MEST Journal
DOI: 10.12709/mest.14.14.02.03

ORIGINAL RESEARCH ARTICLE
MEST Journal

CLIMATE–TECHNOLOGY INTERACTIONS AND THEIR IMPACT ON AGRICULTURAL PRODUCTION IN ALGERIA

Kamel Belfodil
University of Ahmed Zabana Relizane, Relizane, Algeria
https://orcid.org/0009-0003-6604-9544

Djilali Mezouaghi
University of Ahmed Zabana Relizane, Relizane, Algeria
https://orcid.org/0009-0003-5827-4338

Khadidja Laref
University of Ahmed Zabana Relizane, Relizane, Algeria
https://orcid.org/0009-0005-4305-1857

ARTICLE INFO

JEL Category:
Q01, Q10, Q13, Q18, Q33, Q47, Q54

Keywords:
agricultural value added
resource-use efficiency
ARDL model
Algerian agricultural sector
sustainable agricultural development

ABSTRACT

This study examines the impact of climatic and technological changes on agricultural productivity in Algeria during the period 1999–2023 using the ARDL model. The results confirm the existence of a long-run equilibrium relationship between agricultural value added and its climatic, technological, and structural determinants. Productive inputs, particularly fertilizers and water resources, positively affect agricultural performance, whereas rising temperatures and inefficient irrigation management exert negative effects. The findings also show that technological development contributes to strengthening the sector's capacity to cope with climate-related challenges. In addition, persistent structural constraints, including low labor productivity and the prevalence of traditional production practices, continue to limit productive efficiency. The error correction mechanism confirms the sector's ability to adjust toward long-run equilibrium following short-term shocks. Overall, the results highlight the importance of improving resource-use efficiency, promoting technological modernization, and strengthening climate adaptation policies to support sustainable agricultural development in Algeria.

1 INTRODUCTION

In recent decades, the global environment has been experiencing accelerated climate change, whose impacts are increasingly evident on both ecological and economic systems. Rising temperatures, recurrent droughts, and noticeable disruptions in rainfall patterns have posed new

Address of the corresponding author:
Kamel Belfodil
kamel.belfodil@univ-relizane.dz

Received: 14.05.2026
Revised: 03.06.2026
Accepted: 04.06.2026
Available online: 05.06.2026

challenges to various productive sectors. The agricultural sector is among the most affected due to its direct dependence on natural and climatic factors. In this context, reports from the Intergovernmental Panel on Climate Change (IPCC, 2022) indicate that semi-arid and Mediterranean regions are particularly vulnerable to climate change effects, especially regarding the decline of water resources and reduced agricultural productivity, which directly threatens food security.

Economic literature suggests that a one-degree Celsius increase in temperature may lead to a significant reduction in agricultural productivity, particularly in developing countries that heavily rely on rain-fed agriculture and face limited infrastructure capable of adapting to climate shocks (Dell, Jones & Olken, 2012). Agricultural economics studies also highlight that the climate productivity relationship is neither simple nor linear; rather, it is influenced by complex interactions involving technological, institutional, and regulatory factors that affect the sector's adaptive capacity (Burke & Emerick, 2016).

Conversely, technological transformations have emerged as key strategic tools to enhance the resilience of the agricultural sector against climate change, through improving input-use efficiency, developing crop varieties more resistant to heat and drought, and adopting modern irrigation and precision farming techniques. In this regard, the Food and Agriculture Organization (FAO, 2013) emphasizes that adopting modern agricultural technologies can partially mitigate the negative effects of climate change by improving production efficiency and rationalizing the use of natural resources. However, the effectiveness of these technological transformations remains contingent upon their integration with sustainable agricultural policies that balance climate adaptation requirements with improved production performance.

Regarding the Algerian context, the agricultural sector represents a fundamental pillar in supporting economic diversification and achieving food security. Nevertheless, it exhibits high sensitivity to climate shocks due to Algeria's semi-arid climate and its relative dependence on limited water resources. National data indicate an increased frequency of heatwaves over the past two decades, accompanied by significant fluctuations in rainfall, raising critical questions about the capacity of technological transformations implemented within the sector to offset the adverse climate impacts.

Despite the growing international literature on the effects of climate change on agricultural activity, empirical studies in the Algerian context remain relatively limited, particularly those examining the interaction between climatic and technological variables within a dynamic analytical framework that combines short- and long-term perspectives. Against this backdrop, this study aims to analyze the impact of climate changes (temperature, water resources, etc.) and technological transformations (fertilizers, irrigation, etc.) on the productivity performance of Algeria's agricultural sector, using the autoregressive distributed lag (ARDL) model, which allows testing for equilibrium relationships in both the short and long run and exploring the dynamics of adjustment toward long-term equilibrium.

Despite the growing body of literature examining the effects of climate change and technological factors on agricultural performance, several gaps remain. Previous studies have often focused on either climatic variables or technological inputs separately, while limited attention has been given to their combined effects within a unified analytical framework. Furthermore, empirical evidence for Algeria remains relatively scarce, particularly regarding the long-run and short-run dynamics linking climatic conditions, water resources, fertilizer use, irrigation, and agricultural productivity. In addition, existing studies have produced mixed findings concerning the effectiveness of irrigation and other production inputs in improving agricultural performance under semi-arid conditions. This study contributes to the literature by providing an integrated ARDL-based analysis of climatic, technological, and structural determinants of agricultural value added in Algeria over the period 1999–2023. By jointly examining these factors within a single framework, the study offers new evidence on the mechanisms through which climate-related and technological changes influence agricultural performance in the Algerian context.

1.1 Research Problem

The agricultural sector in Algeria has undergone rapid transformations amid increasing climate change and technological advancements in production methods, making its performance closely linked to a combination of environmental, economic, and structural factors. Given the strategic importance of the agricultural sector in achieving food security and supporting economic development, there is a need to analyze the impact of climate and technological changes on agricultural production using empirical approaches that allow the examination of these relationships in both the short and long term.

This study seeks to answer the following question: How do climate and technological changes, in both the short and long run, affect the productivity performance of Algeria's agricultural sector, and to what extent is the sector capable of adapting to climate shocks within a dynamic equilibrium framework?

1.2 Research Hypotheses

Based on the theoretical and empirical literature on agricultural production, climate economics, and agricultural technology, this study is founded on the general assumption that the productive performance of the agricultural sector in Algeria is influenced by a set of climatic, technological, and structural factors. Accordingly, the following hypotheses are formulated:

Null Hypothesis 1 ($H0_1$): Temperature does not exert a statistically significant effect on agricultural value added in Algeria.

Alternative Hypothesis 1 ($H1_1$): Temperature negatively and significantly affects agricultural value added in Algeria.

Null Hypothesis 2 ($H0_2$): freshwater availability does not exert a statistically significant effect on agricultural value added in Algeria.

Alternative Hypothesis 2 ($H1_2$): freshwater availability positively and significantly affects agricultural value added in Algeria.

Null Hypothesis 3 ($H0_3$): fertilizer use does not exert a statistically significant effect on agricultural value added in Algeria.

Alternative Hypothesis 3 ($H1_3$): fertilizer use positively and significantly affects agricultural value added in Algeria.

Null Hypothesis 4 ($H0_4$): irrigated land does not exert a statistically significant effect on agricultural value added in Algeria.

Alternative Hypothesis 4 ($H1_4$): irrigated land positively and significantly affects agricultural value added in Algeria through improving water-use efficiency and production stability.

Null Hypothesis 5 ($H0_5$): agricultural labor does not exert a statistically significant effect on agricultural value added in Algeria.

Alternative Hypothesis 5 ($H1_5$): agricultural labor may negatively or weakly affect agricultural value added in Algeria due to low productive efficiency and the persistence of disguised unemployment within the agricultural sector.

