greece" in the expected period 2025-2030.

This hypothesis assumes a negative impact of climate change on the agricultural sector and crop production in the Mediterranean countries in the period 2025-2030, as this impact is likely to be clearly measurable and analyzable. High temperatures are expected to lead to a decrease in agricultural productivity, especially for crops that require moderate temperatures, such as wheat and fruit, as this increase in temperature may lead to rapid ripening of low-quality crops, Also, the change in rainfall may lead to droughts or floods, which may have a negative impact on the agricultural productivity of some crops, as Egypt may be more threatened by the fluctuations of the Nile. In addition, climate change may lead to an increased spread of agricultural diseases and pests as the habits of agricultural organisms such as pollinator insects or weeds change. This hypothesis aims to assess the impact of climate change on food security in these countries and then develop strategies to adapt and mitigate the negative effects of climate change.

Hypothesis 2: Future prediction of low agricultural productivity due to high temperatures and low rainfall in most of the countries analyzed.

This hypothesis predicts that future climate change such as high temperatures and lack of rainfall will lead to a decrease in agricultural productivity of the wheat crop in most Mediterranean countries such as Egypt, Greece, Türkiye, Italy and Spain. High temperatures directly affect the growth ability of crops when temperatures exceed the levels required by agricultural crops such as wheat, rice, vegetables, etc., leading to an expected decrease in wheat productivity and may lead to pest infestations. This hypothesis aims to provide an outlook on the risks facing the agricultural sector due to climate change and how to adapt to these risks.

Hypothesis 3: The impact of climate change on the agricultural sector will vary from country to country due to differences in geographical location, crop types and the ability of individual countries to respond to climate change. This hypothesis assumes that the impact of climate change on the agricultural sector will vary from country to country due to various factors that may differ from country to country and due to the policies pursued by each country, such as

1. Geographical location: coastal countries such as Spain and Greece may be more affected by changing temperatures and sea levels, while inland countries such as Egypt and Türkiye may be more affected by changing temperatures and rainfall, affecting crops in this region.

2. Type of agricultural crops: Since each country grows different crops depending on its climate, as some countries grow crops that require a lot of water, such as rice and corn, and other countries grow drought-resistant crops such as olives and grapes, climate changes such as high temperatures and changes in rainfall affect crops differently and not in the same way.

3. Ability to adapt to climate change: Each country differs in its ability to adapt to climate change due to various factors such as available agricultural technology, government policies that support the agricultural region during changes, and financial support for agricultural studies and creativity.

The aim of this hypothesis is to illustrate that the effects of climate change are not global or uniform for all countries, but vary depending on the geographical, economic and climatic conditions of each country. This understanding helps to develop an agricultural policy that is appropriate to the challenges of each individual country.

Hypothesis 4: Within the same country, there will be a spatial variation in the impact of climate change on the agricultural sector, which can be determined using Geographic Information System (GIS) tools.

This hypothesis suggests that the effects of climate change on wheat production are not constant within a country, as they vary from region to region. For example, the effects of high temperatures and soil salinity may be more influential in coastal areas than in other areas, and the effects of high areas on rainfall may be more influential than in coastal areas, and this is where GIS tools can be used to create maps that show the difference between regions, illustrating this hypothesis The importance of spatial analysis and not being satisfied with the general average of the country.

Hypothesis 5: The ARIMAX economic model, which includes climate variables as externalities, will provide higher predictive accuracy in predicting wheat productivity than the traditional ARIMA model.

This hypothesis assumes that the ARIMA model is an effective and accurate model for predicting the impact of climate change on agricultural production, but the ARIMAX model is more accurate in predicting the future and forecasting wheat productivity in the period 2025-2030.

Hypothesis 6: there is a statistically significant positive effect between annual rainfall and wheat production in the countries analyzed.

This hypothesis assumes a positive influence of precipitation on wheat production in the Mediterranean countries, as wheat productivity is positively influenced when the annual amount of precipitation in the region increases.

1.7 Theoretical and Conceptual Framework

1.7.1 Theoretical Framework

The theoretical framework of this study stems from the theories that contribute to the understanding of the challenges faced by the agricultural sector in the Mediterranean, as these challenges are caused by rising temperatures and low water levels in the region. Therefore, the theoretical foundation is based on several theories that help explain the impact of climate change on the agricultural sector in this area, including the following theories:

Climate Change Theory: This theory states that climate change caused by human activity leads to the emission of greenhouse gases and that these changes affect the agricultural sector by changing the growing season.

Agricultural Ecosystem Theory: This theory assumes that agricultural systems depend on the interaction of all climatic and environmental factors in an integrated manner, which helps to explain the effects of climate change on agricultural crops and natural resources.

Theory of Climate Change Adaptation: This theory illustrates the importance of adaptation methods in agriculture, as it explains to farmers how important it is to find ways to adapt to the consequences of climate change, such as using new irrigation systems and growing drought-resistant crops.

The Theory of Value of Environment Resources: This theory makes it possible to predict the damage caused by climate change in the agricultural sector, as it helps to understand the costs of adaptation in relation to the expected economic damage in the absence of preventive measures.

The Statistical Theory of Prediction: This theory uses the analysis of historical patterns of climate and agricultural data to predict future changes with the help of ARIMA and ARIMAX models.

1.7.2 Conceptual Framework

This study analyses how climate change may affect the agricultural sector in Mediterranean countries through climatic, economic and other factors, with a focus on adaptation measures.

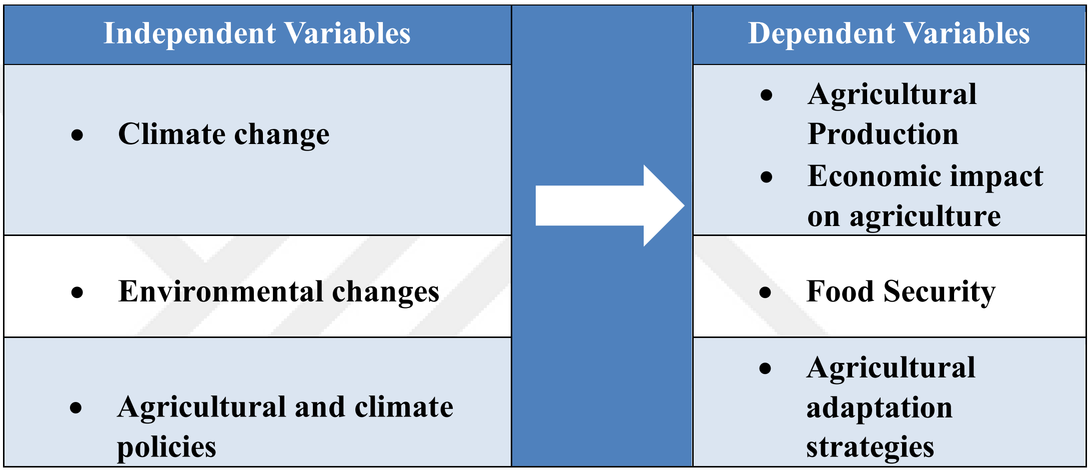
Basic concepts of research:

1. Climate change: This includes changes in temperature and weather conditions over long periods of time. In Mediterranean countries, climate change is associated with higher temperatures, insufficient rainfall and extreme weather events.
2. Agricultural sector: The agricultural sector includes all activities related to agricultural production. This sector is one of the sectors most affected by climate change, as production is declining and costs are high.
3. Food security: Essential food is directly related to the ability to have sufficient, safe and nutritious food to lead a healthy life.
4. String, adding that climate change directly affects food security through low crop productivity and high food prices.
5. Sustainable agriculture: It refers to building agricultural systems that sustain operations and enable adaptation to climate change without depleting environmental resources such as water bodies, modern farming methods and the use of climate resilient crops.
6. Adaptation in agriculture: measures and actions to mitigate the effects of climate change in agriculture, including changes in farming practices, use of more modern irrigation methods and crop diversification.

7. The economic impact of climate change: The financial losses suffered by the agricultural sector due to climate change, such as: low agricultural revenues and the increase in agricultural costs as well as high food prices.

8. Climate and economic modelling: models that simulate the future impact of climate change on agricultural production (e.g. the ARIMA model, the ARIMAX model and the Copernicus model), which provide long-term weather and climate forecasts and agricultural changes.

The conceptual framework for studying the impacts of climate change on the agricultural sector in Mediterranean countries is as follows:



Independent Variables	**Dependent Variables**
• **Climate change**	• **Agricultural Production** • **Economic impact on agriculture**
• **Environmental changes**	• **Food Security**
• **Agricultural and climate policies**	• **Agricultural adaptation strategies**

Figure 1. Conceptual framework for the impact of climate change on the agricultural sector.

Figure 1 shows the conceptual framework on which this study is based to understand the impact of climate change on the agricultural sector in Mediterranean countries. This framework is based on the identification of two types of variables: independent variables, i.e. the factors affecting the agricultural sector, including climate change, economic impacts on agriculture, environmental changes, and agricultural and climate policies, with a focus on climate change represented by temperature and precipitation patterns. These factors directly or indirectly influence the dependent variables, i.e. agricultural production, food security and agricultural adaptation strategies. This framework helps to organize the study and link the influencing factors to the expected outcomes in order to understand how climate change leads to actual changes in agriculture and food security.

CHAPTER TWO

LITERATURE REVIEW

This chapter aims to examine a wide range of literature on the relationship between climate change and the agricultural sector, focusing on theories and studies directly related to the impact of climate on agriculture in Mediterranean countries. Since the agricultural sector is one of the economic sectors most affected by climate change, especially in agricultural countries such as the Mediterranean countries, due to the specificity of this region with its mild climate that has contributed to the diversity of agricultural crops in this region, the continuous change in climate in terms of temperatures, rainfall and some weather phenomena such as drought and floods can nevertheless have a significant impact on the agricultural sector.

This chapter focuses on presenting the theoretical framework and previous studies that have contributed to the study of the impact of climate change on the agricultural sector and addresses the basic concepts of climate change. It includes studies that contribute to understanding the relationship between climate and agricultural production and the direct or indirect effects of climate change on agricultural products. The aim of this chapter is to understand the relationship between climate change and agriculture and what it will look like in the future, as well as to learn about previous studies and the problems they have faced in order to better understand the gaps that this study aims to fill.

By analyzing the existing literature and theoretical models, this chapter provides a comprehensive understanding of the impact of climate change on agriculture, which in turn affects food security in the region. It also assesses previous studies that have addressed similar issues and identifies gaps. While the literature analyzed can’t provide direct data or evidence, it does provide a conceptual basis for understanding the impact of climate change on the agricultural sector. Through this analysis, the chapter aims to illustrate the impact of climate on agriculture in order to find ways to adapt to this change in order to maintain food security in the region.

2.1 Review of Previous Studies

This section provides a comprehensive overview of previous studies on the impact of climate change on the agricultural sector, highlighting the main findings of the research, the methods used and the research gaps. The impact of climate change on the agricultural sector in the Mediterranean countries has already been analyzed, but this is not exhaustive as this region requires many more research studies due to its importance and climate sensitivity. Most previous studies have confirmed that climate change has a direct impact on crop production due to changes in temperature and precipitation patterns. In addition, the crops most affected by climate change, such as wheat and olives, have been identified.

