How to Cite:
Sara, M., & Abdallah, B. (2024). The effect of temperature on agricultural productivity: Econometric panel approach. *International Journal of Economic Perspectives*, *18*(12), 2385–2399. Retrieved from https://ijeponline.org/index.php/journal/article/view/783

The effect of temperature on agricultural productivity: Econometric panel approach

Mokhbat Sara
PhD Student, High School of Commerce, University of Manouba, Tunisia
Email: sarahmokhbat2@gmail.com

Boukrouh Abdallah
Senior Lecturer A, Faculty of Economics and Business, University of Algiers 3, Algiers, Algeria
Email: abdallah.boukrouh2018@gmail.com

***Abstract*---**Globally, the agricultural sector constitutes a significant part of economic activities and serves as the primary source of income and employment for rural populations. Representing approximately 35% of GDP in some countries, agricultural performance is highly sensitive to climatic hazards, which can disrupt crop cycles, reduce incomes, and diminish purchasing power. These disruptions often lead to rural exodus, food insecurity, and shifts in cultural practices. Using a panel data approach and a fixed-effects (FE) model, this study evaluates agricultural potential in each country through two key indicators: the capacity to cultivate cereals and the degree of water scarcity within watersheds. The findings demonstrate that enhancing agricultural potential, particularly by addressing water scarcity, significantly improves agricultural productivity. For instance, an optimal alignment with cereal cultivation requirements can boost agricultural productivity by over 4%. Conversely, severe water scarcity can reduce productivity by up to 18.25%. Effective water resource management is therefore critical in mitigating the adverse effects of rising temperatures. Additionally, incorporating measures to address food crises is essential in strategies to combat the impacts of climate change, particularly in the most vulnerable countries.

***Keywords*---**global warming, agricultural potential, agricultural efficiency, water scarcity, water resource.

Submitted: 27 September 2024, Revised: 18 November 2024, Accepted: 03 December 2024

Introduction

The issue of climate change (CC) has become increasingly prominent in public debate since the latter half of the 20th century. This heightened attention stems from significant changes in climate patterns, their growing impact on ecosystems, human societies, and activities, and the recognition that human actions are a major driver of these changes. Observations reveal accelerated increases in global average temperatures, alterations in precipitation patterns, regional variations in rainfall, intensification of extreme weather events, rising sea levels, and a decline in snow and ice cover (Climate Action Network, n.d.). These findings, as highlighted in successive reports of the Intergovernmental Panel on Climate Change (IPCC), particularly their Fifth Assessment Report (2014a), attribute 95% confidence to human responsibility for these changes.

Numerous studies document the adverse effects of climate change on agricultural efficiency across various countries (IPCC, 2007; Deressa et al., 2008; BNRCC, 2008). These impacts are particularly pronounced in low-income nations, where agriculture relies heavily on climate conditions and coping capacities are limited (Spore, 2008; Apata et al., 2009).

In recent years, farmers have struggled to predict the onset and duration of rainy seasons, complicating agricultural planning (Diop et al., 1996; Houndenou et al., 1998; AFFO, 2007). This uncertainty has led to significant challenges in crop production. For example, Diouf et al. (2000) observed a tendency toward shorter crop growth periods, a trend that began in the late 1960s in parallel with increasing aridification. Thornton et al. (2006) further confirm that climate change significantly affects the duration of crop growth periods, making it a critical concern for agricultural productivity.

Previous studies on the impact of climate change on agriculture forecast a decline in agricultural yields, particularly in tropical regions (Mendelsohn and Dinar, 1999; Kurukulasuriya and Rosenthal, 2008). These studies highlight substantial negative effects on agricultural productivity, particularly for small-scale farmers whose livelihoods heavily depend on farming output. Furthermore, according to the World Bank (2003), global warming is likely to exacerbate poverty levels.

The annual average surface temperature has been rising at a rate of 0.23°C per decade, a trend expected to persist well into the future (Brown and Caldeira, 2017; Huang et al., 2017). Agricultural production, which is essential for global food security and the livelihoods of families in many developing regions, is highly dependent on climatic and meteorological conditions. This dependency renders agriculture one of the most vulnerable sectors to the effects of climate change.

The academic community has conducted extensive research on the impacts of climate change, revealing that extreme weather events, such as floods and droughts, disproportionately affect agricultural production in developing and low-income countries compared to developed and high-income nations (Su et al., 2021; Fahad et al., 2022a). The risk of food shortages remains a pressing concern, as every 1°C increase in temperature is estimated to reduce global grain production by approximately 10% (Yi et al., 2018; Fahad et al., 2022b; Hossain et al., 2022).

As global climate variability becomes a topic of debate across all continents, it has also emerged as a priority area for scientific research, particularly through the efforts of the Intergovernmental Panel on Climate Change (IPCC). This study aims to address a critical question: What is the effect of temperature and rainfall variability on agricultural production worldwide?