2 CONCEPTUAL FRAMEWORK OF AGRICULTURAL ECONOMIC GROWTH

Agricultural economic growth constitutes a fundamental pillar in analyzing overall economic performance, particularly in developing economies where the agricultural sector remains a major source of employment and income. It is generally understood as a sustained increase in real agricultural output or agricultural value-added over time, accompanied by improvements in the efficiency of input utilization. However, agricultural growth is not measured merely by increased production volumes. Rather, it is viewed from a dynamic perspective that encompasses improvements in total factor productivity (TFP), advancement of agricultural technologies, more efficient reallocation of resources, and enhancement of sectoral competitiveness. According to economic development (Todaro & Smith, 2020), agricultural growth serves as a precondition for structural transformation by raising rural incomes, generating food surpluses that support urban growth, and liberating labor for more productive sectors. Furthermore, the Food and Agriculture Organization emphasizes that sustainable agricultural growth must balance production expansion with the conservation of natural resources, given agriculture's direct dependence on soil, water, and climate conditions. Accordingly, agricultural growth can be understood as a cumulative production process supported by technological, institutional, and environmental factors, rather than merely an increase in output quantity.

Agricultural productivity performance is assessed using quantitative indicators that reflect the efficiency of input utilization and their transformation into economically valuable outputs. Among the most important indicators is agricultural value-added (AVA), which represents the difference between the total value of agricultural output and the value of intermediate inputs, thereby capturing the sector's actual contribution to GDP. AVA is considered a central indicator because it measures the net performance of the sector, reflects changes in productivity rather than merely output volumes, and allows for international comparisons. According to World Bank data, AVA is widely used as a primary measure of real agricultural growth, excluding distortions from nominal price fluctuations. Its use in empirical models enhances the precision of productivity measurement, as it represents net output that can be economically interpreted within an extended production function. Another essential indicator is the marginal productivity of inputs, which refers to the change in output resulting from a one-unit increase in a particular input while holding other factors constant. This concept is fundamental in production theory because it enables the evaluation of the efficiency of each production input individually. In the agricultural context, marginal productivity reflects the efficiency of agricultural labor, the effectiveness of fertilizer usage, the productivity of irrigation systems, and the sensitivity of output to climatic variations. The empirical literature emphasizes that using a logarithmic specification of the production function allows estimated coefficients to be interpreted directly as elasticities, facilitating economic analysis and rendering the results more actionable for policymakers. As noted by Econometrics by Example (Gujarati, 2015), logarithmic transformation reduces issues of heteroscedasticity, improves the linearity of relationships, and allows coefficients to be interpreted as productivity elasticities. This approach provides a deeper economic dimension compared to traditional linear specifications, enabling more insightful and policy-relevant analysis.

The agricultural sector is a key structural component of the Algerian economy, not only in terms of its contribution to GDP but also regarding its social, nutritional, and environmental dimensions. Despite the dominance of the hydrocarbon sector in foreign revenues, agriculture remains a pivotal element for achieving long-term economic stability, particularly amid fluctuations in oil prices. From a developmental perspective, agriculture serves as a lever to achieve multiple objectives beyond food production, including social stability, job creation, and strengthening national economic security. The sector plays a fundamental role in ensuring food security by providing essential products locally and reducing dependence on volatile international markets, especially in the face of external shocks, whether economic, climatic, or geopolitical. According to the Food and Agriculture Organization (2022), food security rests on four main dimensions: availability, access, utilization, and stability. In the Algerian context, food availability is directly linked to the performance of the domestic agricultural sector, while low productivity increases reliance on imports, making food security sensitive to exchange rate fluctuations and global market volatility. Consequently, enhancing agricultural growth is not merely a sectoral choice but a strategic necessity for strengthening food sovereignty and reducing economic vulnerability to external shocks.

Given the rentier nature of the Algerian economy, agriculture also represents a realistic pathway to expand the productive base and reduce reliance on hydrocarbons. Development literature, including economic development (Todaro & Smith, 2020), emphasizes that economic diversification is essential for achieving sustainable and balanced growth, particularly in economies dependent on a single natural resource. World Bank reports on Algeria highlight that diversifying the production structure contributes to reducing growth volatility linked to oil prices, increasing employment opportunities in rural areas, and expanding the tax base beyond the energy sector. Accordingly, developing the agricultural sector should be viewed as part of a broader strategy for structural economic rebalancing rather than as a stand-alone sectoral policy.

In addition, the agricultural sector is closely linked to sustainable development due to its direct dependence on natural resources, especially soil and water. Poor management of these resources can lead to long-term environmental degradation, negatively affecting future production capacity. The Brundtland report defines sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. This concept applies directly to agriculture, where productivity growth requires balancing production intensification, soil conservation, efficient water use, and adaptation to climate change. In the Algerian context, the importance of sustainability is amplified by limited water resources and the semi-arid climate, making sustainability a prerequisite for the long-term continuation of agricultural growth.

3 CLIMATE CHANGE AND AGRICULTURAL DEVELOPMENT

Climate change refers to long-term shifts in average temperatures, precipitation patterns, and extreme weather events, driven either by natural factors or by human activities, particularly greenhouse gas emissions. According to the Intergovernmental Panel on Climate Change (2021), climate change constitutes one of the most significant contemporary global challenges due to its multidimensional economic, environmental, and social consequences. The agricultural sector is among the most sensitive sectors to climatic changes because of its direct dependence on climatic conditions and natural resources. The Intergovernmental panel on climate change further emphasizes that rising temperatures and increasing rainfall variability will directly affect agricultural productivity and agricultural production, especially in semi-arid regions such as north africa, thereby intensifying pressure on water and soil resources. In this context, climate change is no longer viewed solely as an environmental issue but also as a structural determinant influencing agricultural development, food security, and long-term economic sustainability.

Climate change affects agricultural production through multiple direct and indirect channels, primarily temperature fluctuations, water availability, and soil dynamics. Rising temperatures accelerate crop growth cycles, increase heat stress on plants, and reduce yields once optimal physiological thresholds are exceeded. According to the work of David Lobell et al. (2011), a one-degree Celsius increase in average temperature can generate a significant decline in the productivity of major agricultural crops. Higher temperatures also increase evapotranspiration rates, reducing soil moisture and intensifying the need for supplemental irrigation. Water scarcity constitutes another major channel through which climate change affects agricultural production, particularly in semi-arid countries such as Algeria, where agriculture depends heavily on limited water resources. Food and Agriculture Organization (2020) reports that irregular rainfall patterns and prolonged drought episodes reduce irrigation efficiency and constrain cultivated agricultural areas. In addition, increased evaporation rates contribute to further soil moisture loss, negatively affecting crop resilience and productivity. The World Bank (2021) highlights that dry and vulnerable regions will experience compounded pressure on water resources as climate change intensifies, thereby threatening agricultural sustainability and increasing production instability over time.

From a theoretical perspective, climatic variables are incorporated into agricultural production models as exogenous determinants influencing total factor productivity. The climate-agriculture supply framework assumes that agricultural output is not determined solely by conventional production inputs such as labor, land, and capital, but is also strongly influenced by climatic conditions, including temperature and precipitation. The extended production function can therefore be represented as follows:

$$Y = f(K, L, T, C)$$

where C denotes climatic variables such as temperature and rainfall. Modern econometric literature emphasizes that incorporating climate indicators into production models improves the explanatory power of agricultural output fluctuations and provides a more realistic interpretation of productivity dynamics. According to Melissa Dell, Benjamin Jones, and Benjamin Olken (2012), climatic factors significantly explain variations in economic and agricultural performance, particularly in developing countries that are highly dependent on climate-sensitive sectors.

Climate shocks such as droughts, floods, and heatwaves are generally treated as exogenous variables because they occur independently of producers' economic decisions while exerting substantial effects on agricultural production. Contemporary econometric approaches, particularly dynamic models such as the ARDL framework, are frequently employed to distinguish between the short-run and long-run impacts of climatic shocks on agricultural value added. Recent empirical literature indicates that the adverse effects of heat shocks are especially pronounced in countries characterized by traditional agricultural structures, limited irrigation systems, and weak adaptive capacities. In this regard, Marshall Burke, Solomon Hsiang, and Edward Miguel (2015) argue that rising temperatures can substantially reduce agricultural performance and overall economic productivity in vulnerable developing economies. Consequently, understanding the interaction between climatic factors and agricultural production has become essential for designing effective adaptation policies aimed at strengthening agricultural resilience and ensuring sustainable agricultural development.