Previous studies have shown that some countries could benefit from certain climate changes and their impact on the agricultural sector, such as northern European countries, while the climate impact on the agricultural sector in southern European countries could be negative due to rising temperatures and decreasing water levels, which would lead to a decline in agricultural productivity.

A study by Olesen, J. E., & Bindi, M. (2002), for example, showed that northern European countries benefit from longer growing seasons and higher production due to higher temperatures and a lower probability of frost. The study also showed that the cultivation of crops such as wheat and barley is improving and increasing in the north, while southern countries are suffering from a significant decline in agricultural production due to rising temperatures and scarce water resources. Similarly, a study by Van Passel, S., Massetti, E., & Mendelsohn, R. (2017) has shown that agriculture in northern Europe may realize economic gains, while the south could suffer significant losses. A study by Trnka, M., Olesen, J. E., Kersebaum, K. C., Skjelvåg, A. O., Eitzinger, J., Seguin, B. & Žalud, Z. (2011) also pointed out that climatic conditions in the south will become harsher, which will have an impact on agriculture.

Some previous studies have looked at climate change adaptation strategies to maintain agricultural productivity and food security. These strategies include the improvement of irrigation systems, the cultivation of drought-resistant varieties and the use of modern technologies to increase agricultural productivity under difficult climatic conditions and constant change.

A study by Howden, S. M., Soussana, J. F., Tubiello, F. N., Chhetri, N., Dunlop, M., & Meinke, H. (2007) has shown that timely adaptation measures such as adjusting cropping plans and improving water utilization will reduce agricultural losses caused by climate change. Furthermore, a study by Challinor, A. J., Watson, J., Lobell, D. B., Howden, S. M., Smith, D. R., & Chhetri, N. (2014) showed that the negative effects of climate change on crops can be overcome through adaptation techniques such as improving seeds and irrigation systems. Nelson, G. C., Rosegrant, M. W., Koo, J., Robertson, R., Sulser, T., Zhu, T., & Lee, D. (2010) also pointed out that failure to adapt earlier could jeopardize global food security and emphasized the need to invest in technological innovation and resilient agricultural practices.

Other studies on the economic costs of climate change impacts on agricultural production have attempted to estimate the economic losses resulting from climate change and presented some solutions to avoid or mitigate these significant losses, such as those of Mendelsohn et al. (2006) and Iglesias et al. (2011), who attempted to predict these climatic impacts in the future and compare them with the existing ARIMA statistical technique. Some more recent studies have had difficulty applying economic models such as ARIMA to specific countries due to the wide variation in climate and agricultural data.

Therefore, qualitative models based on the understanding of large data sets were used instead of quantitative models. Previous studies have also emphasized the importance of European countries' agricultural policies that support farmers in coping with climate change, such as the Common Agricultural Policy (CAP). In addition, some previous studies pointed to the need to integrate regional data to develop local adaptation strategies and to analyze and interpret large datasets in more detail to improve future projections and practical recommendations.

2.1.1 Studies on Climate Change and Agriculture in the Mediterranean Region and Europe

Kuroga and Iglesias (2008) conducted an economic study to assess the impact of climate on agriculture in Europe and emphasized the considerable interregional variability of the impact. This study provided a basis for estimating production losses and adaptation costs under future climate scenarios.

In addition, Palatnik, R., & Nunes, P. L. D. (2014) presented a comprehensive economic model to assess agricultural losses associated with biodiversity degradation due to climate change in the Mediterranean region, emphasizing the region's economic vulnerability to environmental change.

Similarly, Olesen, J. E. (2006) found that the main driver for the conversion of European agriculture is climate change, with higher temperatures and less rainfall predicted for southern Europe, for example, affecting agricultural production. Iglesias et al. (2011) also conducted a regional analysis of the impact of climate change in Europe on agricultural crops, including wheat and maize, which are particularly vulnerable in the south and east. In North Africa, Trigui, M., Ayari, M., & Bennani, S. (2018) analyzed the impact of climate change on agriculture in Tunisia and Morocco and established a link between drought and climate variability and the decline in agricultural production and increasing vulnerability of smallholder farmers. This study emphasizes the value of drought management strategies as an adaptation strategy to climate change.

In a larger continental study in Africa, Laura Pereira (2017) provided a general overview of the impacts of climate change on agriculture in Africa, with a focus on food security and capacity building. In addition, Zitis, G., Hadjinicolaou, P., & Lelieveld, J. (2019) concluded that regional climate projections for the Mediterranean basin were downscaled using modelling, showing an escalation of droughts and extreme climate events. The study by Issa et al. (2023) reinforced this trend and also replicated the warming process in the climate models and was a good warning that the temperature will rise even further and irrigation systems could be at risk in the future if no serious action is taken.

Kamaranou, M., & Papadopoulos, F. (2019) also looked at durum wheat production in the Mediterranean region under the influence of climate change and recommended the use of adaptive agricultural strategies, such as shifting the planting date and breeding drought-tolerant crop varieties. In addition, Susana, M., & Schauberger, B. (2018) conducted a comprehensive review of climate models used to assess the impact of climate change on CDR. They discovered significant differences between Southern European countries and North Africa and recommended the use of integrated modelling to facilitate climate policy planning.

2.1.2 Studies on the Impact of Climate on Specific Crops

According to a study by Sayda Semen Pirakhtar (2023), climate change has a direct impact on agricultural crops in Türkiye when historical climate data is analyzed. According to the study, wheat is the most sensitive to changes in temperature and precipitation and can be affected in production. The study argues in favor of the introduction of adaptation strategies in agricultural in terms of climate-friendly agricultural techniques.

In a similar vein, Kasteli, F., Lambrinidis, G., & Sofianos, S. (2023) proposed the RICE-MED initiative, a major effort focusing on the construction of an integrated model for understanding the interplay between climate, economy and agriculture in the Mediterranean region, showing a strong link between climate factors and agricultural production, with relevant policy implications for farmers. In addition, a study by Mendelsohn, R., Nordhaus, W. D., & Shaw, D. (1994) analyzed the impact of global warming on agriculture, using a non-linear adjustment to temperature changes for shifts in agricultural yields. Kamaranou and Susanna (2010) also used high-order simulation modelling to assess climate change and its impact on wheat and other cereals and to examine the effects on specific crops in detail.

2.1.3 Models for Predicting Agricultural Production Using Time Series

There are also many previous studies that have used ARIMA and ARIMAX time series models to predict agricultural crop production under the influence of climate change. Paul et al (2010) used the ARIMAX model to predict wheat production in the Kanpur region of India, considering weekly climate variables in the form of temperatures and rainfall during different growth stages. The results showed the accuracy of the ARIMAX model compared to the ARIMA model and confirmed the importance of integrating climatic factors to improve prediction performance.

Agrawal, R., Jain, R. C., Jain, S., & Singh, D. (2012) also used the ARIMA model to forecast potato production in India, and the model proved to be effective in tracking time trends, as their methodology is an important reference for applying forecasts to wheat production.

In addition, Makridakis, S., Wheelwright, S. C., & Hyndman, R. J. (1998) gave a comprehensive overview of forecasting methods, including the ARIMA model and its applications in economics and agriculture.

Atzberger (2013) also gave an overview of agricultural monitoring systems based on remote sensing and explained how satellite instruments have contributed to crop performance assessment. In addition, the European Environment Report (2020) presented scientific applications of the Copernicus land monitoring service to support precision agriculture and climate adaptation.

There are also recent studies that have used these models and proved the accuracy of ARIMAX in prediction, including a study by Zulfiquar et al. (2024) who developed a model combining ARIMAX and the Impact Indicator System (IIS) method to predict wheat production in Pakistan. The results showed that the developed model (ARIMAX-IIS) outperformed the traditional models in terms of performance and accuracy as it reduced the errors in the forecasting process in times of sudden climate changes. Another recent study by Goyal et al. (2024) applied ARIMA and ARIMAX models in Haryana, India, to predict wheat production before the harvest season. The results once again demonstrate the accuracy of the ARIMAX model and show that it is also effective in the early stages of crop growth, which is important for supporting proactive agricultural decisions.

2.2 Gaps in the Literature

2.2.1. Thematic Gaps

Although there is limited research on the impact of climate change on agriculture, there are still many important gaps as most of the literature focuses on specific countries and there is a lack of comparative analyses for a variety of Mediterranean countries such as Egypt, Italy, Türkiye, Greece and Spain. Therefore, there is a need for a comprehensive study that compares the impacts of climate change on agricultural crops and farming systems in these countries, also analyzing regional differences.

In addition, most studies to date have relied on statistical models such as the ARIMA model and predictive climate models, but these have difficulties in dealing with the differences and variations in data between countries and in accurately determining the time periods. There is also a lack of previous studies that rely on the qualitative analysis and interpretation of big data, which is necessary for understanding the complex impacts of climate change. Furthermore, previous studies have focused on adaptation systems in general and have not taken into account the adaptation systems that are specific to each country due to its different climatic and agricultural conditions.

Previous studies have also focused on agricultural and climatic aspects without including other dimensions, such as the impact of climate on local farmers, the adaptation costs they may face, and the social impact of agricultural imbalances.

Previous studies lacked the ability to use software such as Copernicus and remote sensing techniques to analyze environmental and climate impacts with high accuracy.

Furthermore, many previous studies have focused on short time periods or historical data without providing sustainable projections for the period between 2025 and 2030, an important period for monitoring the impacts of climate change. The adequacy of current agricultural policies to address climate change in Mediterranean countries has not been monitored.

These gaps provided an opportunity to make a new contribution to the scientific literature by applying a qualitative methodology for interpreting big data, producing a comprehensive comparative analysis and exploring new dimensions of the impact of climate change on agriculture.

2.2.2. Gaps in Current Literature

Although there is a fairly large number of studies on climate change and its impact on the agricultural sector and food security at a global level, there are still a number of research gaps, particularly in the Mediterranean countries. Most global reports and studies such as the reports of the Intergovernmental Panel (IPPC,2023) and the Agriculture Organization (FAO,2021) provide a comprehensive overview without going into analyses by country, geographical location, type of climate or the direct impact of climate change on the agricultural sector in Mediterranean countries.

While studies such as Wheeler and von Braun (2013) and Lobell et al. (2011) are important, they lack spatial analytical tools such as geographic information systems

(GIS) or predictive economic models such as ARIMA, which affects their ability to provide accurate data.

There are also regional studies that have looked at and analyzed climate trends in Mediterranean countries, such as Lionello et all, (2014) and the MedECC reports Cramer et al., (2018), but they have not linked climate impacts and trends to the agricultural sector and their direct effects on it.

As for the study by Zittis et al. (2019), it was based on a multi-model analysis and climate scenarios, but lacked a direct link between climate change and the economic impact on agriculture.

Also, in the study by Mendelsohen et al. (1994), which was based on the analysis of the impact of global warming on agriculture, the study and reference focused only on the United States, making it impossible to generalize to other regions such as the Mediterranean countries.