Brief review of literature

The evaluation of climate change's impact on agricultural production has been the focus of extensive research. This body of work enables us to first present a theoretical framework and subsequently explore empirical studies examining the effects of climate change on agricultural productivity.

Various approaches and methods have been employed to analyze how changes in climate parameters influence agricultural output. Prominent among these are the production function approach (Adams et al., 1995), market equilibrium models (Zhai et al., 2009), and the Ricardian approach (Mendelsohn et al., 1994). Each approach offers unique strengths while compensating for the limitations of others (Mendelsohn, 2007). For instance, studies by Rosenberg (1993) and Rosenzweig & Parry (1994) use simulation techniques to modify climate factors (e.g., temperature, CO_2 concentration) and examine their impact on crop productivity, extrapolating these findings to broader economic scales. However, such simulation methods, though applied successfully in fields like psychology and sports medicine (Hsiang, 2016), face challenges in explaining economic responses to climate change across diverse regions.

Hsiang (2016) also notes that the effects of climate change assessed using long differences and panel data approaches yield comparable results, whether analyzing impacts on crop yields or economic growth. This consistency suggests that gradual climate changes produce effects similar to those seen in rapid climate shifts.

Several empirical studies further highlight the significant consequences of climate change on crop yields. For example, Amadu et al. (2020) detail its impact on maize yields, while Asfaw et al. (2016) and Coulibaly et al. (2017) underscore the broader threat of climate shocks to agricultural productivity across Africa. Other research (FAO, 2017; IPCC, 2018; Müller et al., 2011) confirms that climate-related changes jeopardize food security by exacerbating productivity losses on the continent.

Studies by Guntukula and Goyari (2020) corroborate Sarker et al. (2019), revealing that variations in temperature and rainfall significantly affect crop production efficiency. Similarly, Sinnarong et al. (2019) and Pipitpukdee et al. (2020) demonstrate negative associations between weather variables and crop yields in Thailand, with projections showing adverse impacts on rice and cassava production.

Ozdemir (2022) explored short- and long-term impacts of climate change on agricultural productivity in Asia (1980–2016) using dynamic panel autoregressive distributed lag models. The study identified a long-run relationship between climate change variables and agricultural productivity, consistent with findings by Gul et al. (2022) and Baig et al. (2022), who observed long-term effects of climate change on agricultural outputs.

Dongbei et al. (2022) examined the marginal effects of climate change on agricultural productivity using ordinary least squares and spatial Durbin model (SDM) approaches. Their findings highlight a significant negative impact of climate change, confirmed through robustness tests such as index replacement, quantile regression, and tail reduction.

Finally, Jean-Luc et al. (2023) investigated the temporal effects of temperature and precipitation variability on agricultural output. Their results indicate that temperature variability has a long-term impact on agricultural production, while precipitation variability primarily affects output in the short run.

Methodology

When examining the issue of climate change and its potential effects, early studies relied on experimental and laboratory-based methods to isolate its impact. This approach was primarily justified by the need to understand how climatic conditions influence agriculture, the sector most directly affected by climate fluctuations. This section outlines the theoretical framework and empirical specification of the model used in our study.

We adopt an agricultural perspective, a mechanism widely recognized in the literature due to the natural interplay between climate and agriculture, and its broader implications for income and economic performance. However, our approach differs from conventional studies. Rather than directly quantifying the effect of climate change on resources, we focus on measuring the interaction between Climate Change and a reference Agricultural Potential for countries. This allows us to assess countries' vulnerability to Climate Change through the lens of agricultural potential.

To address our research question, it is crucial to define a methodological framework that accounts for the empirical challenges and the specific dynamics of the climate-agriculture relationship. The theoretical model underlying this study is structured as follows:

$$\text{A Pro} = Temperature + A\ P\text{ot} + (Tempeature * A\ P\text{ot}) + \text{controls} \qquad (1)$$

To the left of equation (1), we observe our dependent variable APro, which represents agricultural productivity. On the other hand, we note our variables of interest which are temperature, APot (agricultural potential), as well as their interaction and the different controls added to our equation, which are: GDP / ha, inflation, the population growth rate, the trade index, as well as the level of education.

Temperature

In the literature, climate is typically represented by two primary factors: temperature and precipitation. For this study, we have chosen to focus on temperature. This decision is motivated by the observation that most prior studies have primarily examined the effects of rainfall. By concentrating on temperature, we aim to contribute to the literature by exploring a less commonly analyzed aspect of climate's impact.

Our sample includes a larger and more economically diverse panel of countries compared to previous studies. In this context, temperature emerges as a more comprehensive variable with tangible effects across diverse economies. Moreover, temperature projections in global climate models tend to be more consistent and reliable than those for precipitation, which often carry higher degrees of uncertainty and controversy (Burke et al., 2009). For these reasons, we emphasize temperature in our analysis, ensuring that our reasoning is as robust and free from ambiguity as possible.

