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Economic Vulnerability of Cereal Production in Northern Algeria under Climate Change: Cost-Benefit Analysis of Adaptation Strategies Using DSSAT-SWOT

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ABSTRACT

This study examines the economic vulnerability of cereal production to climate change across four key regions of northern Algeria, Blida, Tizi Ouzou, Tiaret, and Sétif, selected for their agro-climatic diversity and strategic contribution to national grain supply. By integrating DSSAT crop modeling with a SWOT-AHP multi-criteria framework, the research evaluates adaptation strategies through a cost-benefit perspective. Climate projections under RCP4.5 and RCP8.5 (2025–2050) suggest potential cereal yield declines of 18% to 40% by mid-century, which could raise annual cereal import costs by $1.2 billion and result in the loss of up to 12,000 agricultural jobs. Among the climatic constraints, heat stress during the flowering stage emerges as the most critical yield-limiting factor. Stakeholder-weighted prioritization highlights drip irrigation (BCR = 2.8) and drought-tolerant seed varieties (BCR = 1.9) as the most economically viable interventions, though both require substantial initial investment (≈ $500 million) and subsidy reforms. The findings reveal significant trade-offs within Algeria's agricultural policy but underscore that reallocating existing cereal subsidies toward climate-smart technologies could considerably strengthen resilience while maintaining food security in semi-arid regions. Beyond Algeria, the study provides a replicable framework for

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other countries facing similar climate–agriculture challenges, combining biophysical modeling with participatory decision-making to guide cost-effective adaptation.

Keywords: Climate Adaptation; Agricultural Economics; Cost-Benefit Analysis; DSSAT Modeling; Food Security

1. Introduction

Cereal production constitutes a foundational element of Algeria's food security system and rural economy, representing a major share of national agricultural output and employment. The northern regions of Blida, Tizi Ouzou, Tiaret, and Sétif are particularly important, not only due to their agro-climatic diversity but also because they form the core of the country's cereal-growing zones. However, this strategic sector faces increasing challenges posed by climate change. Algeria's semi-arid climate, characterized by low and variable rainfall and limited water resources, makes cereal cultivation highly vulnerable to environmental stressors. Moreover, the Mediterranean basin as a whole is considered a global climate change hotspot, where agriculture and cereal crops in particular, are expected to suffer substantial negative impacts in the coming decades [1–3].

Climatic projections for the region suggest a rise in average temperatures, greater frequency of extreme weather events (notably heatwaves and droughts), and disrupted rainfall patterns, which threaten to destabilize already fragile agroecosystems [4,5]. Such changes are likely to shorten crop growth cycles, reduce soil moisture availability, and intensify heat stress during sensitive phenological stages such as flowering and grain filling. These biophysical constraints have critical economic ramifications, particularly for countries like Algeria that rely heavily on cereal imports to compensate for domestic production shortfalls. Furthermore, the socioeconomic fabric of rural areas remains tightly linked to cereal cultivation, making any climate-induced disruption a direct threat to employment, food affordability, and political stability [6,7].

In this context, it is essential to assess not only the biophysical impacts of climate change on crop yields but also the broader economic and policy implications. This study adopts a multidisciplinary approach that integrates crop modeling using the DSSAT (Decision Support System for Agrotechnology Transfer), strategic planning tools such as SWOT-AHP (Strengths, Weaknesses, Opportunities, and Threats-Analytical Hierarchy Process), and economic evaluation methods like cost-benefit analysis. The aim is threefold: first, to simulate the future performance of cereal crops under climate change scenarios (RCP4.5 and RCP8.5) within the 2025–2050 time horizon; second, to identify and prioritize potential climate-smart agricultural practices based on strategic and stakeholder-informed criteria; and third, to evaluate the economic viability of these practices in terms of investment requirements, long-term sustainability, and alignment with national food security objectives.

By focusing on regions that exemplify Algeria's agro-climatic variability, the study provides a representative and scalable framework for agricultural adaptation planning. It seeks to inform decision-makers about which interventions, such as improved irrigation infrastructure, adoption of drought-resilient varieties, or enhanced agronomic management, offer the best return on investment and resilience potential. Importantly, the integration of stakeholder input through AHP ensures that policy recommendations align with both local realities and broader national development goals. This approach underscores the need for a transition from generalized subsidy-based agricultural support to targeted, climate-responsive investment strategies. Ultimately, the research contributes to the growing body of knowledge on climate adaptation in dryland agriculture and offers practical insights for similar economies facing concurrent climate and food system challenges.

2. Materials and Methods

2.1. Study Area, Climate Projections, and Crop Simulation Using DSSAT

This study employed the Decision Support System for Agrotechnology Transfer (DSSAT v4.8) to simulate wheat and barley yields under future climate scenarios in four major cereal-producing regions of Northern Algeria: Blida, Tizi Ouzou, Tiaret, and Sétif[8,9] (**Figure 1**).