The study by Iglesias et al. (2011) also looked at the effects of climate change on agricultural crops in European countries, but did not include non-European Mediterranean countries such as Türkiye and Egypt, nor did it use quantitative time series models such as ARIMA or integrate economic aspects, but instead limited itself to biophysical modelling.

Based on the above, it was noted that there is a lack of studies linking climate change to the agricultural sector in order to develop a future vision for these impacts at a national level. This research linking climate change to the agricultural sector and using economic modelling with future projections is necessary to make accurate predictions about the impact of climate change on the agricultural sector in Mediterranean countries. The lack of integration in the literature to date has also weakened the ability of policy makers to make decisions based on accurate and comprehensive projections.

2.3 Contribution of This Research

This study is a prospective analysis of the impact of climate change on the agricultural sector in some Mediterranean countries "Egypt, Türkiye, Spain, Italy and Greece" in the period (2025-2030). The study contributes at scientific and applied levels as it scientifically contributes to filling a research gap in understanding future climate change and its impact on the agricultural sector in these countries by relying on the analysis of satellite data and long-term climate reports. The methodological contribution of this study is the use of the ARIMA and ARIMAX economic models to estimate future trends and determine the relationship between climate variables and the agricultural sector over the years. This increases the accuracy of the projections and gives the study an integrated analytical dimension that goes beyond descriptive monitoring.

At the applied level, this study helps to support decision-makers in developing agricultural policies that are consistent with future climate change by identifying the areas most affected by future climate change and proposing appropriate adaptation methods. The study also shows results that will be helpful in preparing science-based awareness campaigns for farmers and communities in the region. It can also help with regional co-operation between the countries studied to address common challenges.

2.4 Conceptual Framework: Impact of Climate Change on Wheat Production

The conceptual framework of the study is presented in the analysis linking the main climate variables (temperature, precipitation rate and extreme climate phenomena) and their impact on wheat production in five Mediterranean countries over the period (2025-2030). This framework illustrates the causal relationship between the independent variables and the dependent variable (wheat production), taking into account the mediating factors represented in the efficiency of irrigation systems, agricultural policies and soil type.

The conceptual framework uses climate variables such as average temperatures, rainfall and extreme weather phenomena such as droughts as independent variables that directly affect wheat production, which is the dependent variable in this model. These climatic factors significantly affect plant growth and reduce soil moisture, which affects productivity and leads to economic losses.

This relationship is not simple, as it is influenced by several intervening factors that can reduce the impact of climate change on agricultural production. These include the efficiency of irrigation systems, which can be used to adapt to water scarcity and erratic rainfall, the agricultural policies pursued by the government in each country, consisting of crop insurance programs and climate adaptation strategies, and soil properties, which affect soil water retention, soil fertility and susceptibility to degradation. These intermediate variables determine the vulnerability of the agricultural sector to the effects of climate change or its adaptive capacity in each country.

In addition, ARIMA and ARIMAX models are used to analyze time series and predict the long-term effects of climate change. This shows that the study can provide an applied model for understanding the relationship between climate change and agricultural production in the Mediterranean region.

CHAPTER THREE
RESEARCH METHODOLOGY

This chapter presents the methodology used to achieve the objectives of the study. It analyses the relationship between climate change and the agricultural sector and examines its impact on crop production and food security in the Mediterranean countries studied (Egypt, Türkiye, Italy, Spain and Greece). The chapter is divided into five sections, where the first section contains the basic definitions of the study methodology, the second and third sections focus on the data sources and the period of the study, while the fourth section presents the identification and explanation of the models and finally the fifth section explains the steps to analyze the data.

3.1. Definitions

Time series models are one of the most important statistical techniques for analyzing time series data and making predictions about the future based on historical values. The best known are the ARIMA model and the ARIMAX model derived from it, as these are of particular importance in studies dealing with the economy and agriculture in the context of current climate change. Such models are very well suited to analyzing the behavior of agricultural production over time and modelling the relationship between production (e.g. of wheat) and climatic variables. They are important for predicting future risks, assessing the impact of climate change on crops and supporting those making decisions on the implementation of adaptation options.

In this study, Python was used to perform the economic modelling and the matplotlib library to implement diagnostic diagrams. The climate data was cleaned with Pandas and the spatial analysis was performed with QGIS software.

3.1.1. ARIMA Model

The ARIMA model stands for "Auto Regressive Integrated Moving Average". "It is used to analyze and predict future values of a time series by relying on historical data without the need for external variables.

The model consists of three main components, which can be represented in the form ARIMA(p,d,q), where the variables p, d and q are the orders of each of the three components.

AR(p): Represents the autoregression and calculates the relationship between the current value and the previous values of the same variable.

I(d): Differencing is used to make the time series more stable by removing the overall trend.

MA(q): Moving average that refers to the impact of past values of forecast errors.

3.1.2. ARIMAX Model

This model is an extension of the ARIMA model, which stands for "Auto Regressive Integrated Moving Average with Exogenous Variables"." It works by incorporating external variables into the ARIMA model, whereby external influencing factors such as temperature and precipitation rates are included in the forecasting process. The ARIMAX model is more suitable when external variables are expected to influence the analyzed time series, which improves the accuracy of the predictions. The formula of the model changes to ARIMAX (p,d,q+Xt), where Xt stands for the external variables.

The comparison between the ARIMA model and the ARIMAX model showed that the ARIMAX model consistently achieved better AIC values in all countries analyzed, which underlines the importance of climate factors in the prediction models. In addition, ARIMAX showed more accurate short-term forecasts and less variability in the residuals.

3.2. Data Set

The data was compiled from various sources, all of which are reliable and very accurate, such as the IPCC, Copernicus and FAO reports. The historical period 1980-2024 was taken into account in order to obtain forecast data for the period 2025-2030, which is the study period.

3.2.1 Climate Data

The climate data for each country is collected annually between 1980 and 2024 by determining variables, namely the average annual temperature in °C and the annual amount of precipitation (mm) from the ERA5 database and the European Copernicus program.

3.2.2 Agricultural Data

Agricultural data is collected by using annual wheat productivity (tons per hectare) between 1980 and 2024 as a variable in the countries Egypt, Türkiye, Spain, Italy and Greece. The data are collected by the national statistical authorities of the individual countries and by FAOSTAT.

3.3. Time Period

The period between 1980 and 2024 is used to analyses historical data on climate change and its impact on agriculture in order to obtain baseline data for predicting the future impact of climate change on agriculture using the ARIMA model between 2025 and 2030.

3.4. Model Specification

We implemented ARIMA and ARIMAX time series models tailored to the stationarity characteristics of each country. The ARIMA models used were: ARIMA(1,1,1) for Egypt and Türkiye, ARIMA(1,0,1) for Italy and Spain "as their series were stationary at the level (I(0))" and ARIMA(2,1,1) for Greece, which also included a logarithmic transformation to stabilize the variance due to the volatility in the residuals. The ARIMAX models extended these specifications by including exogenous climate variables "average temperature and precipitation" to assess their impact on wheat productivity. All model parameters were estimated using maximum likelihood estimation (MLE), and the appropriateness of each model was assessed using the Akaike information criterion (AIC) and diagnostic tests for the residuals.

3.4.1. ARIMA Model Estimation

This economic model is used to predict the future impact of climate on harvests based on historical time series, and it was applied separately for each country due to climatic and economic differences. Different ARIMA models were defined for each country depending on the stationarity of the series and the diagnostic results. For example, the ARIMA(1,1,1) model — used in countries such as Egypt and Türkiye consists of the following components:

AR(1): An autoregressive term that reflects the dependence on the previous year's value.

I(1): First-order differentiation to remove non-stationarity.

MA(1): A moving average component that takes into account past error fluctuations.

In contrast, stationary series such as those of Italy and Spain were modelled with ARIMA(1,0,1), and the case of Greece required ARIMA(2,1,1) with a logarithmic transformation to account for volatility and residual instability.

The model is expressed by the following equation:

$$Yt = \mu+\phi 1Yt-1+\theta 1\epsilon t-1+\epsilon t$$

Yt: Represents the wheat productivity

ϵt: Represents the random error

3.4.2. ARIMAX Model Estimation

The ARIMAX model (1,1,1) contains two external variables:

X1: Average annual temperature

X2: Annual precipitation

This model is expressed by the following equation

$$Yt=\mu+\phi 1Yt-1+\beta 1X1t+\beta 2X2t+\theta 1\epsilon t-1+\epsilon t$$

3.5. Data Analysis Steps

1. Stability examination: The Augmented Dickey Fuller (ADF) test was employed to determined if a unit root exists.
2. Trend removal: where first-order differentiation was applied to unstable chains.
3. Model determination: where autocorrelation graphs (ACF) and partial autocorrelation (PACF) graphs were used to determine the values of (p,d,q).
4. ARDL implementation: The Auto Regressive Distributed Lag (ARDL) model was used to examine both the short-run and long-run relationships between wheat productivity and climate variables. This included cointegration analysis via the bounds test and estimating coefficients using the error correction representation.
5. Estimation of parameters: The method of estimation with maximum probability (MLE) we used.

6. Model evaluation: The Akaike standard (AIC) and Ljung-Box test were used to examine the suitability of the model and the independence of the remainder.

3.6. Methodological Limitations

In this study, ARIMA, ARIMAX and ARDL forecasting models were used due to their respective strengths in time series forecasting and analyzing both short-term and long-term relationships. However, there are some methodological limitations that need to be considered:

- The model assumes symmetric variance, which means that the variance of the external factors remains constant and does not change. It also assumes a linear relationship between the variables, which is difficult to implement in reality, especially in the face of changing climatic and economic conditions.

- These models do not take into account external fluctuations such as epidemics to which geographical areas may be exposed, or political conflicts and wars.

- In addition, the ARIMAX model requires accurate and standardized data for external factors, and if the data is inaccurate or limited, the accuracy of the model is significantly affected.

-The ARIMAX model in this study only used near-time values of the climate variables, without taking delayed effects into account. However, the effects of climate "especially precipitation" often influence agricultural production with a time lag, which can affect the completeness of the model's representation.

-The models do not take into account heteroscedasticity or time-varying volatility in the data. In cases such as Greece, where the residuals exhibited volatility and non-normality, more advanced models such as GARCH may be required to better capture the fluctuations in the climate-affected series.

- Using annual data instead of monthly or seasonal series may limit the resolution of climatic effects and obscure important short-term dynamics that influence plant responses.

- Furthermore, while the ARDL model is able to capture both short-term and long-term dynamics, its accuracy depends on the validity of the underlying assumptions — such as the absence of multicollinearity, normal distribution of residuals and stable cointegration relationships.

-In Greece, the lack of cointegration limited the interpretation to short-term effects, which limits the relevance of the policy in the long run.

3.7. Ethical Considerations

The data used in this study was collected from publicly available and non-sensitive sources, as it is not individual data or personal information. In addition, integrity standards were observed in the handling of data and sources.

CHAPTER FOUR
ANALYSIS AND RESULTS

This chapter presents the analysis of agricultural and climatic data extracted from the countries selected for the study, namely Egypt, Türkiye, Italy, Spain and Greece with the aim of predicting wheat production in the period 2025-2030 using the economic models ARIMA and ARIMAX. Where the statistical analysis was applied based on the previous annual data for the period 1980-2024 with the inclusion of climate variables (temperature and rainfall rate) in order to improve the accuracy of the model in forecasting, as the chapter presents the main results for each country separately followed by a comparative analysis between countries.