In our model, global warming—represented by rising temperatures—is conceptualized as a multiplier of productivity disturbances, interacting dynamically with other variables to influence agricultural outcomes.

The climate data used in this study is sourced from the Climate Research Unit (CRU) at the University of East Anglia (UEA), an institution widely recognized as a global leader in the study of natural and anthropogenic climate change (UEA, 2017). The CRU has developed a range of datasets that are extensively utilized in climate research, including global temperature records, statistical tools, and advanced climate models.

Agricultural potential

In our model, Agricultural Potential (AP) is treated as a reference potential specific to each country. This represents the intrinsic characteristics unique to each nation, which tend to remain relatively stable over time. A higher AP indicates a country's richness in resources, enhancing its agricultural capacity, whereas a lower AP imposes greater constraints on productivity.

In this study, AP is represented by two variables: the Cereal Crop Adaptability Index (CCAI) and the Water Scarcity for major Watersheds (WSW). The CCAI reflects a country's agro-ecological potential and productivity, while the WSW measures the availability of hydrological resources. Together, these variables provide a comprehensive view of a country's agricultural and water resource potential. Both variables are sourced from the Global Agro-Ecological Zones (GAEZ) database, ensuring data reliability and consistency for our analysis.

Interaction terms

The core problem addressed in this work is evaluating the interaction between climate and Agricultural Potential (AP), specifically the interplay between temperature and either the Cereal Crop Adaptability Index (CCAI) or the Water Scarcity for major Watersheds (WSW). To capture this relationship, we constructed an interaction term by multiplying temperature (expressed as annual averages, along with other variations to be detailed later) with land quality indicators, such as levels of cereal adaptability (good or poor) and water scarcity (moderate or very high) in the main watersheds.

The focus of our analysis is the sign of this interaction term, which carries critical implications for understanding the dynamics at play. We hypothesize that an increase in temperature will exacerbate the negative effects on agricultural productivity when combined with poor AP, while these effects may be mitigated or diminished in the presence of favorable AP.

Controls

Economic growth in this study is represented by the logarithm of GDP per capita, expressed in constant 2010 US dollars. This measure accounts for differences in wealth between economies while also considering variations in population size. Although other indicators, such as purchasing power parity (PPP), might provide a more nuanced view of economic conditions within countries, GDP per capita remains the most widely available and comprehensive metric. Furthermore, it enjoys broad support in the literature as a reliable measure of economic performance.

Sample

This section is dedicated to the presentation of an unbalanced panel sample from 139 countries spanning the period 1960-2014 which was used in our study. A breakdown by region shows: 24.35% for Europe, 8.63% for the Middle East, 19.49% for Asia, 25.11% for Africa and 22.43% for Americas.

Econometric model

The chosen model is defined as follows:

$$A\,Pro_{i,t} = \beta_0 + \beta_1 Temperature_{i,t} + \beta_2 (Temperature_{i,t} * APot_i) + \delta' X_{i,t} + \alpha_i + \gamma_t + \varepsilon_{i,t} \quad (2)$$

In this model, the dependent variable represents agricultural productivity. β_1 is the coefficient relating to temperature and β_2 that related to the interaction of the latter with APot (the latter is omitted from the Fixed Effects (FE) model, since it is invariable over time). The $X_{i,t}$, illustrate our control variables (GDP / ha, inflation, population growth, trade and level of education). Finally, the α_i and γ_t represent respectively the FE countries and years and $\varepsilon_{i,t}$, t the error term.

As previously mentioned, this study aims to establish a causal link between the interaction of climate change (CC) and natural resources (NR) on agricultural productivity. Like any econometric analysis, it faces the unavoidable issue of endogeneity. To address this challenge, careful consideration was given to the selection of variables, the choice of the model, and the methodology employed, all of which are explained in subsequent sections.

One key source of endogeneity is simultaneity, also known as reverse causality. We believe this issue was mitigated through the selection of our variables of interest. Specifically, temperature, AP, and their interaction terms are exogenous by nature. Temperature is inherently exogenous, while AP is largely invariant over time as it represents an intrinsic characteristic of each country. Thus, agricultural productivity cannot influence these variables. Another potential source of endogeneity is measurement error. To minimize this bias, all variables were sourced from reputable and reliable databases.

Additionally, the inclusion of control variables helps to partially address biases caused by omitted variables. However, some degree of omitted variable bias is inevitable, given data limitations and the challenge of capturing all relevant factors. This issue is addressed further in our methodological approach, particularly in the selection of the econometric model, which aims to account for unobserved heterogeneity.