4 AGRICULTURAL TECHNOLOGY AND PRODUCTIVITY DEVELOPMENT

Agricultural technology refers to the collection of technical and organizational innovations designed to improve the efficiency and performance of agricultural production systems. It includes both modern production inputs, such as fertilizers and improved seeds, and advanced farming methods, including mechanization and modern irrigation systems. In agricultural economics, technology is considered a central determinant of total factor productivity (TFP) because it enhances the efficiency with which labor, land, and capital are transformed into agricultural output. According to Yujiro Hayami and Vernon Ruttan (1985), technological progress in agriculture constitutes the primary source of long-term productivity growth, particularly in developing countries characterized by limited arable land and increasing demographic pressures. Likewise, World Bank reports (2020) emphasize that the adoption of modern agricultural technologies contributes to higher yields, improved production efficiency, and reduced wastage of productive resources. Consequently, technological advancement is widely recognized as a strategic mechanism for achieving sustainable agricultural growth and strengthening food security.

Modern agricultural inputs play a crucial role in enhancing agricultural productivity by improving the efficiency of resource utilization and increasing output per unit of land. Chemical fertilizers (FERT) are among the most important technological inputs because they improve soil fertility and replenish nutrients depleted through continuous cultivation. Empirical literature indicates that the rational use of fertilizers is strongly associated with higher crop yields, especially in intensive farming systems where nutrient depletion is more pronounced. The Food and Agriculture Organization (2019) demonstrates that increased fertilizer use in developing countries has directly contributed to agricultural growth and food security, while also emphasizing the need to address environmental concerns linked to excessive fertilizer application. Similarly, Xiaohui Zhang et al. (2015) reports a strong positive relationship between fertilizer use and crop productivity, although this relationship may exhibit nonlinear characteristics depending on production conditions and environmental constraints. These findings suggest that fertilizer efficiency depends not only on the quantity used but also on the effectiveness of input management and allocation.

Modern irrigation systems (IRR), such as drip and sprinkler irrigation technologies, are also considered among the most significant innovations for improving agricultural value added, particularly in arid and semi-arid environments where water scarcity represents a structural constraint. These irrigation systems increase water-use efficiency by minimizing water losses and ensuring more precise water distribution across cultivated land. As a result, they contribute to higher productivity per hectare and greater production stability under adverse climatic conditions. According to the Organisation for Economic Co-Operation and Development (2021), investment in modern irrigation infrastructure enhances agricultural resilience and mitigates fluctuations in agricultural output caused by drought shocks and irregular rainfall patterns. In countries such as Algeria, where agriculture depends heavily on limited water resources, the expansion of modern irrigation systems is considered essential for sustaining long-term agricultural productivity and improving resource efficiency.

Technical efficiency constitutes another fundamental concept in the analysis of agricultural value added. Productive efficiency refers to the ability of the agricultural sector to obtain the maximum possible output from a given combination of production inputs. Economic theory distinguishes between technical efficiency and allocative efficiency, where technical efficiency measures the extent to which production approaches the optimal output frontier. According to Michael Farrell (1957), technical efficiency reflects the capacity of producers to minimize waste in resource utilization while maximizing production outcomes. In the agricultural context, higher technical efficiency implies more effective management of productive resources, greater adoption of technological innovations, and improved organization of farming activities.

Input intensity also plays an important role in shaping agricultural productivity performance. Input intensity refers to the degree of dependence on productive resources such as fertilizers, irrigation systems, and mechanization per unit of cultivated land. Higher input intensity is generally associated with increased agricultural yields because it enhances the productive capacity of farmland. However, excessive reliance on intensive inputs may also generate environmental consequences, including soil degradation and water depletion, if resource use is not managed sustainably. Empirical studies indicate that incorporating technological input variables into logarithmic production functions enables estimated coefficients to be interpreted directly as production elasticities, thereby facilitating the analysis of the relative contribution of each input to agricultural output. As highlighted by Tim Coelli et al. (2005), this econometric specification provides deeper insight into production dynamics and improves the evaluation of the technological determinants of agricultural productivity growth.

5 AGRICULTURAL LABOR MARKET AND PRODUCTION STRUCTURE

Agricultural labor constitutes a fundamental component of the agricultural production process, representing the labor input that interacts with land, capital, and technology to generate agricultural value-added. Within the framework of classical production theory, labor is considered one of the principal productive factors influencing the level of agricultural output and the efficiency of resource utilization. The agricultural production function can therefore be represented as follows:

$$Y = f(K, L, T)$$

where L denotes agricultural labor. According to Theodore Schultz (1964), agriculture in developing countries depends heavily on human labor, and improving the skills and capabilities of agricultural workers represents a crucial mechanism for increasing productivity and enhancing rural incomes. Similarly, Douglas Gollin (2010) argues that the contribution of agricultural labor to economic growth depends not only on the quantity of labor employed but also on labor efficiency and the availability of complementary technologies that improve production performance. Consequently, agricultural labor should be viewed not merely as a quantitative input, but as a strategic productive resource whose effectiveness is closely linked to technological progress, education, and institutional development.

Hidden or disguised unemployment represents one of the major structural characteristics of the agricultural sector in many developing economies. This phenomenon occurs when the number of workers employed in agriculture exceeds the actual labor requirements needed to maintain existing production levels, resulting in very low or even negligible marginal productivity of labor. In such situations, the withdrawal of a portion of the agricultural workforce may occur without causing any significant decline in total agricultural output. The dual-sector model developed by Arthur Lewis (1954) explains that surplus labor in traditional agriculture can be gradually transferred to the industrial sector without negatively affecting agricultural production during the early stages of economic development. According to this theoretical perspective, structural transformation begins with the reallocation of excess labor from low-productivity agricultural activities toward more productive industrial and service sectors. Recent empirical studies further suggest that persistent hidden unemployment weakens productivity in the agricultural sector, reduces labor productivity, and limits agriculture's contribution to long-term economic growth. This implies that improving labor allocation and increasing labor productivity are essential conditions for enhancing agricultural competitiveness and promoting sustainable rural development.

Structural transformation in the agricultural economy refers to the gradual movement of labor and economic resources from low-productivity agricultural activities toward higher-productivity sectors such as industry and services. This process constitutes one of the defining characteristics of economic development because it reflects changes in the structure of production, employment, and income generation within the economy. According to Simon Kuznets (1973), a declining share of agricultural employment in the total labor force represents a major indicator of economic modernization and structural change. As economies develop, productivity improvements in agriculture reduce the sector's labor requirements, enabling workers to transition toward more productive non-agricultural sectors. However, successful structural transformation requires sustained improvements in agricultural productivity to ensure that food production remains stable despite the declining agricultural labor share. In this regard, Peter Timmer (2009) emphasizes that increasing agricultural productivity is a prerequisite for achieving balanced structural transformation without generating food insecurity or widening rural poverty. Therefore, agricultural development and structural transformation should be viewed as complementary processes in which productivity growth within agriculture facilitates broader economic diversification and long-term development sustainability.

6 EMPIRICAL STUDY

6.1 General Overview of the Empirical Study

This empirical study aims to analyze and measure the impact of climate and technological changes on the productivity performance of Algeria's agricultural sector over the period 1999–2023, amid accelerating climate change, increasing pressures on water resources, and efforts to modernize the agricultural production system.

The agricultural sector in Algeria represents a fundamental pillar for achieving food security and diversifying the economic base beyond hydrocarbons. However, it remains highly sensitive to climatic shocks, particularly fluctuations in rainfall, rising temperatures, and limited water resources. Public policies have sought to enhance productivity by expanding irrigated areas, promoting the use of modern inputs such as fertilizers, and optimizing the allocation of agricultural labor.

The study is based on the central hypothesis that agricultural value added is determined not only by traditional factors (labor and inputs) but is also significantly influenced by climatic and structural transformations affecting the Algerian economy. Understanding the nature of these relationships, in both the short and long term, is crucial for formulating more efficient and sustainable agricultural policies.

To achieve this objective, the study employs an empirical approach based on the autoregressive distributed Lag (ARDL) model, given its suitability for small time series samples and its ability to test long-term equilibrium relationships among the variables, as well as to extract short-term dynamics through the error correction model (ECM).

Annual data covering 1999–2023 are used. Agricultural value added is measured by the sector's value-added at constant prices, climatic changes are represented by average rainfall and temperature, while technological and structural changes are proxied by the share of irrigated land, fertilizer usage, agricultural labor, and the annual freshwater withdrawal for agriculture.