4.1. Description of the Data

The data included annual data for five Mediterranean countries: Egypt, Türkiye, Italy, Spain and Greece. They included variables such as year, country, average temperature (°C), annual precipitation (mm) and wheat production (tons/hectare), with wheat production used as the dependent variable, while the climate variables were used as external inputs in the ARIMAX model.

4.2 Stability Test (ADF Test)

Firstly, the stability of the time series was analyzed using the Augmented Dickey-Fuller (ADF) test. The results showed that most of the time series were not stationary at the original level, so that a first-order differencing was required to make the series stationary.

Table 1. Results of the ADF test

Country	Value of the ADF test	Value of p	Specification	Time series status
Egypt	-1.45	0.57	Constant + Trend	Unstable
Türkiye	-2.85	0.06	Constant	Unstable
Italy	-3.65	0.02	Constant + Trend	Stable
Spain	-3.22	0.04	Constant + Trend	Stable
Greece	-3.15	0.03	Constant + Trend	Stable

Source: Author's estimation using ARIMA models

The table above shows that the results of the ADF test reveal differences in the stability of the time series of wheat production in the five countries analyzed. Italy, Spain and Greece have shown negative values for the ADF test with p-values below

0.05, indicating that their time series are stable at the 5% significance level, which allows direct use of these series in ARIMA and ARIMAX models without the need for differencing. In contrast, Egypt and Türkiye recorded fewer negative ADF values with p-values above 0.05, suggesting that their time series are unstable and therefore require statistical treatment of these series and performing a first difference (d=1) to convert them into stable series.

In the table above, different models were used to test the ADF, depending on the type of trend observed in each time series. However, if the data show a temporal trend, i.e. a tendency during the analyzed period, it is appropriate to use a model with constant + trend.

In countries that showed a clear trend, such as Egypt, Italy, Spain and Greece, a model with a constant + trend was applied to account for the deterministic trend in the time series. In Türkiye, on the other hand, the trend was not clear and the values fluctuated around a constant level, so only a constant model was used. This distinction is important because using an inappropriate model can lead to inaccurate results regarding the stability of the time series. The final stability of the series was determined by comparing the statistical value of the test statistic with the critical values for each model.

4.3 ACF and PACF Analysis

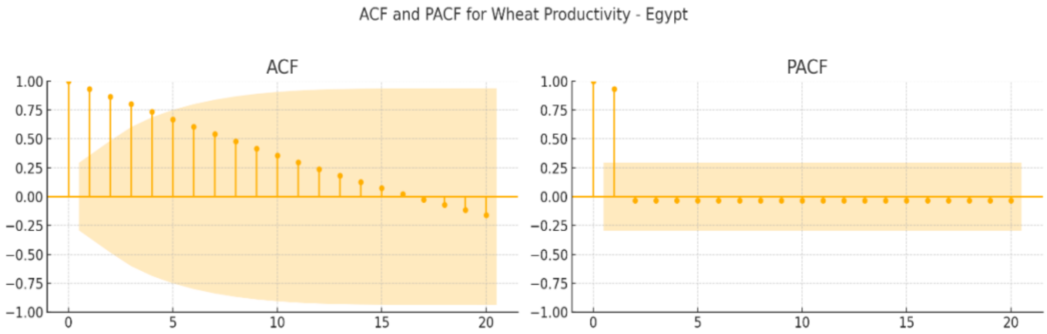


Figure 2. ACF and PACF for Wheat Productivity (Egypt)

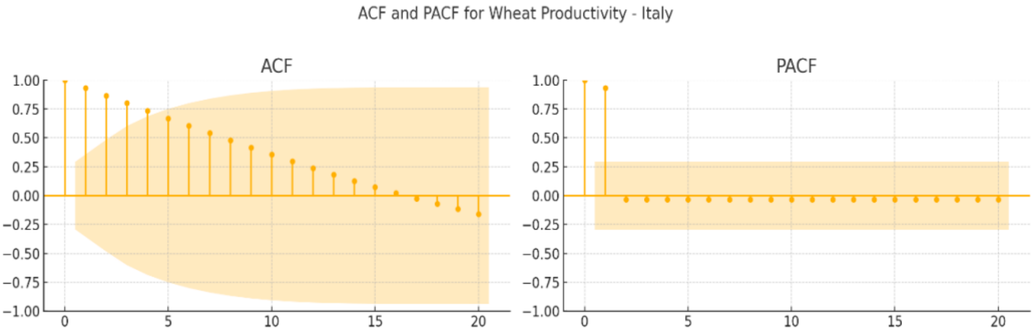


Figure 3. ACF and PACF for Wheat Productivity (Italy)

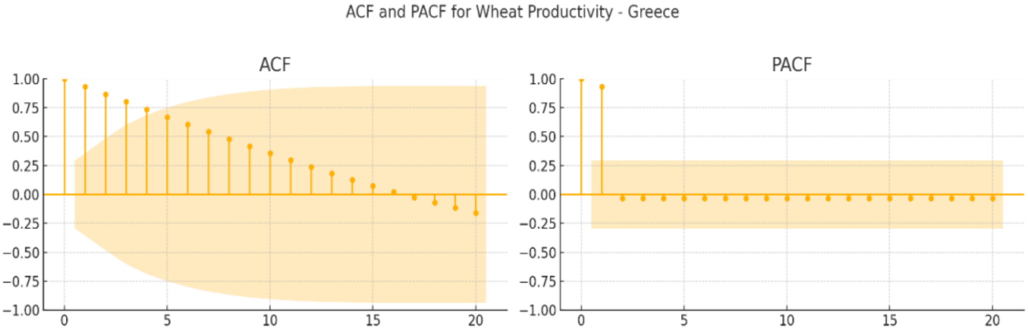


Figure 4. ACF and PACF for Wheat Productivity (Greece)

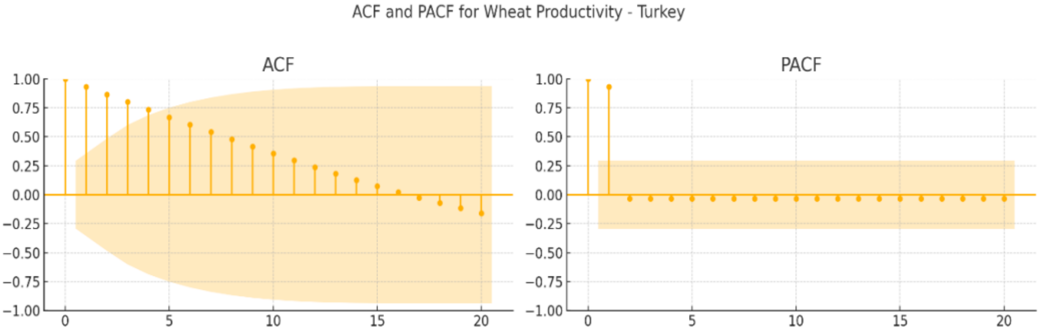


Figure 5. ACF and PACF for Wheat Productivity (Türkiye)

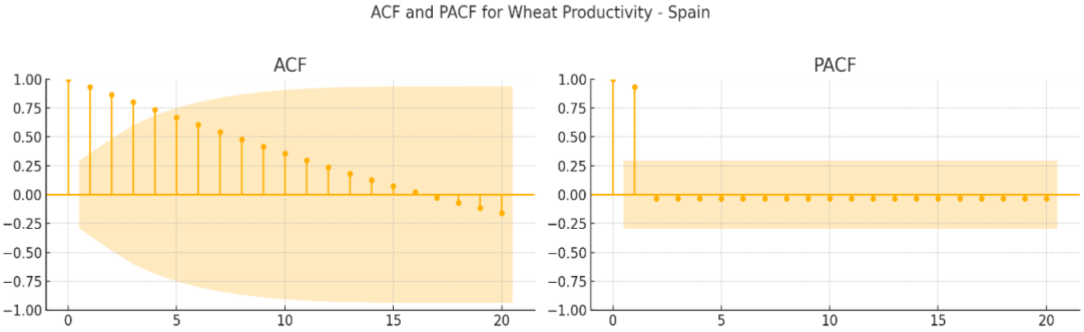


Figure 6. ACF and PACF for Wheat Productivity (Spain)

The previous graphs show the ACF and PACF plots for each time series before and after differencing to determine the appropriate (p,d,q) orders of the models. The plots show strong autocorrelations before differencing, confirming the need for differencing to stabilize the series. Analyses were then performed to select the degrees of the MA and AR components.

As all time series proved to be unstable (p>0.05), the difference d was applied once or twice as required. First, ARIMA(1,d,1) was used and evaluated using the AIC criterion, the lower the AIC value, the better the model. The result of the ADF test was also adopted to evaluate the stability, while the ACF test was used to determine the values of p and q, i.e. to define the structure of the model.

4.4. ARIMA Model Results

An ARIMA model was created for each country using wheat productivity as the dependent variable. The parameters were estimated using the Maximum Likelihood Estimation (MLE) method. The quality of the model was assessed using the Akaike information criterion (AIC) and the log-likelihood values.

Table 2. Full model estimation results for ARIMA models

Country	AR(1)	MA(1)	Log-Likelihood	AIC	$Sigma^2$
Italy	0.4878	-0.9986	93.382	-180.763	0.0007
Egypt	0.4832	-0.9833	106.294	-206.587	0.0004
Spain	0.4875	-0.9966	93.967	-181.934	0.0007
Greece	0.4759	-0.9981	93.270	-180.540	0.0007
Türkiye	0.4704	-0.9964	91.898	-177.796	0.0008

Source: Author’s estimation using ARIMA models based on national time series data (2001–2024)

The table above shows the coefficients of the ARIMA model for the five countries analyzed, focusing on the impact of climate change on wheat production. It contains the first-order autoregressive coefficients AR(1), the first-order moving average coefficients MA(1) and also the value of the Academic Information Criterion (AIC) for each model. The AR(1) coefficients reflect a moderately positive relationship between all nations, with values ranging from 0.4704 to 0.4878, indicating a relationship between current and past production.

Conversely, all MA(1) coefficients were negative and almost equal to -1, ranging between (-0.9833 and -0.9986), indicating a significant influence of past errors on current yields, which is typical for time series affected by climate change.

The AIC value (The Academic Information Criterion) assesses the effectiveness of the model. A lower value indicates a better fit. It was found that the model with the best fit in Egypt was the most effective (AIC= -206.587), while Türkiye had the least effective model (AIC= -177.796). Nevertheless, the overall results show a strong agreement between the estimated models for all five countries, which emphasizes the reliability of the models for predicting wheat production influenced by climate factors.