Results and Discussion

Main Results

Our study focuses on the interaction between temperature and Agricultural Potential (AP), specifically represented by the **Cereal Crop Adaptability Index (CCAI)** and the **Water Scarcity for Watersheds (WSW)**. The initial results highlight the interaction between temperature and a **CCAI greater than 40**.

The findings indicate that, as expected, temperature has a positive effect on agricultural productivity. However, to assess the total effect of temperature, we must first consider the interaction variable. The impact of temperature on productivity is contingent on the level of AP. The negative sign associated with the interaction term suggests that as the CCAI increases (indicating better soil quality), the effect of temperature on productivity becomes less pronounced. In other words, when a country has a larger proportion of land with favorable AP, the positive effect of temperature on productivity is dampened. This indicates a substitution relationship between the two variables. It is important to note, however, that these results are not statistically significant, which will be discussed further later.

From these results, we can infer that the ability to grow cereals acts as a buffer against rising temperatures. A contrasting phenomenon occurs when temperature interacts with a CCAI less than 40 (indicating poor soil quality). Here, the signs of both temperature and the interaction term are reversed, suggesting that countries with poor-quality land experience an exacerbated effect of temperature on agricultural productivity. This indicates a complementary relationship between the two variables. The positive effect of temperature on productivity in this case arises exclusively through its interaction with poor CCAI. These findings largely support our initial hypotheses.

As described in the methodology, the inclusion of two representative variables for AP helps validate the robustness of our assumptions. The subsequent estimation illustrates the interaction between temperature and WSW at moderate levels.

The results follow a similar pattern to those above: while temperature shows a positive effect, the interaction term exhibits a negative sign. Again, the opposite effect is observed in countries with high water scarcity, where water scarcity amplifies the positive impact of temperature on productivity. Notably, the results for the interaction of temperature with WSW are statistically significant at the 5% level across all regressions.

We also note that, as part of our methodological approach, we included the robust command to correct for heteroscedasticity. The results of the interaction between temperature and WSW are more robust than those involving CCAI, particularly when control variables are included. However, regressions without control variables still produce significant results at the 5% level, even after correcting for heteroscedasticity. This contrast is particularly interesting since some studies in the literature use Fixed Effects (FE) models without including controls, while others incorporate controls but omit FE and time trends.

It is important to highlight that our sample size (N = 9,344) includes data from 172 countries over a long period (1946–2014). This is contrasted with our basic regressions, which have a smaller N due to the inclusion of control variables, which are not consistently available for the entire period and across all countries. The inclusion of control variables necessitates the exclusion of some countries from the sample. For example, the inclusion of the education variable alone eliminates 31 countries and results in the loss of 1,531 observations (results not shown). Other countries experience a reduction in the number of observations. Control variables are generally available from 1960 onward, but for many countries, the data start much later.

Maintaining a consistent sample across all regressions is essential, but it also means dealing with missing data at various points in the panel, which complicates the analysis. Despite this, we believe that the 5,413 observations in our final dataset are a robust sample for panel data analysis, and the inclusion of 139 countries ensures good representation.

As explained previously, our analysis focuses primarily on the study and measurement of the effect of temperature on productivity. As this is an interaction, the calculation is governed in this case by the following formulation:

$$\textit{Temperature Effect} = \beta 1 + (\beta 2 * AP) \qquad (3)$$

The table below therefore illustrates the effect of temperature by considering the extreme values that the AP index can take (always its 4 variants), namely 0 or 1.

Table 1: Effect of temperature as a function of its interaction with AP

Extreme values of AP ***Variants of AP***	**AP=0**	**AP=1**
CCAI greater than 40	2,43%	-4,17 %
CCAI less than 40	-3,13 %	2,66 %
moderate WSW	15,8 %	0,12 %
Very high WSW	0,39 %	18,25 %

In the case where the CCAI greater than 40 is equal to 0, meaning a country has no land classified as favorable for cereal production, an increase of 1°C in average temperatures leads to a 2.43% increase in the probability of productivity improvement. However, when the CCAI is equal to 1, implying that all of a country's land is classified as suitable for cereals, this same temperature increase results in a reduced effect, with the probability of productivity improvement dropping to -4.17%.

Conversely, when the CCAI is less than 40, and the country has no land categorized as unsuitable for cereals, a 1°C rise in temperature causes a 3.13% decline in the probability of productivity improvement. On the other hand, if all land is classified as unsuitable for cereals (i.e., CCAI less than 40 equals 1), the probability of improvement increases by 2.66%.

A similar pattern is observed with WSW. When no land in a country is classified as having moderate water scarcity (WSW = 0), a 1°C temperature increase corresponds to a 15.8% increase in the likelihood of productivity improvement. However, when all of the land is classified as having moderate water scarcity (WSW = 1), this probability almost cancels out.