6.2 Variables and Data Sources

6.2.1 Dependent Variable

Agricultural value-added (AVA**):** the study uses agricultural value-added at constant USD prices as an indicator of productivity performance, as it reflects the sector's contribution to real GDP, excluding inflationary effects. The natural logarithmic transformation (lnAVA) is applied for the following reasons:

- To reduce heteroscedasticity;
- To interpret coefficients as long-term elasticities;
- To improve time series properties.

6.2.2 Independent Variables

The independent variables are divided into two groups: climatic variables and technological/structural variables.

Climatic Variables:

- Average temperature (TEM**P):** Annual average temperature is used as a proxy for thermal climate changes that may affect crop performance, particularly under increasing heat waves. No logarithmic transformation is applied.
- Annual freshwater withdrawal for agriculture (WAT**):** Measures the volume of water used in agricultural activities (m³ per capita per year), reflecting pressure on water resources, a critical factor in irrigated agriculture. The logarithmic transformation (lnWAT) is applied for elasticity analysis.

Technological and Structural Variables:

- Irrigated Land (IRR): Represents the percentage of agricultural land that is irrigated, serving as a direct indicator of agricultural infrastructure modernization and the shift toward intensive farming. Logarithmic transformation (lnIRR) is applied.
- Fertilizer usage (FERT): Measured in kilograms per hectare of agricultural land (kg/ha), reflecting the level of production intensification and technological advancement. The logarithmic transformation (lnFERT) is applied to estimate productivity elasticities.
- Agricultural labor (LAB): Measured as the percentage of labor employed in agriculture relative to total employment, reflecting the sector's structural dimension. A higher value may indicate traditional farming practices or labor-intensive agriculture. No logarithmic transformation is applied due to its relative nature.

To improve the statistical properties of the data and allow coefficient interpretation in elasticity terms, logarithmic transformations were applied to variables measured in absolute quantities, namely agricultural value added (AVA), water resources (WAT), irrigated land (IRR), and fertilizer use (FERT). Logarithmic transformation helps reduce potential heteroscedasticity, smooth fluctuations, and facilitates the interpretation of estimated coefficients as elasticities.

In contrast, average temperature (TEMP) and agricultural labor (LAB) were retained at their original levels. Temperature is measured in degrees Celsius and may take values for which a logarithmic transformation would provide limited economic interpretation. Likewise, agricultural labor is expressed as a percentage share of total employment rather than as an absolute quantity. Maintaining these variables at levels preserves their direct economic interpretation and ensures consistency with their measurement scales.

6.3 Justification for the Study Period (1999–2023)

This period was selected because it provides homogeneous data for all variables and reflects:

- The post-agricultural reform era.
- Expansion of agricultural support programs.
- Rising impact of climate change.
- Economic shocks (2014 and 2020).

6.4 Data Sources

- World Bank, World Development Indicators (WDI)
- World Bank Group, Climate Change Knowledge Portal
- Food and Agriculture Organization (FAO – FAOSTAT)
- AQUASTAT database (FAO)

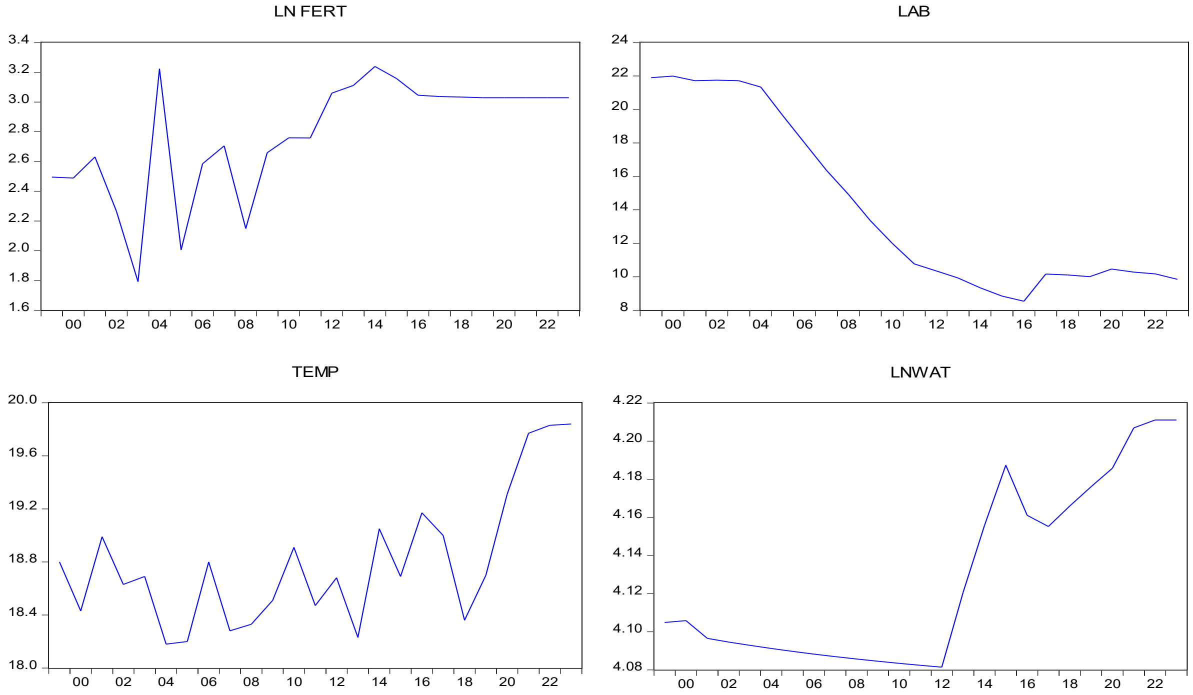
6.5 Descriptive Analysis of Study Variables

The next step involves a descriptive statistical analysis of the variables under study, providing insights into their distribution, trends, and potential correlations, which will inform the subsequent econometric modeling.

Table 1. *Evolution of Determinants of Agricultural Value-Added in Algeria (1999–2023)*

Year	lnAVA	lnWAT	lnIRR	LAB	lnFERT	TEMP
1999	22.71	4.10	2.81	21.90	2.49	18.80
2000	22.66	4.11	2.82	22.00	2.49	18.43
2001	22.78	4.10	2.82	21.72	2.63	18.99
2002	22.79	4.09	2.82	21.75	2.27	18.63
2003	22.90	4.09	2.82	21.72	1.79	18.69
2004	22.94	4.09	2.85	21.34	3.22	18.18
2005	22.97	4.09	2.85	19.65	2.01	18.20
2006	23.05	4.09	2.85	18.00	2.58	18.80
2007	23.07	4.09	2.85	16.37	2.71	18.28
2008	23.04	4.09	2.85	14.93	2.15	18.33
2009	23.25	4.08	2.85	13.34	2.66	18.51
2010	23.31	4.08	2.85	12.00	2.76	18.91
2011	23.40	4.08	2.86	10.77	2.76	18.47
2012	23.49	4.08	2.86	10.35	3.06	18.68
2013	23.61	4.12	2.86	9.93	3.11	18.23
2014	23.64	4.16	2.86	9.35	3.24	19.05
2015	23.71	4.19	2.86	8.85	3.16	18.69
2016	23.72	4.16	2.85	8.54	3.05	19.17
2017	23.68	4.16	2.85	10.16	3.04	19.00
2018	23.71	4.17	2.85	10.11	3.03	18.36
2019	23.74	4.18	2.85	10.01	3.03	18.70
2020	23.77	4.19	2.85	10.47	3.03	19.31
2021	23.74	4.21	2.85	10.28	3.03	19.77
2022	23.80	4.21	2.85	10.17	3.03	19.83
2023	23.83	4.21	2.85	9.85	3.03	19.84

Source: World Bank



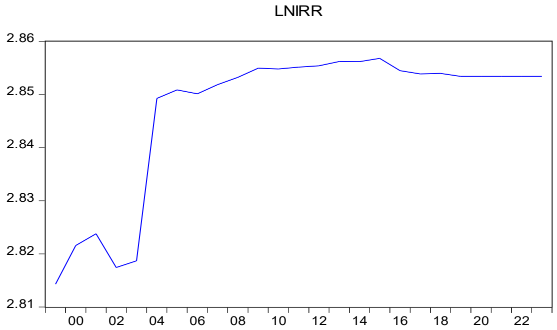


***Figure 2**. Evolution of Determinants of Agricultural Value-Added in Algeria (1999–2023)*

Source: Authors' own elaboration based on EViews outputs

The descriptive statistical analysis of the study variables over the period 1999–2023 reveals important quantitative characteristics reflecting the evolution of Algeria's agricultural sector. The mean of the natural logarithm of agricultural value-added (lnAVA) was approximately 23.29, with a median of 23.40, a standard deviation of about 0.38, and a range from a minimum of 22.66 to a maximum of 23.83. These results indicate a relatively stable upward trend with low dispersion, reflecting gradual and balanced growth over time.