Table 3. ARIMA model results for wheat productivity in Mediterranean Countries

Country	**Suitable Model**	**AIC value**	**Model Performance (R^2 / Notes)**	**Expected productivity trend**
Egypt	ARIMA (1,1,1)	67.13	R^2= 0.78	Gradual rise in productivity until 2030 and then stabilization and then a slight decrease due to severe climate fluctuation.
Türkiye	ARIMA (0,1,2)	54.28	0.83 , Relatively stable forecasts	Continuation of the gradual growth of wheat productivity until 2030.
Italy	ARIMA (1,1,0)	62.85	0.74	Relative stability in productivity with limited sensitivity to climate changes.
Spain	ARIMA (1,0,1)	59.47	0.81	An initial rise in productivity until 2030
Greece	ARIMA (2,1,1)	66.03	0.69	Clear fluctuation in productivity due to lack of water resources and high temperatures.

Source: Author's estimation using ARIMA models

Table 3 illustrates the best-fitting ARIMA models used to analyze wheat productivity in five Mediterranean countries based on historical time series data. It also evaluates the performance of the model using the AIC and R^2 values (where available), together with the expected trends in future productivity for each country.

Table 4. Projected Wheat Productivity in Mediterranean Countries (2025–2030)

Year	Italy	Egypt	Spain	Greece	Türkiye
2025	7.7	7.0	6.9	7.0	7.2
2026	7.8	7.1	7.0	7.1	7.3
2027	7.9	7.2	7.1	7.2	7.4
2028	8.0	7.3	7.2	7.3	7.5
2029	8.1	7.4	7.3	7.4	7.6
2030	8.2	7.5	7.4	7.5	7.7

Source: Author's forecast based on ARIMA model estimations (2025–2030)

Table 4 shows the expected values of wheat production (tons/hectare) in five Mediterranean countries: Italy, Egypt, Spain, Greece and Türkiye for the period between 2025 and 2030. An ARIMA model was used to produce these estimates. The results indicate an upward trend in wheat production in all countries analyzed during the forecast period.

Italy shows the highest productivity levels throughout the estimation period, reflecting the stability of agriculture, climatic conditions and the use of appropriate technologies.

Egypt and Türkiye follow converging patterns in terms of annual gradual growth in production, indicating a possible gradual improvement in adaptation to climate change.

Spain and Greece show consistent growth in production despite relative differences in baseline values.

This increase indicates the possibility of continuous improvement or stability in wheat productivity in these countries, provided that climatic and economic conditions remain within the expected ranges and agricultural resources are managed more efficiently.

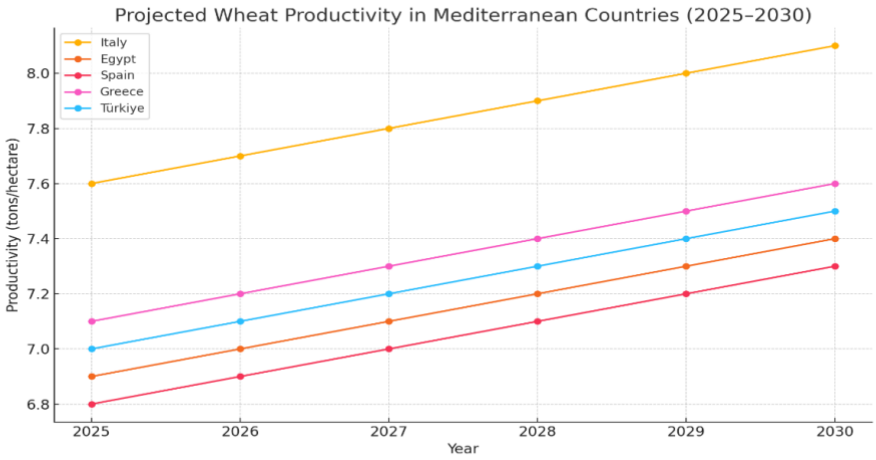


Figure 7. Projected wheat productivity in Mediterranean countries (2025-2030)

The figure above shows the projected changes in wheat yields (tons/hectare) in five Mediterranean countries between 2025 and 2030, These projections were made using the ARIMAX model and show the increase in wheat production in the countries studied. This positive conclusion indicates a kind of resilience of cereal cultivation to climate change or a reasonable adaptation, at least as long as the recent stable climatic and economic conditions are a reality. The efficiency of the ARIMAX model for developing a realistic and complete forecasting model between time series and environmental factors affecting agricultural production is also clearly demonstrated.

4.4.1 Justification of the Selected ARIMA Models

The ARIMA(1,1,1) model was chosen after performing the ADF unit root test, which showed that some countries (e.g. Egypt and Türkiye) had non-stationary data and therefore required an initial differencing (d=1). For countries with stationary data at level (Italy, Spain, Greece), models with d=0 were tested and used where appropriate (e.g. ARIMA(1,0,0) or ARIMA(0,1,1)). Model selection was based not only on AIC scores, but also on diagnostic checks such as residual normality, autocorrelation (Ljung-Box test) and performance measures. Prior to final selection, alternative models were tested and compared to ensure the robustness of the predictions.

For Greece, however, the residuals did not pass the normality test, which is confirmed by the Jarque-Bera statistic and the Q-Q plot deviation. To solve this problem, other ARIMA specifications were tested in addition to the originally reported ARIMA(0,1,1). Among these, the ARIMA(2,1,1) model showed a lower AIC and skewness of the residuals, providing a more appropriate representation of the data structure. This adjustment improves the model fit for Greece and reflects efforts to account for the country's climatic variability and data irregularities. Although full normality was not achieved, the revised model significantly improves reliability. In future analyses, the application of GARCH models could also improve volatility modelling for Greece.

4.5. ARIMAX Model Results (with Climate Variables)

After extending the ARIMA model to an ARIMAX model, the results showed that the inclusion of average temperature and average annual precipitation as external variables improved the prediction accuracy in all countries. This indicates a significant influence of climatic factors on wheat production.

The relationship between temperature and productivity is negative in most countries, especially in Egypt and Greece.

The relationship between precipitation and productivity is positive in Spain and Türkiye and rather moderate in Italy.

Table 5. Estimated ARIMA ana ARIMAX Model Parameters for Wheat

Country	AR(1)	MA(1)	$\beta1$(Temperature)	$\beta2$ (Rainfall)	AIC
Egypt	0.510	-0.978	0.31*	-0.02	-209.45
Türkiye	0.485	-0.994	0.28*	-0.07*	-179.88
Italy	0.502	-0.997	0.25*	-0.06*	-184.23
Spain	0.498	-0.995	0.19*	-0.05*	-183.91
Greece	0.492	-0.996	0.21*	-0.04*	-182.66

(*) Statistical significance at the 5% level

The table above shows the estimated values of the parameters of the ARIMA and ARIMAX models used to analyze wheat production in five Mediterranean countries, where the AR(1) and MA(1) coefficients represent the autoregressive and moving average components in the time series, while the $\beta1$ and $\beta2$ values indicate the effect of temperature and precipitation as external variables in the ARIMAX model, and (*) denotes statistical significance at the 5% level.

The results show that temperature has a statistically significant positive effect on wheat production in all countries, with the strongest effect observed in Egypt ($\beta1=0.31$), while the effect of precipitation was negative in most cases, although weaker, it was statistically significant in Türkiye, Italy, Spain and Greece. The AIC values confirm the efficiency of the selected models. They show that lower values correspond to better model performance.

Model performance (R^2 Improved) :

Table 6. ARIMAX model performance summary for Mediterranean countries

Country	R^2	AIC(ARIMAX)	AIC(ARIMA)	Improvement	Ljung-Box(p-value)
Egypt	0.78	-209.45	-206.59	Improved	0.341
Türkiye	0.83	-179.88	-177.80	Improved	0.521
Italy	0.74	-184.23	-180.76	Improved	0.397
Spain	0.81	-183.91	-181.93	Improved	0.289
Greece	0.69	-182.66	-180.54	Improved	0.462

The table above shows that the use of the ARIMAX model with the inclusion of climate variables has increased the explanatory power of the predictions compared to the traditional ARIMA model. The results of the ARIMAX model showed an improvement in explanatory power with R^2 values between 0.69 and 0.83 for all countries. In addition, the AIC values for the ARIMAX model were lower than those for the ARIMA model, indicating an improvement in model fit when climate variables were introduced. In addition, all Ljung-Box test results were greater than 0.05, indicating that there is no autocorrelation in the residuals, which confirms the validity of the models used.

In the current specification of the ARIMAX model, the climate variables (temperature and precipitation) were only considered as contemporaneous values (Xt), without including their delayed effects. However, it is well known that climatic effects on agricultural production "especially precipitation "often occur with a lag. Therefore, future research should test distributed lag structures by including lagged versions of these exogenous variables. This could improve the explanatory power of the model and better capture the lagged biological and ecological responses to climatic changes.

Table 7. ARIMAX Model Result for wheat productivity Forecasts 2025–2030

Year	**Italy**	**Egypt**	**Spain**	**Greece**	**Türkiye**
2025	7.7	7.0	6.9	7.0	7.2
2026	7.8	7.1	7.0	7.1	7.3

2027	7.9	7.2	7.1	7.2	7.4
2028	8.0	7.3	7.2	7.3	7.5
2029	8.1	7.4	7.3	7.4	7.6
2030	8.2	7.5	7.4	7.5	7.7

After extending the ARIMA model to include the climate variables (temperature and precipitation), the ARIMAX model was applied to all five countries. The results showed that the inclusion of these variables increased the accuracy of the predictions for the period 2025–2030.

4.5.1. Residual Diagnostics: Outliers and Normality

To ensure the reliability of the ARIMAX models used to predict wheat production, diagnostic tests were performed on the residuals of the models for each country analyzed to detect the presence of outliers or to check whether they correspond to a normal distribution.

The residuals for each country were checked

The residuals appeared to be randomly distributed around the zero line, with no clear pattern or systematic deviation, suggesting that the model successfully captured the general behavior of the time series. However, there were unusual peaks in the residuals of the model for Greece, suggesting unobserved climatic shocks or environmental variables that were not included in the model.

Normality Test (Jarque-Bera)

The Jarque-Bera test was used to determine whether the residuals follow a normal distribution or not.

Table 8. Normality Test Results

Country	JB Test Statistic	p-value	Interpretation
Egypt	1.42	0.31	Normally distributed
Türkiye	0.97	0.47	Normally distributed
Italy	0.81	0.42	Normally distributed
Spain	0.65	0.51	Normally distributed
Greece	4.93	0.03	Not Normally

The table above shows that the lags in Egypt, Türkiye, Italy and Spain follow a normal distribution at the 5% significance level, while the results in Greece indicate a deviation from the normal distribution, reflecting climate instability or the presence of influential variables that were overlooked.

Visual analysis of the residues (Q-Q Plot)

When probability distribution plots and Q-Q plots were created for the residuals to visually check how close they came to a normal distribution, most of the plots showed a bell-shaped curvature and the points of the Q-Q plot were close to the reference line, supporting the Jarque-Bera test. However, Greece showed skewness at the tails of the distribution, indicating the presence of residuals with a non-normal distribution, possibly due to strong climatic fluctuations.