For countries without a very high level of water scarcity, a 1°C rise in temperature results in a 0.39% increase in the probability of productivity improvement. In contrast, when all land is classified as having very high water scarcity (WSW = 1), this probability rises significantly, to 18.25%.
These findings reinforce the earlier observation that the effect of warming temperatures on agricultural productivity can either be amplified or inhibited depending on the interaction with **AP** (whether restrictive or favorable).

As for the control variables, GDP per capita, represented by the logarithm of GDP, consistently shows a positive effect in all regressions. This is in line with the expectation that wealthier nations are more likely to experience productivity improvements due to better resources and technology.

Regarding inflation, no significant effect is observed. While inflation can influence economic growth, its relationship with productivity is complex. Inflation can either spur growth by stimulating spending or hinder it by reducing investments, thus slowing economic development. For example, Paul, Kearney, and Chowdhury (1997) found no causal relationship between inflation and economic growth in 40% of countries in their study. In about 12% of cases, there was a two-way relationship, while a one-way causality was found in the rest. Thus, inflation, when analyzed in isolation, does not offer clear insights into productivity improvement.

The population growth variable is found to have a positive and significant effect at the 5% level. Specifically, a one-percentage point increase in population growth is associated with a 1.81% increase in the probability of productivity improvement. This result reflects the idea that a growing population can contribute to greater labor supply and economic output.

In terms of trade, increased trade and a better business environment lead to an improved likelihood of productivity growth, significant at the 10% threshold. The rise in international trade fosters interdependence among countries, which strengthens national economies and boosts agricultural productivity.
Lastly, education is positively associated with productivity improvements. An additional year of schooling for individuals over 15 years old is linked to a more than 2% increase in productivity. This aligns with expectations, as higher education levels often result in a more skilled and efficient workforce. Educated populations are more likely to enter the labor market, earn higher incomes, and contribute to the economy. Furthermore, education can support agricultural research, particularly in adapting to climate change, further enhancing productivity.

Mechanisms

As discussed earlier, two main scenarios emerge regarding the rise in temperature, depending on the Agricultural Potential (AP) available to a given country. In summary, if the AP is low, the interaction with rising temperatures has a significant impact on productivity. This is particularly evident when the land available to the country is considered unsuitable for cereal cultivation or when its main watersheds face very high water scarcity. Upon closer examination of these interactions, it becomes apparent that the effect is more pronounced in the case of water scarcity than with the CCAI. In this final section, we will explore these results further, attempting to describe the underlying mechanisms driving these interactions.

It is important to recall a historical perspective that links development inequalities between countries, in part, to their AP. This idea suggests that a differentiation between countries has already occurred based on their AP. Countries with more abundant resources have typically developed more, built stronger institutions, and created more sustainable economies. As we mentioned in the introduction, there has been a long-standing recognition of the connection between climate and economic performance. Some scholars argue that part of the economic inequality observed at the international level can be attributed to climato-geographical factors, such as proximity to the coast, temperature, and, importantly, agriculture. For instance, some researchers have highlighted the role of agricultural surpluses in the development of institutions or the link between agriculture and Europe’s industrial revolution (De Vries, 1994).

Another mechanism at play is the natural relationship between AP and food security. Poor harvests, in addition to causing direct harm such as death and disease, can lead to higher food prices, affecting the broader economy. The 2007-2008 food crisis serves as a pertinent example. According to the FAO, this crisis affected 37 countries and approximately 800 million people, resulting in price spikes and food riots, such as those in Egypt (Ayeb, 2008). Furthermore, poor harvests can have institutional repercussions. State spending, typically allocated for development (e.g., food subsidies, health, infrastructure), may be redirected to address the consequences of poor harvests, slowing overall economic development.

It is also crucial to note that the manifestations of climate change extend beyond warming alone. Warming is accompanied by disturbances such as changes in rainfall patterns or an increase in the frequency of natural disasters, which directly affect agricultural production and infrastructure, further weakening governments' ability to foster productivity improvements. One key point in our results is the greater significance of the temperature effect in relation to AP, especially when considering water scarcity (WSW) compared to cereal crop adaptability (CCAI). Let us delve into this observation further.

Water, in general, appears to be a more decisive factor than other elements in agriculture. For instance, Kang, Khan, and Ma (2009) found that crop yields are more sensitive to changes in precipitation than to temperature. More broadly, water resources have a more direct relationship with socioeconomic realities, whereas suitability for cereal cultivation is an estimate tied to agriculture and food security. Water's importance extends beyond agriculture. A UN report on water resources titled “Water and Jobs” (World Water Assessment Program [WWAP], 2016) notes that nearly 78% of jobs worldwide depend, either directly or indirectly, on water resources. Often overlooked, water is critical to several sectors beyond agriculture, including mining, resource extraction, power generation, manufacturing, and industries such as food, pharmaceuticals, and textiles (WWAP, 2016). Therefore, the availability of water resources affects not only agriculture but the broader economy as well.