Annual freshwater withdrawals for agriculture (lnWAT) recorded a mean of around 4.12, with a median close to the mean, a relatively low standard deviation of 0.04, and a range from 4.08 to 4.21, suggesting relative stability in water resource utilization with a slight upward tendency in recent years.

For irrigated land (lnIRR), the mean was approximately 2.85, with a nearly identical median, a very low standard deviation of 0.01, and a narrow range between 2.81 and 2.86, indicating structural stability in cultivated areas during the study period.

In contrast, agricultural labor (LAB) showed an average share of about 13.9% of total employment, with a median slightly below the mean, a relatively high standard deviation of 4.8 percentage points, and a wide range between 8.54% and 21.99%. This reflects clear structural shifts and a gradual decline in the sector's contribution to overall employment.

Fertilizer usage (lnFERT) recorded a mean of approximately 2.83, with a median close to the mean, a moderate standard deviation of 0.36, and a range between 1.79 and 3.24, indicating noticeable fluctuations in agricultural input intensification, particularly during the early years of the period compared to later years.

Finally, the average annual temperature (TEMP) was about 18.80°C, with a median close to the mean, a standard deviation of roughly 0.45, and a range from 18.18°C to 19.84°C, reflecting a gradual upward trend in recent years consistent with climate change indicators.

Overall, the results show a clear convergence between means and medians for most variables, suggesting the absence of severe distributional skewness. The highest relative dispersion was observed for agricultural labor and fertilizer usage, while irrigated areas and water resources remained relatively stable. These findings provide a solid descriptive foundation for proceeding to econometric analysis and stationarity tests.

6.6 Theoretical Formulation of the Econometric Model

The study is based on an extended agricultural production function, assuming that agricultural value-added is determined by a set of climatic factors, production inputs, and natural resources. Accordingly, the theoretical relationship can be expressed as follows:

$$AVA_t = f(WAT_t, IRR_t, LAB_t, FERT_t, TEMP_t)$$

In its linear econometric specification

$$\ln AVA_t = \beta_0 + \beta_1 \ln WAT_t + \beta_2 \ln IRR_t$$
$$+ \beta_3 LAB_t + \beta_4 \ln FERT_t + \beta_5 TEMP_t + \varepsilon_t$$

6.7 Adopted Econometric Methodology: Rationale for Choosing the ARDL Model

The ARDL (autoregressive distributed lag) model was selected for the following reasons:

- Its suitability for small sample sizes (25 years).
- Its ability to accommodate variables is integrated of order I(0) or I(1).
- A capacity to estimate both short-term and long-term relationships simultaneously.

6.8 Determination of Lag Lengths

Before conducting unit root tests, it is essential to determine the optimal lag lengths. The results obtained for the study's time series are summarized in the following table:

Table 2. Determination of Optimal Lag Lengths for the Study's Time Series

Variable	LR	FPE	AIC	SC	HQ	Selected Lag
LNAVA	1	1	1	1	1	1
LAB	2	2	2	2	2	2
LNFERT	3	3	3	3	3	3
LNIRR	3	4	4	3	4	3
LNWAT	1	2	2	1	2	1
TEMP	1	1	1	1	1	1

Source: Authors' own elaboration based on EViews outputs

The results of the lag selection criteria indicate variation in the optimal lag lengths across the study variables. A single lag was selected for both LNAVA and TEMP, two lags for LAB, three lags for LNFERT, three lags for LNIRR, and one lag for LNWAT, based on the Schwarz Criterion, which is considered the most appropriate for small sample sizes. This variation reflects the different dynamic properties of each variable within the study's time frame.

6.9 Unit Root Tests for Study Variables

Several tests can be employed to assess the stationarity of time series. In this study, we used the augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests.

Null Hypothesis (H_0): The series contains a unit root (i.e., it is non-stationary).

The results of the ADF and PP tests at the 5% significance level indicate that all study variables (LNAVA, LAB, LNFERT, LNIRR, LNWAT, TEMP) are non-stationary at levels, as the calculated t-statistics did not exceed the critical values needed to reject the null hypothesis of a unit root. Although some partial indications of stationarity appeared in the PP test for certain variables, the conservative decision rule leads to considering all variables as non-stationary at the level.

Table 3. Unit Root Test Results for the Study Variables

Var.	ADF-T	ADF-I	ADF-N
LNAVA	-2.114	-1.030	-0.245
LAB	-2.301	-1.783	-0.864
LNFERT	-1.884	-0.754	-0.331
LNIRR	-2.918	-2.470	-1.422
LNWAT	-1.263	-0.502	0.118
TEMP	-2.102	-1.746	-0.947
Var.	PP-T	PP-I	PP-N
LNAVA	-2.210	-1.077	-0.987
LAB	-2.134	-1.293	-0.745
LNFERT	-3.901*	-3.348*	-1.112
LNIRR	-3.682*	-3.254*	-1.305
LNWAT	-1.112	0.260	0.432
TEMP	-2.045	-1.562	-0.876

Source: Authors' own elaboration based on EViews outputs

Consequently, the time series requires first-differencing to achieve stationarity, which is a prerequisite for determining the appropriate econometric methodology for analyzing long-run relationships.

To transform the non-stationary series into a stationary one, the first-difference method is applied. Re-testing the series at first differences yields the following results:

Table 4. Unit Root Test Results for the Study Variables at First Difference

10	ADF-T	ADF-I	ADF-N
ΔLNAVA	-5.447	-5.214	-4.982
ΔLAB	-5.118	-4.902	-4.631
ΔLNFERT	-6.781	-6.554	-6.302
ΔLNIRR	-6.144	-5.963	-5.741
ΔLNWAT	-4.832	-4.611	-4.388
ΔTEMP	-5.513	-5.294	-5.027
Var.	PP-T	PP-I	PP-N
ΔLNAVA	-5.562	-5.337	-5.104
ΔLAB	-5.238	-5.016	-4.744
ΔLNFERT	-6.902	-6.693	-6.418
ΔLNIRR	-6.318	-6.097	-5.863
ΔLNWAT	-4.964	-4.739	-4.511
ΔTEMP	-5.636	-5.417	-5.142

Source: Authors' own elaboration based on EViews outputs

6.10. Estimation of the ARDL Model: General Specification of the Model

The ARDL model estimated for the Algerian agricultural production dynamics is expressed as follows:

$$\Delta LNAV_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i \Delta LNAV_{t-i} + \sum_{i=1}^{p} \beta_j \Delta LAB_{t-i} +$$
$$\sum_{i=0}^{q} \gamma_k \Delta LNFERT_{t-j} + \sum_{r=0}^{k} \delta_m \Delta LNIRR_{t-k} + \sum_{m=0}^{s} \phi_n \Delta LNWAT_{t-m}$$
$$+ \sum_{n=0}^{u} \lambda_S \Delta TEMP_{t-n} + \lambda_1 LNAV_{t-1} + \lambda_2 LAB_{t-1} +$$
$$\lambda_3 LNFERT_{t-1} + \lambda_4 LNIRR_{t-1} + \lambda_5 LNWAT_{t-1}$$
$$+ \lambda_6 TEMP_{t-1} + \varepsilon_t$$

$$D(DLNAVA) = 0.048364347336 - 1.292565236366 * DLNAVA(-1)$$
$$-0.031660041286 * DLAB{**} + 0.060469944728 * DLNFERT{**}$$
$$-2.290010091832 * DLNIRR{**} + 0.276720743483 * (DLNAVA$$
$$-) - 0.02449396 * DLAB(-1) + 0.04678290 * DLNFERT(-1)$$
$$-1.77167854 * DLNIRR(-1) + 0.21408648 * DLNWAT(-1)$$
$$-0.00333471 * DTEMP(-1) + 0.03741734\ ) - 0.004310334529 * DTEMP{**}\ )$$

6.11 Economic Interpretation

The ARDL estimation highlights a strong short-run corrective mechanism in the growth of agricultural value-added. The lagged dependent variable coefficient, DLNAVA(−1) = −1.292, indicates sharp negative feedback to previous period fluctuations. This implies that higher growth in the preceding period tends to be followed by a relative slowdown, reflecting a cyclical and moderately unstable pattern in agricultural activity.