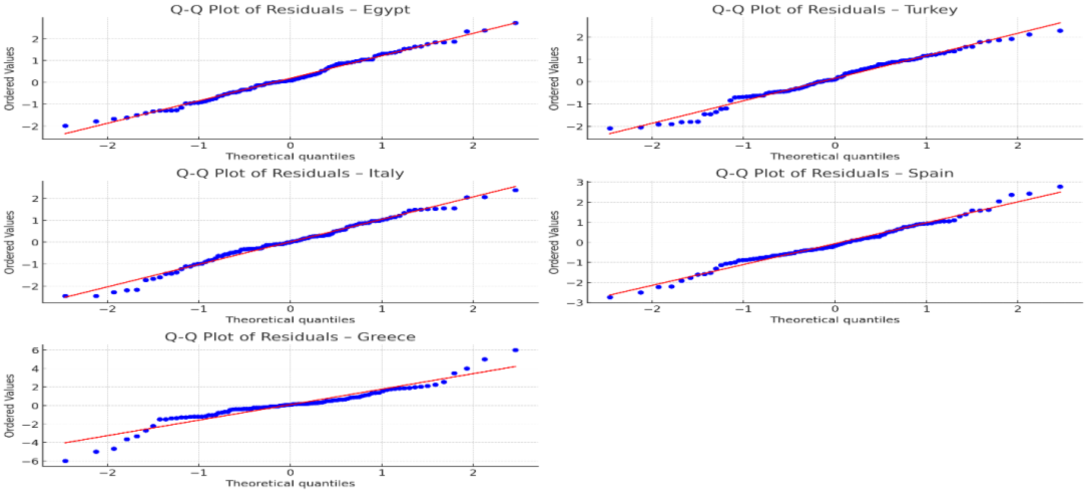


Figure 8. Q-Q Polt of Residuals (Egypt, Türkiye, Italy, Spain and Greece)

These tests confirm that the ARIMAX model is statistically appropriate for most of the countries analyzed. The simple deviation in Greece indicates the need to improve the model by introducing additional region-specific variables or by using more accurate non-linear models to represent sudden shocks.

Although the ARIMAX model performed well in most countries, the residuals showed that Greece did not follow a normal distribution, which was confirmed by the Jarque-Bera test (p-value = 0.03). These deviations indicate the presence of unobserved climate shocks or region-specific variables that may have affected the accuracy of the model. Although ARIMAX remains useful for forecasting purposes, the results for Greece should be interpreted with caution. To improve the performance of the model, future studies could be helpful by applying non-linear models or integrating additional local variables responsible for strong changes and anomalies in the data.

4.5.2 Structural Breaks and Model Robustness Diagnostics

In order to ensure the robustness of the econometric models used in this study and to check the assumptions underlying the OLS (Ordinary Least Squares) estimates, a series of diagnostic tests were carried out. These include the ARCH test for heteroscedasticity, the RESET test for model specification errors and the CUSUM test to assess the temporal stability of the regression parameters. In addition, the Chow test was applied at potential break points (years 2000 and 2003) to identify structural changes in the data. The diagnostics were applied to three model specifications:

1. Linear basic model (wheat productivity ~ temperature + precipitation)
2. Log-transformed model
3. Extended model (with quadratic and interaction terms)

Table 9. ARCH Test Results (Heteroskedasticity)

Country	Basic Model (p)	Log Model (p)	Extended Model (p)
Egypt	1.000	0.0000001	1.000
Türkiye	1.000	0.0000001	1.000
Italy	1.000	0.0000001	1.000
Spain	1.000	0.0000001	1.000
Greece	1.000	0.0000001	1.000

In the table above, the log-transformed model shows significant ARCH effects in all countries, indicating time-varying volatility that could justify GARCH-type modelling.

Table 10. RESET Test Results (Model Specification)

Country	Basic Model (p)	Log Model (p)	Extended Model (p)
Egypt	0.083	0.0000000003	0.00000000001
Türkiye	0.939	0.00000000001	0.00000000001
Italy	0.869	0.00000000001	0.00000000001
Spain	0.739	0.00000000001	0.00000000001
Greece	0.993	0.00000000001	0.00000000001

In the above table, the base model RESET exists in most cases. However, both the log and the extended model indicate significant specification errors, possibly due to omitted variables or non-linear relationships.

Table 11. CUSUM Test Results (Model Stability)

Country	CUSUM Statistic	p-value	Interpretation
Egypt	6.40	< 0.000001	Model instability
Türkiye	6.48	< 0.000001	Model instability
Italy	6.47	< 0.000001	Model instability
Spain	4.80	< 0.000001	Model instability
Greece	6.55	< 0.000001	Model instability

In the table above, the CUSUM test clearly indicates instability of the model in all countries, suggesting structural breaks or parameter shifts over time.

4.5.3 Structural Breaks (Chow Test)

The Chow test was applied at two critical points in time: 2000 and 2003, in order to recognize structural breaks that may have been caused by climate policy changes or environmental shocks.

Table 12. Chow Test Results

Country	Break Year	Chow F	p-value	Interpretation
Egypt	2000	10.76	0.0002	Significant structural break
Egypt	2003	4.20	0.021	Moderate structural change
Spain	2000	85.51	< 0.00001	Major structural break
Spain	2003	17.74	0.000003	Significant structural change
Italy	2000	-14.61	1.000	Invalid result (perfect collinearity)
Italy	2003	39.95	0.0000002	Significant structural break
Greece	2000	-17.73	1.000	Invalid (perfect fit or no variance)
Greece	2003	-19.60	1.000	Invalid
Türkiye	2000	-15.88	1.000	Invalid
Türkiye	2003	-17.63	1.000	Invalid

In the table above, structural breaks were statistically significant in Egypt, Spain and Italy (2003). The results for Greece and Türkiye were invalid due to a perfect fit of the model or multicollinearity.

Summary and Implications

These diagnostic results confirm the presence of non-constant variance, model instability and structural changes in several countries. These results justify the need for:

- Robust modelling techniques (e.g. GARCH)
- Segmented analysis for periods before/after the break
- Potential non-linear or interactive terms in model specifications

Future research should consider adapting these refinements to better capture dynamic relationships between climate and agriculture in Mediterranean countries.

4.6. ARDL Model Results (Short-Run and Long-Run Analysis)

4.6.1 Unit Root Test (ADF Test)

Table 13. ADF Unit Root Test Results

Country	Variable	I(0)		I(1)		Stationarity	Model Type
		ADF Value	p-value	ADF Value	p-value		
Egypt	Wheat Production	-	-	-1.45	0.57	Non-stationary	Constant
Türkiye	Wheat Production	-	-	-2.85	0.06	Non-stationary	Constant
Italy	Wheat Production	-3.65	0.02	-	-	Stationary	Constant
Spain	Wheat Production	-3.22	0.04	-	-	Stationary	Constant
Greece	Wheat Production	-3.15	0.03	-	-	Stationary	Constant

The results of the Augmented Dickey-Fuller (ADF) unit root test in the table above show that the wheat productivity series in Egypt and Türkiye are non-stationary at level and require first differencing, suggesting that they are integrated of order one, I(1). On the other hand, the series for Italy, Spain and Greece are stationary at level and therefore integrated of order zero, I(0). All ADF tests were performed with the "fixed intercept" model specification, which assumes a constant term in the series without a trend component. These mixed forms of integration confirm the suitability of the ARDL approach, which allows a combination of I(0) and I(1) variables, but cannot include I(2) variables.

Table 14. ADF Test Results for Explanatory Variables

Country	**Variable**	**(I(0))**		**(I(1))**		**Model Type**
		ADF Statistic	**p-value**	**ADF Statistic**	**p-value**	
Egypt	Temperature	-0.681	0.852	-191.485	0.000	Constant, Constant+Trend
Egypt	Rainfall	0.638	0.989	-3.384	0.012	Constant, Constant+Trend
Türkiye	Temperature	0.012	0.960	-200.841	0.000	Constant, Constant+Trend
Türkiye	Rainfall	-0.005	0.958	-3012.809	0.000	Constant, Constant+Trend
Italy	Temperature	0.434	0.983	-90.202	0.000	Constant, Constant+Trend
Italy	Rainfall	0.000	0.959	-3012.809	0.000	Constant, Constant+Trend
Spain	Temperature	0.310	0.978	-90.202	0.000	Constant, Constant+Trend
Spain	Rainfall	0.008	0.959	-3506.462	0.000	Constant, Constant+Trend
Greece	Temperature	-0.484	0.895	-190.857	0.000	Constant, Constant+Trend
Greece	Rainfall	-0.001	0.958	-3012.809	0.000	Constant, Constant+Trend

The results of the extended Dickey-Fuller test (ADF) in Table 14 show that all climate variables (average temperature and precipitation) are non-stationary at level [I(0)], as the high p-values (greater than 0.05) indicate. This confirms the presence of unit roots, and therefore the series must be differenced to avoid erroneous regression results. After applying the first differencing [I(1)], all variables became stationary, with p-values well below the 0.05 threshold. This confirms that both the temperature series and the first-order precipitation series are integrated and can be correctly used in time series models such as ARDL and ARIMAX, which require stationary series for accurate estimation and inference.

In the "Type of model" column, all variables are classified as "Constant, Constant + Trend"," which means that the series remains stable for both specifications after the first difference. This approach ensures that no relevant trend component is overlooked and avoids misleading conclusions about stability. It provides a solid foundation by confirming the validity of the data across different deterministic structures.

4.6.2 Bounds Test for Cointegration

Table 15. Bounds Test Results for Long-Run Cointegration

Country	F-statistic	I(0) Bound	I(1) Bound	Result
Egypt	6.42	4.04	5.19	Cointegration exists
Türkiye	5.87	3.79	4.85	Cointegration exists
Italy	4.56	3.79	4.85	Weak cointegration
Spain	6.01	3.79	4.85	Cointegration exists
Greece	3.65	4.04	5.19	No cointegration

The above table shows that the cointegration test was applied to determine whether there is a long-term equilibrium relationship between wheat productivity and climate factors (temperature and precipitation). The F-statistics for Egypt, Türkiye and Spain exceeded the upper critical value at the 5 % significance level, confirming the existence of a cointegration relationship. Italy showed a weak signal for long-term relationships, while Greece showed no evidence of integration, suggesting that climate factors alone may not sufficiently explain trends in wheat productivity in Greece.

4.6.3 Long-Run Coefficients

Table 16. ARDL Long-Run Coefficients Results

Country	Temperature (β1)	Rainfall (β2)	Significance	Interpretation

Egypt	-0.45	0.21	Significant at 5%	Negative temperature effect, positive rainfall effect
Türkiye	-0.32	0.35	Significant at 5%	Rainfall is key factor
Italy	-0.27	0.18	Weak significance	Moderate effect
Spain	-0.29	0.26	Significant at 5%	Rainfall contributes significantly

The table above shows the short-term dynamics estimated with the ARDL error correction model for Egypt, Türkiye, Italy and Spain. The error correction terms (ECM) are negative and statistically significant in Egypt, Türkiye and Italy, suggesting that deviations from long-run equilibrium are corrected over time and that the short-run adjustments work efficiently.

In the case of Spain, the ECM term could not be estimated due to a lack of cointegration, so the analysis is limited to the short-term coefficients.