Conclusion

The objective of this study was to examine the effect of temperature on agricultural productivity, conceptualized through the notion of Agricultural Potential (AP). This study explored the interaction between temperature and AP, using a panel data method. An FE model was employed, where AP was considered a fixed characteristic of each country, based on two distinct variables: CCAI (reflecting suitability for cereal cultivation) and WSW (indicating the level of water scarcity in the main watersheds).

The estimation results support the hypothesis. In the sample of countries analyzed, it was found that a 1°C increase in temperature leads to a -4.17% effect on agricultural productivity in countries where all land is classified as suitable for cereal cultivation (CCAI > 40). Conversely, in countries with no land in this category, the effect of the same temperature increase is estimated at 2.43%. This effect exhibits a mirror image: for countries with unsuitable land (CCAI < 40), the impact of a 1°C rise in temperature is estimated at 2.66%, whereas it decreases to -3.13% if the country has no such land.

For WSW, the results were even more robust. The effect of a 1°C increase in temperature is estimated at 0.12% in countries where the land is moderately affected by water scarcity, whereas it rises to 15.8% in countries where this is not the case. For countries facing very high water scarcity, the effect of the temperature rise is estimated at 18.25%, compared to 0.39% in countries without this level of water scarcity.

In summary, these results suggest that good AP acts as a protective barrier against rising temperatures, whereas poor AP exacerbates the negative impacts of warming on agricultural productivity. Several mechanisms explain how the interaction between warming and AP influences agricultural productivity. The primary channel is economic, particularly for countries where GDP is heavily dependent on agriculture. Poor harvests and food crises can weaken the state, leading to reduced investments and deteriorating relations with citizens, ultimately lowering the probability of improving agricultural productivity.

This research contributes to the literature by emphasizing the importance of incorporating AP in estimating the impacts of global warming. The findings aim to guide political decision-makers in formulating more targeted adaptation and mitigation strategies. By better directing aid to the countries most vulnerable to climate change, these strategies can enhance resilience.

Agriculture must be central to climate change adaptation measures. This involves promoting better management practices and rethinking the spatial dimension of agricultural activity in the context of rising temperatures and resource scarcity. In essence, solutions should be adapted to each region or country, taking into account specific agro-climatic conditions. Given the critical role of water resources in the results, it is essential to not only direct water management, irrigation, and consumption policies towards more sustainable practices but also ensure broader access to water to support economic development.

References

1. Adams RM et al . "World Climate Change and American Agriculture", Nature 345: 219-224. 1995.
2. Amadu, F., McNamara, P. and Millera, D. Yield effects of climate-smart agriculture aid investment in southern Malawi. Food Policy.2020. https://doi.org/10.1016/j.foodpol.2020.101869
3. Apata, Temidayo Gabriel; Samuel, K.D.; Adeola, A.O. Analysis of Climate Change Perception and Adaptation among Arable Food Crop Farmers in South Western Nigeria. Contributed Paper prepared for presentation at the International Association of Agricultural Economists' 2009 Conference, Beijing, China, August 16-22, 2009.
4. Asfaw,S., Mccarthy, N., Lipper, L., Arslan, A. and Cattaneo A. What determines farmers' adaptive capacity? Empirical evidence from Malawi. Food Security, 8(3), 643-664.2016. DOI:10.1007/ s12571-016-0571-0
5. Ayeb, H. Food crisis in Egypt: competition for resources, food sovereignty and the role of the state. Herodotus, 4 (131), 58-72.2008. Spotted at https://www.cairn.info/revue-herodote-2008-4- page-58.htm
6. Baig, I. A., Chandio, A. A., Ozturk, I., Kumar, P., Khan, Z. A., & Salam, M. A. Assessing the long- and short-run asymmetrical effects of climate change on rice production. *Empirical Evidence from India, Environmental Science and Pollution Research*, 29(23), 34209–34230.2022. https://doi.org/10.1007/s11356-021-18014-z
7. Brown, P.T. and Caldeira, K. "Greater future global warming inferred from earth's recent energy budget", Nature, Vol. 552 No. 7683, pp.45-50.2017.