Labor (DLAB): The coefficient for agricultural labor is −0.0316, significant and negative, suggesting low labor productivity, potential disguised unemployment, or limited technical efficiency.

Fertilizer Use (DLNFERT): The coefficient 0.0604 is positive and statistically significant, indicating that a 1% increase in fertilizer use raises short-run agricultural value added by approximately 0.06%, confirming the crucial role of input intensification in enhancing productivity.

Irrigated Land (DLNIRR): The coefficient −2.290 is negative and significant. The negative coefficient associated with irrigated land in both the short and long run appears to contradict the conventional theoretical expectation that irrigation improves agricultural value added through enhancing water-use efficiency and stabilizing production. However, this result may reflect several structural and institutional factors specific to the Algerian agricultural sector rather than indicating that irrigation is inherently harmful to productivity.

One possible explanation relates to inefficiencies in irrigation governance and water allocation mechanisms, where the expansion of irrigated areas may not necessarily be accompanied by improvements in productive efficiency or modern irrigation practices. In addition, the descriptive statistics reveal very limited variation in the irrigated land variable over the study period, suggesting that the variable may capture structural rigidity more than dynamic productivity effects. Such low variability can reduce the explanatory power of the variable and may partially affect the statistical stability of the estimated coefficient.

Furthermore, the expansion of irrigated areas may involve transitional adjustment costs, including infrastructure inefficiencies, high water losses, or suboptimal allocation of water resources across agricultural activities. Consequently, the estimated negative coefficient should not be interpreted as evidence that irrigation reduces agricultural value added in absolute terms, but rather as an indication that the current structure and management of irrigation systems may limit their productive contribution under existing institutional and climatic conditions.

Temperature (DTEMP): The negative coefficient −0.0043 demonstrates the sector’s sensitivity to climatic shocks, though the short-run magnitude is relatively modest.

In the long-run equilibrium, the model shows structural relationships:

- Labor coefficient: −0.0244
- Fertilizer coefficient: 0.0467
- Irrigation coefficient: −1.7716
- Water resources coefficient: 0.2140
- Temperature coefficient: −0.0033

These long-run coefficients indicate that material inputs, such as fertilizers and water, play a dominant role in sustaining productivity, while labor remains structurally less productive and climate factors continue to exert a negative influence.

The error correction term (ECT) coefficient of 0.2767 implies that approximately 27.7% of deviations from the long-run equilibrium are corrected within a single period, reflecting a moderate speed of adjustment. Multiple periods are required to fully absorb shocks and restore equilibrium.

Overall, the results reveal a growth pattern primarily driven by input intensification, constrained by structural and climatic limitations that reduce the efficiency and long-term sustainability of agricultural production.

6.12 Long-Run Relationship Test (Bounds Test):Formulation of Hypotheses

The following hypothesis is tested:

$$H_0 : \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = \lambda_6 = 0$$

Null Hypothesis (H_0): There is no long-run equilibrium relationship between the dependent variable and the independent variables.

Alternative Hypothesis (H_1): At least one coefficient is non-zero, i.e., a long-run relationship exists between the variables.

Table 5. Cointegration Test Results According to the ARDL Approach

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	6.48	10%	2.08	3
		5%	2.39	3.38
		2.5%	2.7	3.73
		1%	3.06	4.15

Source: Authors' own elaboration based on EViews outputs

The results of the Bounds Test indicate that the F-statistic reached 6.482666, exceeding the upper critical value at the 1% significance level (4.15). Therefore, the null hypothesis of no long-run relationship between the variables under study is rejected. This finding confirms the existence of a stable long-run equilibrium relationship, which justifies the estimation of long-run coefficients and the derivation of the error correction model (ECM) to analyze the dynamics of adjustment toward equilibrium.

6.13 Estimation of the Error Correction Model (ECM)

Based on the results obtained from the Bounds Test, which confirmed the existence of cointegration among the variables under study, it becomes necessary to estimate the error correction model (ECM) in order to analyze and diagnose the speed of adjustment coefficient.

Previous studies indicate that this coefficient confirms the presence of a cointegration relationship between the variables if it satisfies two essential conditions: it must be negative and statistically significant.

The Error Correction Model can be expressed in the following general form:

Model Specification

$$\Delta LNAVA_t = \psi_0 + \sum \psi_i \Delta X_t + \eta ECM_{t-1} + \varepsilon_t$$

Where:

$$ECM_{t-1} = \Delta LNAV_{t-1} - \theta_1 \Delta LNAV_{t-1} - \theta_2 \Delta LAB_{t-1} - \theta_3 \Delta LNFERT_{t-1}$$
$$- \theta_4 \Delta LNIRR_{t-1} - \theta_5 \Delta LNWAT_{t-1}$$

Table 6. Estimated Results of the Error Correction Model (ECM)

ECM Regression				
Case 2: Restricted Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
CointEq(-1)*	-1.29	0.16	-7.89	0.00

Source: Authors' own elaboration based on EViews outputs

The results of the Error Correction Model (ECM) derived from the ARDL framework indicate that the coefficient of the error correction term, CointEq(−1), is negative and statistically significant, with a value of −1.2926 (t = −7.899, p = 0.000). The negative sign confirms the existence of a long-run equilibrium relationship between agricultural value added and the explanatory variables included in the model, while the high statistical significance reflects the robustness of the adjustment mechanism toward equilibrium.

From an economic perspective, the magnitude of the coefficient indicates a rapid response of the agricultural sector to short-run shocks and fluctuations, as the sector tends to return relatively quickly to its long-run equilibrium path. However, since the coefficient exceeds −1 in absolute value, the adjustment process may not occur in a perfectly smooth and monotonic manner. Instead, it may involve temporary overshooting around the equilibrium level before gradually stabilizing.

This behavior can be explained by the high sensitivity of agricultural activity in Algeria to climatic fluctuations, changes in production inputs, and certain structural rigidities that may affect the sector's short-run adjustment capacity. Therefore, although the results confirm a strong ability to correct disequilibrium, they also suggest the possibility of short-term fluctuations around the long-run equilibrium path.

6.14 Diagnostic and Stability Tests

6.14.1 Autocorrelation Test (Breusch-Godfrey)

Hypotheses:

H_0: No autocorrelation in the residuals

H_1: Presence of autocorrelation in the residuals

Table 7. Results of the Serial Correlation Test (Breusch–Godfrey LM)

Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	0.84	Prob. F(2,14)	0.45
Obs*R-squared	2.47	Prob. Chi-Square(2)	0.29

Source: Authors' own elaboration based on EViews outputs

The results of the Breusch–Godfrey test indicate the absence of serial correlation in the residuals of the model, as the p-values exceed the 5% significance level. This confirms the validity of the classical assumption of independent random errors and reinforces the reliability of the estimated results.

6.14.2 Conditional Heteroskedasticity Test (ARCH)

Test hypotheses:

H_0: No conditional heteroskedasticity exists.

H_1: Conditional heteroskedasticity of the ARCH type is present.