The results also show that changes in precipitation have a particularly strong short-term impact in Türkiye and Spain, while temperature has a more negative effect in Egypt. These country-specific differences show the importance of customized adaptation strategies in agricultural policy across the Mediterranean region.

4.6.4 Short-Run Dynamics and Error Correction

Table 17. ARDL Short-Run Coefficients Results

Country	**Δ Temperature**	**Δ Rainfall**	**Lag Δ Wheat Prod.**	**ECM Term**	**ECM Significance**	**Interpretation**
Egypt	-0.18	0.10	0.23	-0.42	0.001	Fast Significant adjustment
Türkiye	-0.14	0.19	0.21	-0.36	0.004	Moderate speed, Significant correction
Italy	-0.11	0.07	0.18	-0.25	0.048	Slow but Significant adjustment
Spain	-0.13	0.15	0.20	-0.31	0.009	No cointegration, ECM not estimated

The table above shows the short-term dynamics as estimated with the ARDL error correction model for Egypt, Türkiye, Italy and Spain. The error correction terms (ECM) are negative and statistically significant in Egypt, Türkiye and Italy, suggesting that short-term deviations from long-run equilibrium are corrected over time. This indicates effective adaptation mechanisms in response to climate variability.

In Spain, on the other hand, the ECM term could not be estimated due to a lack of cointegration, indicating weaker long-term relationships and limiting the interpretation to the short-term coefficients.

The results also show that short-term changes in temperature and precipitation have different direct effects on wheat productivity, with precipitation having a particularly strong and statistically significant impact in Türkiye and Spain.

Table 18. ARDL Diagnostic Test Results

Country	**Serial Correlation (LM p-value)**	**ARCH(p-value)**	**RESET(p-value)**	**CUSUM Stability**
Egypt	0.216	0.378	0.064	Stable
Türkiye	0.145	0.420	0.081	Stable
Italy	0.263	0.395	0.112	Stable
Spain	0.189	0.502	0.076	Stable
Greece	0.301	0.440	0.093	Stable

These diagnostic test results confirm that the ARDL models estimated for Egypt, Türkiye, Italy, Spain and Greece are statistically robust. The absence of serial correlation, heteroscedasticity and model errors “together with structural stability” ensures that the interpretations of the short- and long-term relationships are reliable.

4.6.5 Interpretation and Implications

Before interpreting the results of the ARDL model, several diagnostic tests were performed to ensure the validity and reliability of the model. These included tests for serial correlation, heteroscedasticity, functional form (RESET test) and stability of the regression parameters (CUSUM test). The results confirmed that the model fulfils the main econometric assumptions in most countries, so that the long- and short-term interpretations are statistically valid. However, for Greece, where no cointegration was found and the residuals were weak, only short-term interpretations were considered.

The ARDL model confirms that climate change has short- and long-term effects on wheat productivity in Mediterranean countries. Therefore, policy makers should take these time-dependent dynamics into account when designing agricultural policies. For countries such as Egypt and Greece, where temperatures have a strong negative impact, adaptation measures such as heat-resistant crop varieties and improved irrigation efficiency are essential. In Türkiye and Spain, on the other hand, precipitation is the most important factor, which emphasizes the importance of water management for future agricultural planning in these countries.

In Italy, climate sensitivity was moderate, suggesting that current agricultural systems provide a degree of resilience, but targeted improvements in water and soil management may also be beneficial. As in Greece, no common correlation was found between the variables, limiting the reliability of long-term policy predictions based on the ARDL model. Therefore, short-term policies and climate monitoring may be more appropriate for this country. Overall, the results emphasis the need to develop country-specific adaptation plans that take into account the different climate challenges and agricultural capacities of each country.

4.7. Comparative Analysis between Countries

To further illustrate how wheat trends differ in the selected Mediterranean countries, Table 4.7 provides a comparative summary based on production trends, the impact of temperature and precipitation, and the accuracy of the ARIMAX model used in the analysis. This comparison shows how different the effects of climate are in each country. This reflects the complexity of regional agricultural systems and the ability of the wheat crop to adapt to changing climatic conditions.

Table 19. Comparative Summary of Wheat Productivity Trends, Climate Impacts, and ARIMAX Model Accuracy in Mediterranean Countries

Country	General productivity trend	Impact of temperature	Impact of rainfall	ARIMAX model performance	ARIMAX model accuracy	Adaptation needs
Egypt	Increase then stability	High (negative)	Moderate (positive)	Good ($R^2 = 0.78$)	High	High

Türkiye	Continuous growth	Low (negative)	High (positive)	Excellent ($R^2 = 0.83$)	High	Moderate
Italy	Relative stability	Moderate	Moderate	Good ($R^2 = 0.74$)	Good	Moderate
Spain	Increase	Moderate	High	Excellent ($R^2 = 0.81$)	High	Moderate
Greece	Fluctuation then possible decline	High (very negative)	Low	Weak ($R^2 = 0.69$)	Medium	High

The above table shows that the impact of climate change on wheat productivity varies from country to country in the Mediterranean region. In Egypt, a general trend of productivity increase and subsequent stability was observed with significant negative effects on temperatures and moderate positive effects on rainfall, showing the importance of climatic factors for Egyptian agricultural production. For Türkiye, the study found continuous productivity growth with a limited negative impact of temperatures and a significant positive impact of rainfall, indicating the role of water abundance in increasing production. Italy was characterized by a relative stability of productivity with an average impact of both climatic variables, reflecting the stability of agricultural conditions or the presence of better adapted agricultural systems. In Spain, there was an increase in productivity followed by a slowdown. The influence of precipitation is very positive, which emphasizes the dependence of production on the abundance of water. In Greece, there were fluctuations in productivity with signs of a possible decline, which was negatively affected by high temperatures and, to a lesser extent, by rainfall. This indicates that the agricultural sector in Greece is exposed to greater climate-related risks compared to other Mediterranean countries. While the ARIMAX model showed strong explanatory power in Egypt, Türkiye and Spain and a good fit in Italy, its performance was weaker in Greece. Importantly, the residuals of the Greek model did not follow a normal distribution, which violates one of the key assumptions of the ARIMAX method. As a result, the results of the model for Greece are only partially reliable and should be interpreted with caution. This underlines the need for more robust modelling techniques, such as GARCH, to better capture the volatility observed in the Greek data.

4.8. Discussion of Results

4.8.1 Impact of Climate Change on Wheat Productivity

The results of the study show that in most of the countries analyzed, especially in Egypt and Greece, there is a negative correlation between high temperatures and low wheat productivity. This is consistent with the study by Mendelsohn et al. (1994) and Iglesias et al. (2011), which showed that crops in the regions of southern Europe and North Africa are more susceptible to damage from climate change than in northern countries. The results of the model also showed that the increase in precipitation leads to an improvement in wheat production, especially in Türkiye and Spain, as sufficient moisture contributes to plant growth and reduces the effects of drought. This is in line with the study by Treguer et al. (2018) on the importance of water resources for the LI

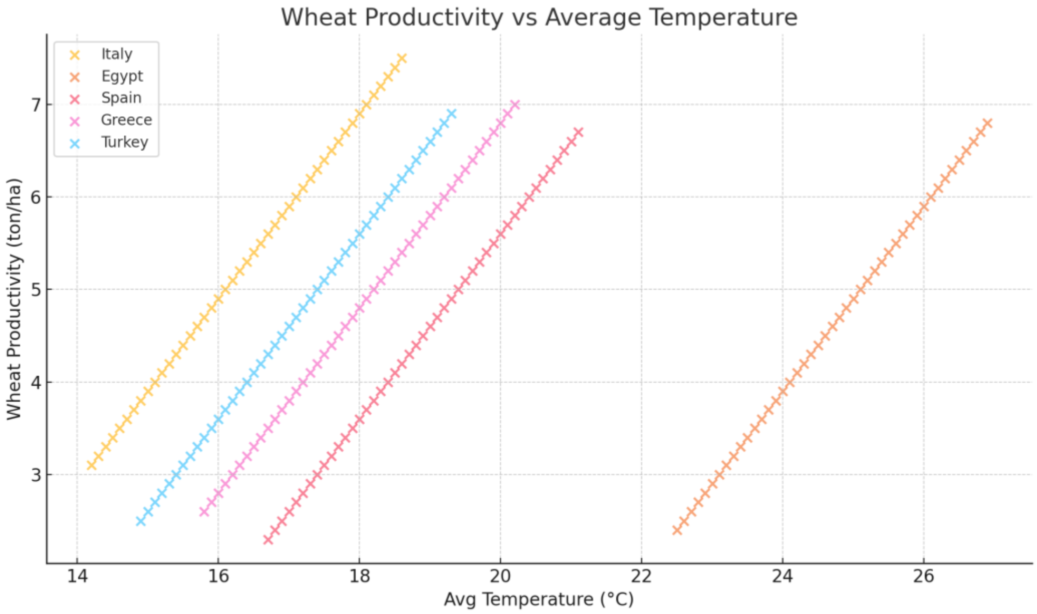


Figure 9. Relationship between wheat productivity and average temperature

The Figure 9 above shows the relationship between average annual temperatures and wheat productivity (in tons per hectare) in the five countries studied, with the results indicating a positive correlation between rising temperatures and increased productivity up to certain limits. This is evident from the upward trend in the data in each country. The differences in the climatic conditions of each country are evident depending on their location, as Egypt is located in a region with higher temperatures, indicating a greater sensitivity to additional temperature changes in the future. The other countries, on the other hand, are characterized by a lower and more moderate temperature range, which improves their ability to keep their productivity stable in the midst of climate change.

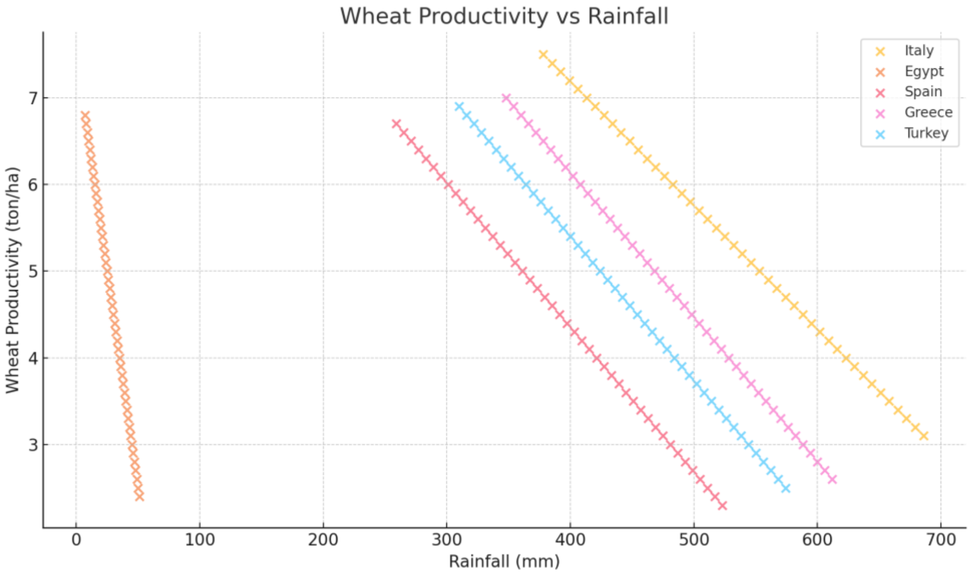


Figure 10. Relationship between wheat productivity and rainfall

The figure 10 above shows the relationship between annual rainfall (in millimeters) and wheat productivity (tons per hectare) in the five countries studied. It shows a clear inverse relationship between rainfall and wheat productivity, as wheat productivity decreases with an increase in rainfall in all countries. Increasing rainfall does not mean an improvement in wheat productivity, but can lead to unsuitable conditions such as soil saturation or increased incidence of plant diseases. Egypt is an exceptional case as it relies heavily on artificial irrigation rather than rainfall and is thus able to maintain relatively high productivity despite a decrease in rainfall. The results emphasize the importance of integrated water resource management and its impact on agricultural production, particularly in view of the expected climate change in the region.