8. Burke, M. B., Miguel, E., Satyanath, S., Dykema, J. A. et Lobell, D. B. Warming increases the risk of civil war in Africa. *Proceedings of the National Academy of Sciences of the United States of America, 106*(49), 20670-20674.2009. http://www.pnas.org/content/106/49/20670.full.pdf
9. Coulibaly, J.Y.,Chiputwa, B., Nakelse, T. and Kundhlande, G. Adoption of agroforestry and its impact on household food security among farmers in Malawi. Agric. Syst.,155, 52-69.2017.
10. De Vries, J. The industrial revolution and the industrious revolution. *The Journal of Economic History, 54*(2), 249-270.1994. Spotted at http://www.unsa.edu.ar/histocat/haeconomica07/lecturas/devries1994.pdf
11. Deressa, T. T., R. M. Hassan, C. Ringler, T. Alemu, and M. Yesuf, Analysis of the Determinants of Farmers' Choice of Adaptation Methods and Perceptions of Climate Change in the Nile Basin of Ethiopia, IFPRI Discussion Paper No. 798 (Washington, DC: International Food Policy Research Institute).2008.
12. Diop M., Houndenou C., Richard Y. Variability of the start and end dates of rainy season in Senegal. AIC publication, 430-436 pp.1996.
13. Diouf, A., Spencer, M. & Gueye, M. Use of the gusA gene marker in a competition study of the Rhizobium strains nodulating the common bean (Phaseolus vulgaris) in Senegal soils. *World Journal of Microbiology and Biotechnology* **16,** 337–340. 2000. https://doi.org/10.1023/A:1008996406752
14. Dongbei Bai, Lei Ye, ZhengYuan Yang, and Gang Wang . "Impact of climate change on agricultural productivity: a combination of spatial Durbin model and entropy approaches", published in the International Journal of Climate Change Strategies and Management as part of a special issue, Vol. ahead-of-print, No. ahead-of-print, 2022. https://doi.org/10.1108/IJCCSM-02-2022-0016e.
15. Fahad, S., Alnori, F., Su, F. and Deng, J. "Adoption of green innovation practices in SMEs sector: evidence from an emerging economy", Economic ResearchEkonomska Istraživanja, Vol. 35 No. 1, pp. 5486-5501.2022b. doi: 10.1080/1331677X.2022.2029713.
16. Fahad, S., Hossain, M.S., Huong, N.T.L., et al. "An assessment of rural household vulnerability and resilience in natural hazards: evidence from flood prone areas", Environment, Development and Sustainability.2022a. doi: 10.1007/s10668-022-02280-z.
17. FAO. The State of Food Security and Nutrition in the World 2017: Building Resilience for Peace and Food Security, Italy, Rome.2017.
18. Gallup, J. L., Sachs, J. D. et Mellinger, A. D. Geography and economic development. *International Regional Science Review, 22*(2).1999. http://pdf.usaid.gov/pdf_docs/Pnace757.pdf
19. Gul, A., Chandio, A. A., Siyal, S. A., Rehman, A., & Xiumin, W. How climate change is impacting the major yield crops of Pakistan? an exploration from long- and short-run estimation. *Environmental Science and Pollution Research*, *29*(18), 26660–26674. 2022. https://doi.org/10.1007/s11356-021-17579-z
20. Guntukula R, Goyari P. Climate change effects on the crop yield and its variability in Telangana, India. Stud Microecon 8(1):119-148.2020. https://doi.org/10.1177/2321022220923197
21. Hossain, M.S., Alam, G.M.M., et al. (2022), "Smallholder farmers' willingness to pay for flood insurance as climate change adaptation strategy in northern

Bangladesh", Journal of Cleaner Production, Vol. 338, p. 130584.2022. doi: 10.1016/j.jclepro.2022.130584.

22. Houndenou C., Hernandez K. Modification of the rainy season in Atacora (1961-1990): an example of drought in northwestern Benin (West Africa). Drought, 9, pp. 23-34.1998.
23. Hsiang, S. Climate econometrics. *Annual Review of Resource Economics, 8*, 43-75.2016. https://static1.squarespace.com/static/55667009e4b04bbb290cc837/t/58fda90f20099eb9a7332d d1/1493018898804/annurev-resource-100815-095343.pdf
24. Huang, J., Zhang, X., Zhang, Q., Lin, Y., Hao, M., Luo, Y., Zhao, Z., Yao, Y., Chen, X. and Wang, L. "Recently amplified arctic warming has contributed to a continual global warming trend", Nature Climate Change, Vol. 7 No. 12, p. 875.2017.
25. IPCC (Intergovernmental Panel on Climate Change), Climate Change 2007: Synthesis Report. Geneva.2007.
26. IPCC . Climate Change Review: The Scientific Elements.2014.
27. IPCC.. Intergovernmental Panel on Climate Change, Global warming of 1.5 °C: an IPCC special report on the impacts of global warming of 1.5 C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.2018. available at: http://www.ipcc.ch/report/sr15/ .
28. Jean-Luc Mubenga-Tshitaka, Johane Dikgang, JohnW. Muteba wamba & Dambala Gelo . Climate variability impacts on agricultural output in East Africa, Cogent Economics & Finance, 11:1.2023. DOI: 10.1080/23322039.2023.2181281
29. Kang, I., Khan, S. et Ma, X. Climate change impacts on crop yield, crop water productivity and food security – A review. *Progress in Natural Science, 19*(12), 1665-1674.2009. https://www.sciencedirect.com/science/article/pii/S1002007109002810
30. Kurukulasuriya, P. and R. Mendelsohn.. "A Ricardian Analysis of The Impact of Climate Change on African Cropland" *African Journal Agriculture and Resource Economics* 2:1-23.2008.
31. Mendelsohn, R. Measuring climate impacts with cross-sectional analysis. *Climatic Change, 8*(1), 1-7.2007. http://www.adaptation-undp.org/sites/default/files/downloads/measuring_climate_impacts_with_cross-sectional.pdf
32. Mendelsohn, R., W. Nordhaus and D. Shaw. "The Impact of Climate Variation on US Agriculture" in *The Impact of Climate Change on the United States Economy*. Robert Mendelsohn and James Neumann (eds) Cambridge University Press, Cambridge, UK, pp 55-74.1999.
33. Mendelsohn, R., W. Nordhaus, and D. Shaw. The impact of global warming on agriculture: A Ricardian analysis', *American Economic Review,* 84: 753–771.1994.
34. Müller, C., Cramer, W., Hare, W.L.and LotzeCampen, H. Climate change risks for African agriculture. Proc. Natl. Acad. Sci., 108 (11), 4313- 4315.2011. DOI:10.1073/pnas.1015078108
35. Ozdemir, D. The impact of climate change on agricultural productivity in Asian countries: a heterogeneous panel data approach. *Environmental Science*