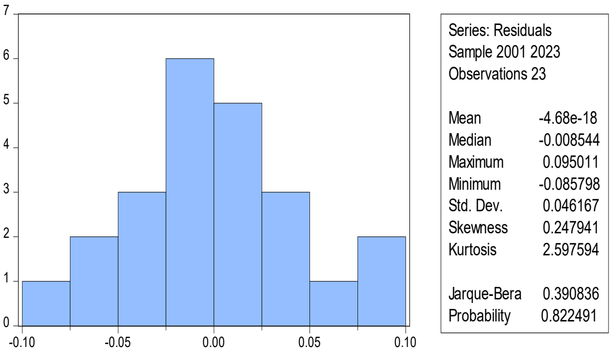
Table 8. Conditional Heteroskedasticity Test (ARCH Test)

Heteroskedasticity Test: ARCH			
F-statistic	0.00	Prob. F(1,20)	0.98
Obs*R-squared	0.00	Prob. Chi-Square(1)	0.98

Source: Authors' own elaboration based on EViews outputs

The very high p-values ($p > 0.05$) indicate that the ARCH test is not statistically significant. In other words, there is no evidence of conditional heteroskedasticity in the residuals, meaning that the null hypothesis of constant variance (homoskedasticity) cannot be rejected. This implies that the residual variance remains stable over time, with no discernible pattern of increase or decrease associated with previous periods.

6.14.3 Normality Test (Jarque-Bera)



```
Series: Residuals
Sample 2001 2023
Observations 23

Mean        -4.68e-18
Median      -0.008544
Maximum      0.095011
Minimum     -0.085798
Std. Dev.    0.046167
Skewness     0.247941
Kurtosis     2.597594

Jarque-Bera  0.390836
Probability  0.822491
```

Figure 2. Results of the residual normality test (Jarque-Bera) and descriptive statistics

Source: Authors' own elaboration based on EViews outputs

The results of the residual normality test indicate that the mean of the errors is extremely close to zero (−4.68E−18), confirming the absence of any systematic bias in the estimation. The standard deviation is 0.0461, reflecting relatively limited dispersion around the mean. Regarding the shape of the distribution, the skewness coefficient (Skewness = 0.2479) is slightly positive, indicating relative symmetry without significant asymmetry, while the kurtosis coefficient (Kurtosis = 2.5975) is close to the theoretical value for a normal distribution (3), suggesting no heavy tails or influential outliers. Importantly, the Jarque-Bera test yielded a statistic of 0.3908 with a high p-value of 0.8225 (> 0.05), indicating that the null hypothesis of normally distributed residuals cannot be rejected. Therefore, the assumption of normality is statistically satisfied, enhancing the reliability of the model's coefficients and associated significance tests, and supporting the validity of the economic conclusions drawn from the estimation over the period 2001–2023 (23 observations).

6.14.4 Stability Tests: CUSUM

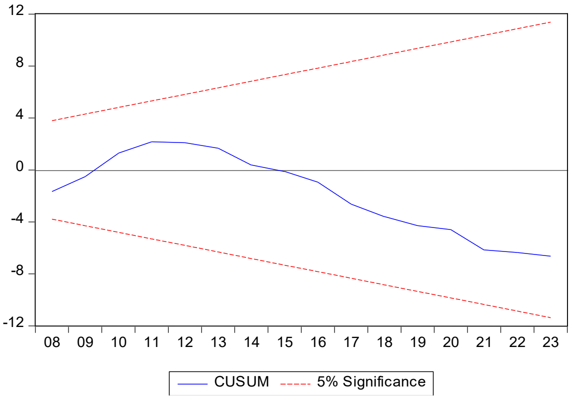


Figure 3. Stability of the model's dynamic structure using the CUSUM test

Source: Authors' own elaboration based on EViews outputs

The results of the CUSUM test indicate that the cumulative sum of recursive residuals remained within the 5% significance bounds throughout the study period, demonstrating the stability of the model's coefficients and the absence of any significant structural breaks. Therefore, the model exhibits a high degree of structural stability, which reinforces the reliability of the estimation results and the validity of the derived economic conclusions.

CUSUMSQ:

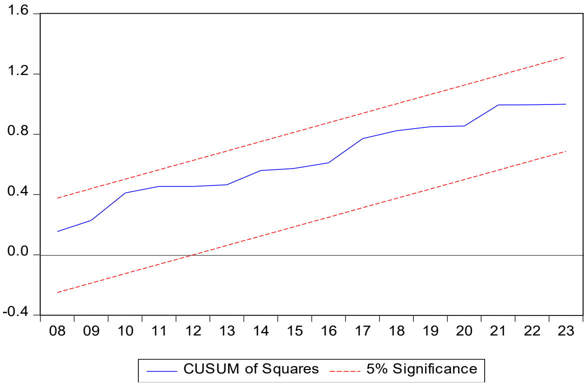


Figure 4. Stability of the model's dynamic structure using the CUSUM of Squares test

Source: Authors' own elaboration based on EViews outputs

The results of the CUSUMSQ test indicate that the cumulative sum of squares of the recursive residuals remained within the 5% significance bounds throughout the study period, demonstrating the stability of the error variance and the absence of any major structural breaks. Accordingly, it can be confirmed that the model exhibits a high degree of structural stability, which reinforces the reliability of the obtained estimation results.

7. ANALYSIS OF RESULTS

The empirical findings confirm the existence of a stable long-run relationship between agricultural value added and its climatic, technological, and structural determinants in Algeria. This result suggests that agricultural performance is shaped by the interaction of productive inputs, resource availability, and climatic conditions rather than by short-term fluctuations alone.

The positive effects of fertilizer use and water resources indicate that agricultural value added remains strongly dependent on the availability and efficient utilization of productive inputs. These findings are consistent with agricultural production theory, which emphasizes the importance of technological inputs in improving productive efficiency and supporting long-term agricultural growth.

In contrast, the negative effect of temperature highlights the vulnerability of Algerian agriculture to climate change. Rising temperatures increase production risks and place additional pressure on already limited natural resources, particularly water. This result supports the growing body of evidence suggesting that climate-related stresses represent a major challenge for agricultural sustainability in semi-arid regions.

The negative coefficient associated with agricultural labor may reflect persistent structural inefficiencies, including low labor productivity and the presence of disguised unemployment. This finding suggests that improvements in agricultural performance depend not only on the quantity of labor employed but also on the efficiency with which labor is combined with technology and other productive resources.

The negative effect of irrigated land should not be interpreted as evidence that irrigation reduces agricultural performance. Rather, it may reflect inefficiencies in irrigation management, suboptimal allocation of water resources, transitional adjustment costs, or the limited variability of the irrigation variable over the study period. Consequently, expanding irrigated areas alone may not be sufficient to improve agricultural outcomes without corresponding improvements in water governance and resource-use efficiency.

Finally, the significant error correction mechanism confirms that deviations from long-run equilibrium are corrected over time. However, the relatively large adjustment coefficient suggests that the adjustment process may involve temporary overshooting and short-run fluctuations around the equilibrium path before stability is fully restored.

Overall, the results indicate that sustainable growth in Algeria's agricultural sector depends on improving resource-use efficiency, strengthening technological modernization, and enhancing adaptation to climate-related challenges.

8. RECOMMENDATIONS

Based on the empirical findings, several policy recommendations can be proposed to improve the efficiency and resilience of Algeria's agricultural sector. First, agricultural labor productivity should be enhanced through technical training programs, modernization of farming practices, and improved integration between labor and agricultural technologies. Policies should prioritize productive efficiency rather than merely expanding agricultural employment.

Second, the positive contribution of fertilizer use suggests the need to support technologically advanced and productivity-enhancing agricultural inputs while maintaining environmental sustainability. This requires promoting precision agriculture techniques and improving monitoring systems for input utilization.

Third, the negative effect associated with irrigated land highlights the importance of improving water management rather than simply expanding irrigated areas. Greater emphasis should be placed on efficient irrigation technologies, better governance of water resources, and policies aimed at optimizing water-use efficiency in agricultural production.

Fourth, climate adaptation strategies should become a central component of agricultural policy. This includes developing drought-resistant crops, strengthening climate-risk monitoring systems, and expanding agricultural insurance mechanisms to reduce the vulnerability of farmers to climatic shocks.

Finally, policymakers should adopt an integrated development strategy combining technological modernization, institutional reform, efficient resource management, and climate adaptation in order to promote sustainable agricultural growth and improve the sector's long-term resilience.