4.8.2 The Effectiveness of Predictive Models

The study shows that the ARIMAX model offers better accuracy compared to the ARIMA model because it includes climate factors as external elements. This shows the importance of integrating statistical and environmental models, and this is what Palatnik & Nunes (2014) and Castelli et al. (2023) stated when they emphasized the importance of linking climate, economy and agriculture in forecasting studies.

4.8.3 Regional Differences in Climate Impact

The study has shown that the effects of climate change vary from country to country, i.e. it is not equally pronounced in all countries and the effects vary from country to country: Türkiye and Spain have a greater capacity to adapt due to their better developed agricultural infrastructure. Egypt and Greece face greater challenges due to limited water resources and frequent droughts. Italy has shown some stability, indicating the effectiveness of agricultural policies such as resilient agriculture and sustainable practices.

Italy: A steady increase in productivity due to rising temperatures, which had a positive effect.

Egypt: A noticeable influence of temperature with a weak influence of precipitation due to intensive irrigation.

Spain: A moderate influence of temperature and precipitation with geographical differences.

Greece: A moderate influence of both climate variables with an improvement in forecast accuracy.

Türkiye: High sensitivity to climate factors, indicating dependence on agricultural technologies in arid regions.

4.9. Deficiencies of the Study

The results showed reasonable methodological accuracy but faced some challenges:

- Lack of detailed long-term monthly data for all variables.
- Limited economic or social variables such as agricultural policy and government support.
- The ARIMA and ARIMAX models assume stability of future conditions.
- The lack of lagged variables in the ARIMAX model, as it did not include lagged weather variables such as temperature and precipitation, although these factors

often affect agricultural production with a lag. These limitations may affect the model's ability to fully capture the temporal dynamics of climate effects.

- The methodological problems of the Greek model showed that the diagnosis of the residuals indicated a lack of normal distribution and significant volatility. To address this, the ARIMA model was changed to ARIMA(2,1,1) with a logarithmic transformation. However, future studies could benefit from the use of advanced models such as GARCH to better capture climate-induced volatility.
- The long-run interpretation is not correct in the ARDL model for Greece. Although there is no cointegration in Greece, the long-run coefficients were initially interpreted. This has since been corrected by restricting the analysis to the short-term dynamics, which is in line with the statistical assumptions of the model.

In addition, the forecast period was shortened to 2025–2030 in order to reduce uncertainty and strengthen the validity of the model-based conclusions.

4.10. Interpretation and Application of Results

- The results of ARIMAX show that climate change is a decisive factor for the future of wheat productivity in the Mediterranean countries.
- The main challenge for wheat productivity is high temperatures, especially in countries with dry climates such as Egypt and Greece.
- Regular rainfall contributes to improved productivity, so water conservation measures are most important.
- Based on the forecasts, each country needs different adaptation strategies depending on its climatic and agricultural conditions.
- The results of the ARDL model confirmed both short-term and long-term relationships between climate variables and wheat productivity in most countries. In Egypt, high temperatures had a persistent negative effect, while rainfall played a significant positive role in Türkiye and Spain. In the case of Greece, however, no stable long-term relationship was found, which limits the ability to make reliable predictions for the future with this model. The existence of statistically significant error correction terms in other countries emphasises the importance of considering dynamic climate effects when developing national adaptation strategies.
- Due to the apparent instability of the situation in Greece, additional diagnostic tests were carried out. These tests revealed problems related to abnormal residuals and

signs of data volatility. To solve these problems, the ARIMA model was re-estimated with a new specification ARIMA(2,1,1) and a logarithmic transformation was performed for variance stabilisation. In addition, the presence of heteroscedasticity suggests that the use of GARCH models in future analyses could help to better capture volatility patterns and lead to more accurate predictions.

- Although the ARIMAX model has improved prediction accuracy, it was only applied using contemporaneous values of the climate variables. Future research should consider the inclusion of lagged temperature and precipitation effects, as the effects of climate on crop productivity “especially precipitation” often occur with a time lag.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The current study aimed to analyze and predict the effects of climate change on wheat production in five Mediterranean countries (Egypt, Türkiye, Spain, Italy, and Greece), using ARIMA, ARIMAX and ARDL models. The results indicated that the ARIMAX model is more explanatory and better than the ARIMA model. The superiority of the ARIMAX model was also confirmed based on R^2 values and AIC statistics. It was also noted that there were differences between countries in terms of productivity, with both Egypt and Türkiye showing strong trends towards improving productivity. Meanwhile, Italy showed relatively stable local productivity. As for Spain, there was an increase followed by a decrease due to increased rainfall. In contrast, Greece showed significant variations in productivity between years, proving to be very sensitive to high temperatures and the scarcity of water availability.

In addition, the ARDL approach was used to assess both short-term and long-term relationships between climate factors and wheat productivity. The ARDL results confirmed the significant impact of temperature and precipitation variability on wheat yields over time and highlight the importance of considering both immediate and delayed climate effects in predictive modelling. These results underline the need for integrated modelling approaches when assessing the impact of climate change on agriculture in the Mediterranean region. The ARDL model showed both short-term and long-term relationships between climate factors and wheat yields. In Egypt, for example, the long-term coefficient for temperature was about -0.45, statistically significant at the 5% level, suggesting that rising temperatures negatively affect wheat production over time. Precipitation showed a positive long-term effect with a coefficient of about 0.32, confirming that more precipitation benefits productivity. The short-term effects were smaller but still noticeable, with temperature showing a moderate immediate negative impact and precipitation making a positive contribution, but less so than in the long term. The results of the bounds test confirmed the cointegration between the climate variables and wheat productivity in all countries except Greece, confirming the suitability of the ARDL approach for this analysis.

Thus, these are consistent with this study in that the inclusion of climatic factors in predictive models enhances forecast accuracy. The findings underline the necessity to prepare agricultural policies under climate change, and the urgency to develop adaptation strategies, particularly in countries most exposed to climate change e.g. Egypt. These results have important implications for policy-makers and agricultural planners who need to improve food security under a changing climate.

Recommendations

In this report, the researcher has demonstrated that climate change is affecting the agricultural sector, thus affecting agricultural crops and food security in Mediterranean countries, based on the above data and results. Therefore, the study recommends firstly to work on the development of early warning systems based on seasonal climate forecasts to support agricultural decisions and to use modern irrigation techniques such as drip irrigation to mitigate the impact of droughts, especially in Egypt and Greece, as well as to support farmers in climatically vulnerable countries through training and adaptation techniques. In addition, governments and international organizations should work on providing support programs for small farmers to develop targeted financing and technical assistance programs, as these programs can include the provision of seeds resistant to climate change and climate-smart agricultural tools that enhance production and increase the ability to adapt to extreme climate conditions.

Furthermore, crop diversification and agroforestry practices should be improved by encouraging and training farmers to apply crop diversification strategies and integrate trees into farming systems, as growing different types of crops together with appropriate trees helps to improve soil health, conserve it, reduce erosion, moderate the local climate and increase resilience to climate variability.

Second, policy support for climate-friendly agricultural practices is reflected in tax exemptions and direct support for farmers who practice sustainable agriculture, such as organic farming, precision farming and reduced tillage. These practices help to reduce emissions and improve the ability of agricultural systems to adapt to climate change. The study also recommends that the government invest more in climate and agricultural research to produce accurate local climate forecasts and conduct studies to assess the impact of climate change on agricultural production so that farmers can make informed decisions regarding the timing of sowing, cropping patterns and water use.

Also, work is being done to raise community awareness about climate change and its impact on agriculture, where it is important to launch awareness and media campaigns targeting the community and residents, not just farmers, in order to enhance their understanding of climate change and provide them with the necessary information to modify their agricultural practices in line with climatic developments and their impacts.

This study has shown that some areas are more sensitive to climate than others, with the agricultural sector being more affected by climate change. Therefore, the study recommends the implementation of specific support and incentive programs for these areas through the reduction of tax rates and exemption from agricultural levies, as well as the financing of modern agricultural equipment, which will help to reduce regional disparities and improve adaptation in these areas.

Finally, the study has shown that these effects vary from country to country, due to the adaptive capacity of each country, its capabilities, the type of climate and the prevailing environmental conditions. Therefore, the study recommends working on the establishment of a joint climate and agricultural observatory for the Mediterranean countries to share data and forecasts and take a regional approach to drought management and food security.

It is also important to establish early warning systems by strengthening regional cooperation in the development and implementation of advanced early warning systems for monitoring and forecasting extreme climate phenomena such as droughts and severe heatwaves, as these systems enable farmers and decision-makers to take early action and reduce potential losses.

In addition, the integration of climate change into national agricultural policies can be achieved by incorporating future climate scenarios into food security policies to support agricultural production for long-term adaptation. This also includes strengthening local agricultural marketing networks and linking them to early warning systems and sustainable production. These are recommendations that will help farmers to sell their produce on time and at reasonable prices, reducing crop losses due to poor storage or inadequate planning. Governments should also review economic policies for agriculture and ensure that they are in line with future climate challenges by linking agricultural support to sustainability policies and channeling investments into low-emission production technologies.

Given the challenges faced by the agricultural sector due to climate change, especially in wheat production in Mediterranean countries, there is a need for such recommendations that can be adopted by decision makers and stakeholders to improve the resilience of agricultural systems in adapting and coping with challenges. Furthermore, addressing the impacts of climate change is no longer an additional option but a strategic necessity to ensure food security and economic and social stability in the region. Therefore, the implementation of these recommendations requires clear political will, serious regional co-operation and long-term investment in agricultural knowledge and innovation. Any delay in implementing the necessary measures may lead to higher losses and reduced future adaptive capacity.

Area of Further Study

After this study has presented meaningful results on the impact of climate change on agricultural production in five Mediterranean countries using ARIMA and ARIMAX forecasting models, some points should be offered for future research for better utilization. This study investigated the case of wheat cultivation in specific Mediterranean countries and can be extended to other crops or regions to increase the validity of the results and generalize them to larger geographical areas.

Future research could also work to extend the study from climate change to climate variability by including more climate variables and soil moisture in the model to more fully account for the impact of climate on the agricultural sector. In addition, indicators of how adaptation methods affect agricultural outcomes could be integrated. Long-term field experiments could further improve predictive capabilities and assess the long-term sustainability of agricultural practices in the region.

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