and Pollution Research, 29, 8205–8217.2022. https://doi.org/10.1007/s11356-021-16291-2

36. Paul, S., Kearney, C. et Chowdhury, K. Inflation and economic growth: A multi-country empirical analysis. *Applied Economics*, *29*(10), 1387-1401.1997. https://eds-a-ebscohost-com.ezproxy.usherbrooke.ca/eds/pdfviewer/pdfviewer?vid=1&sid=b251225f-d903-4adb-92a6- 7bbf23375d78%40sessionmgr4010
37. Pipitpukdee S, Attavanich W, Bejranonda S . Impact of climate change on land use, yield and production of cassava in Thailand. Agric 10(9):402.2020. https://doi.org/10.3390/agriculture10090402
38. Rosenberg, N. *Towards an integrated assessment of climate change: The MINK study.1993.* https://books.google.fr/books?hl=fr&lr=&id=amiSBAAAQBAJ&oi=fnd&pg=PA1&ots=IEI7nokb63&sig=YVNMrDy8P4G75PogLBz5E1YeNzs#v=onepage&q&f=false
39. Rosenzweig, C et M Parry . les impacts potentiels du changement climatique sur l'approvisionnement alimentaire mondial, Nature 367, 133-138.1994.
40. Sarker MAR, Alam K, Gow J. Performance of rain-fed Aman rice yield in Bangladesh in the presence of climate change. Renew Agric Food Syst 34(4):304-312. 2019.https://doi.org/10.1017/S1742170517000473
41. Sinnarong N, Chen CC, McCarl B, Tran BL . Estimating the potential effects of climate change on rice production in Thailand. Paddy Water Environ 17:761–769. 2019.https://doi.org/10.1007/s10333-019-00755-w
42. SPORE; Climate Change, Spore Special Issue-August, 2008.
43. Su, F., Liang, X., Cai, S. et al. “Assessment of parent-subsidiary companies’ geographical distance effect on corporate social responsibility: a case of A-share listed companies”, Economic Research-Ekonomska Istraživanja, Vol. 35 No. 1, pp. 4922-4946.2022. doi: 10.1080/ 1331677X.2021.2019597.
44. Thornton, P.K., Jones, P.G., Owiyo, T., Kruska, R.L., Herrero, M., Kristjanson, P., Notenbaert, A., Bekele, N., Omolo, A., with contributions from Orindi, V., Ochieng, A., Otiende, B., Bhadwal, S., Anantram, K., Nair, S., Kumar, V., Kelkar, U. Mapping climate vulnerability and poverty in Africa. Report to the Department for International Development, ILRI, Nairobi, Kenya, May 2006, 200 pp. 2006b.
45. University of East Anglia. (UEA). Climatic research unit. 2017.http://www.cru.uea.ac.uk
46. Yi, C., Zhao, Z. and Tao, F. “Impacts of climate change and climate extremes on major crops productivity in China at a global warming of 1.5 and 2.0?°C”, Earth System Dynamics, Vol. 9 No. 2, pp. 543-562.2018.
47. Zhai, F., and J. Zhuang. Agricultural Impact of Climate Change: A General Equilibrium Analysis with Special Reference to Southeast Asia. ADBI Working Paper 131. Tokyo: Asian Development Bank Institute.2009. Available: http://www.adbi.org/workingpaper/2009/02/23/2887.agricultural.impact.climate.change/