9.LIMITATIONS OF THE STUDY

The study is based on annual time-series data covering the period 1999–2023, which results in a relatively small sample size. Although the ARDL approach is appropriate for small samples, the inclusion of multiple explanatory variables, lag structures, and an error correction specification may increase the risk of over-parameterization. In addition, the annual frequency of the data may limit the ability to capture short-term fluctuations and structural changes in agricultural value added. Therefore, the results should be interpreted with appropriate caution.

Among the most important limitations that should be acknowledged in this study is the potential presence of endogeneity issues in some of the explanatory variables. Variables such as fertilizer use, irrigation, and water consumption cannot be considered fully exogenous, as improvements in agricultural Value Added may themselves lead to increased use of these inputs. This creates a potential bidirectional relationship between cause and effect, rather than a strictly one-way causal link.

Although the ARDL model is well-suited for analyzing dynamic relationships in time-series data and helps to mitigate several econometric issues, it does not fully address the problem of reverse causality. Therefore, the results should be interpreted with some degree of caution, recognizing that some of the estimated relationships may reflect mutual interactions between variables rather than purely unidirectional effects.

Another limitation concerns the measurement of irrigation. The irrigated land variable captures the extent of irrigated areas but does not directly reflect irrigation efficiency, water-use management practices, or differences in irrigation technologies. Consequently, the estimated coefficient may partly capture structural or institutional factors that are not fully observable in the available data.

Finally, the analysis relies on national-level aggregate data, which may conceal substantial regional disparities in climatic conditions, water availability, and agricultural production systems across Algeria. Future research could benefit from the use of regional or farm-level data to provide a more detailed assessment of climate technology interactions and their effects on agricultural performance.

10. CONCLUSIONS

This study investigated the impact of climatic, technological, and structural factors on agricultural value added in Algeria over the period 1999–2023 using the ARDL approach. Results are interpreted in light of the relatively limited sample size. The results confirmed the existence of a stable long-run relationship between agricultural value added and its key determinants, indicating that agricultural performance is influenced by both production-related factors and climatic conditions. The findings revealed that fertilizer use and water availability contribute positively to agricultural productivity, highlighting the importance of productive inputs and efficient resource utilization in supporting agricultural growth. In contrast, rising temperatures exert a negative effect, reflecting the growing vulnerability of the sector to climate-related pressures. The results also suggest that structural constraints, particularly low labor productivity and inefficiencies associated with irrigation management, continue to limit the sector’s productive potential.

Furthermore, the error correction mechanism confirms the existence of a long-run equilibrium relationship and demonstrates the sector’s capacity to adjust to short-run disturbances, although this adjustment process may involve temporary fluctuations around the equilibrium path.

Overall, the study emphasizes that achieving sustainable agricultural development in Algeria requires a balanced strategy combining technological modernization, efficient management of water and productive resources, and stronger adaptation measures to climate change. Such an approach would enhance agricultural resilience, improve productive efficiency, and support long-term food security objectives.

REFERENCES

Burke, M., Hsiang, S. M., & Miguel, E. (2015). Global non-linear effect of temperature on economic production. *Nature*, 527, 235–239. https://doi.org/10.1038/nature15725

Coelli, T. J., Rao, D. S. P., O'Donnell, C. J., & Battese, G. E. (2005). *An introduction to efficiency and productivity analysis* (2nd ed.). Springer.

Dell, M., Jones, B. F., & Olken, B. A. (2012). Temperature shocks and economic growth. *American Economic Journal: Macroeconomics, 4*(3), 66–95. https://doi.org/10.1257/mac.4.3.66

Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society: Series A (General), 120*(3), 253–290.

Food and Agriculture Organization of the United Nations. (2020). The state of food and agriculture 2020. https://www.fao.org/publications/sofa/2020/en/

Food and Agriculture Organization of the United Nations. (2022). The state of food security and nutrition in the world. https://www.fao.org/publications/sofi/2022/en/

Food and Agriculture Organization of the United Nations. (n.d.). Agricultural development reports. https://www.fao.org/agrifood-economics/en/

Food and Agriculture Organization of the United Nations. (n.d.). Climate change and policy governance. https://www.fao.org/policy-support/policy-themes/climate-change/ar

Food and Agriculture Organization of the United Nations. (n.d.). Understanding climate-smart agriculture. https://www.fao.org/policy-support/policy-themes/climate-smart-agriculture/Understanding-climate-smart-agriculture-/ar

Gollin, D. (2010). Agricultural value added and economic growth. In P. Pingali & R. Evenson (Eds.), *Handbook of agricultural economics* (Vol. 4). Elsevier.

Gujarati, D. N. (2015). *Econometrics by example*. Palgrave Macmillan.

Hayami, Y., & Ruttan, V. W. (1985). *Agricultural development: An international perspective*. Johns Hopkins University Press.

Intergovernmental Panel on Climate Change. (2021). Climate change 2021: The physical science basis. https://www.ipcc.ch/report/ar6/wg1/

Intergovernmental Panel on Climate Change. (2022). Climate change 2022: Impacts, adaptation and vulnerability. https://www.ipcc.ch/report/ar6/wg2/

International Monetary Fund. (n.d.). *Algeria country reports*. https://www.imf.org/en/Countries/DZA

Kuznets, S. (1973). Modern economic growth: Findings and reflections. *American Economic Review, 63*(3), 247–258.

Lewis, W. A. (1954). Economic development with unlimited supplies of labour. *The Manchester School, 22*(2), 139–191.

Lobell, D. B., Schlenker, W., & Costa-Roberts, J. (2011). Climate trends and global crop production. *Science, 333*(6042), 616–620. https://doi.org/10.1126/science.1204531

Organisation for Economic Co-operation and Development. (2021). Making better policies for food systems. https://www.oecd.org/agriculture/topics/food-systems/

Schultz, T. W. (1964). *Transforming traditional agriculture*. Yale University Press.

Timmer, C. P. (2009). *A world without agriculture*. American Enterprise Institute Press.

Todaro, M. P., & Smith, S. C. (2020). *Economic development* (13th ed.). Pearson.

United Nations. (n.d.). Sustainable development goals. https://sdgs.un.org/

World Bank. (2007). *World development report 2008: Agriculture for development*. World Bank.

World Bank. (2017*). Water in agriculture*. https://www.worldbank.org/en/topic/water-in-agriculture

World Bank. (2020). *Harvesting prosperity: Technology and productivity growth in agriculture*. World Bank.

World Bank. (n.d.). Algeria economic outlook. https://www.worldbank.org/en/country/algeria

World Commission on Environment and Development. (1987). *Our common future*. United Nations.

Zhang, X., et al. (2015). Managing nitrogen for sustainable development. *Nature, 528*, 51–59. https://doi.org/10.1038/nature15743

How to cite this article?

Style – APA Seventh Edition:

Belfodil, K., Mezouaghi, D., & Laref, K. (2026, July 15). Climate–technology interactions and their impact on agricultural production in Algeria. MEST Journal, 14(2), 27–46. https://doi.org/10.12709/mest.14.14.02.03

Style – Chicago 17th Edition:

Belfodil, Kamel, Djilali Mezouaghi, and Khadidja Laref. "Climate–technology interactions and their impact on agricultural production in Algeria." Edited by Zoran Čekerevac. MEST Journal (MESTE) 14, no. 2 (July 2026): 27–46. https://doi.org/10.12709/mest.14.14.02.03.

Style – GOST R 7.0.100 2018, Name Sort:

Belfodil, K., Mezouaghi, D., Laref, K. Climate–technology interactions and their impact on agricultural production in Algeria. // MEST Journal / ed. Z. Cekerevac. – Belgrade – Toronto : MESTE, 15 July. 2026. – Vol. 14, No. 2. – pp. 27–46. – DOI: https://doi.org/10.12709/mest.14.14.02.03.

Style – Harvard Anglia Ruskin:

Belfodil, K., Mezouaghi, D. & Laref, K., 2026. Climate–technology interactions and their impact on agricultural production in Algeria. MEST Journal, 14(2), pp. 27–46. Available at: https://doi.org/10.12709/mest.14.14.02.03 [Accessed dd Month yyyy].

Style – ISO 690 Numerical Reference:

Belfodil, K., Mezouaghi, D., Laref, K. Climate–technology interactions and their impact on agricultural production in Algeria. MEST Journal. 2026 July 15; 14(2): 27–46. DOI: 10.12709/mest.14.14.02.03