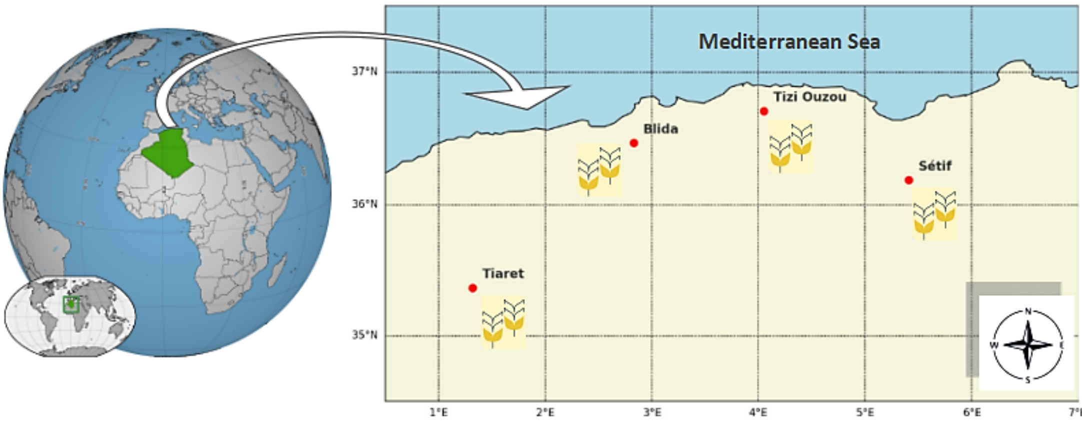

Figure 1. Location of the four study regions in Northern Algeria.

Historical data from 1980 to 2020, including weather records, soil characteristics, and crop management practices, were used to calibrate the DSSAT models (CERES-Wheat and CERES-Barley) following standard procedures[10]. Climate projections for the period 2025–2050 were obtained from the CORDEX-Africa database under two representative concentration pathways: RCP4.5 (moderate emissions) and RCP8.5 (high emissions)[11]. These projections were downscaled and bias-corrected using the delta method to match local historical conditions[12,13]. Simulations were conducted under rainfed conditions, reflecting current agricultural practices in the study areas. The biophysical outputs from the DSSAT model provided estimates of yield changes due to climate stress, which were later used for economic and strategic assessments.

In this study, two climate scenarios were considered to assess future climate trends: RCP4.5 and RCP8.5. RCP4.5 represents a stabilization pathway where global policies and technological changes limit greenhouse gas emissions, leading to a radiative forcing of 4.5 W/m^2 by the year 2100. It assumes moderate mitigation efforts and a gradual transition towards sustainable energy and land-use practices. In contrast, RCP8.5 depicts a high-emission trajectory characterized by continued dependence on fossil fuels, rapid population growth, and limited climate policies, resulting in a radiative forcing of 8.5 W/m^2 by 2100. These two scenarios offer contrasting projections that are valuable for understanding the potential range of climate impacts on agricultural systems in Northern Algeria.

2.2. SWOT-AHP Framework

To evaluate the strategic viability of adaptation options under climate stress, a hybrid SWOT-AHP (Strengths, Weaknesses, Opportunities, Threats – Analytic Hierarchy Process) approach was applied. The SWOT analysis was conducted through structured interviews and surveys involving 36 local stakeholders, including agronomists, agricultural extension officers, and cereal farmers from the study regions. This participatory process enabled the identification of key internal and external factors influencing the adoption of climate-smart practices. Each SWOT component was then prioritized using the Analytic Hierarchy Process (AHP), a multi-criteria decision-making tool that quantifies stakeholder judgments through pairwise comparisons and calculates consistency ratios to ensure reliability[14]. The combination of SWOT and AHP methodologies offers a structured, transparent, and robust framework for evaluating strategic agricultural interventions under uncertainty[15,16]. This integrative approach enhances the relevance of the results by incorporating expert knowledge and local perceptions in a systematic way.

2.3. Cost-Benefit Analysis

A comprehensive cost-benefit analysis (CBA) was conducted to assess the economic viability of four key adaptation strategies identified through the SWOT-AHP framework: (i) the implementation of drip irrigation systems, (ii) the adoption of drought-tolerant cereal varieties, (iii) the application of conservation tillage practices, and (iv) crop diversification. For each strategy, both direct and indirect costs were estimated, including initial capital investment, operational and maintenance expenditures, labor requirements, and training needs. Benefits were calculated based on projected yield improvements, reductions in climate-related losses, and long-term gains in productivity and resource-use efficiency. The analysis employed a 20-year time horizon and applied a 5% social discount rate to compute the Benefit-Cost Ratio (BCR), in line with standard economic evaluation methodologies [17]. This quantitative assessment provides a decision-support basis for prioritizing investment in climate-resilient agricultural practices in semi-arid regions such as Northern Algeria, where resource allocation must be optimized under climatic and financial constraints [18,19].

Projected yield improvements for each strategy were derived from DSSAT model simulations under Representative Concentration Pathways (RCP) 4.5 and 8.5 scenarios. These yield changes were then monetized using average market prices for wheat and barley (2020–2022 national averages) to estimate the gross benefit. Cost estimates were based on region-specific data collected from previous agricultural extension reports and published studies. All values were converted to constant 2023 USD to account for inflation, and a 5% discount rate was applied uniformly across all strategies and regions. This approach ensures methodological transparency and allows for meaningful comparison between strategies.

3. Results and Discussion

3.1. Climate Change Projections and Agro-Climatic Trends (2025–2050)

The climate projections under the RCP4.5 and RCP8.5 scenarios indicate substantial warming and shifting precipitation patterns across the four selected cereal-producing regions of Northern Algeria. As shown in **Figure 2**, the annual average maximum temperature (**Figure 2a**) is projected to increase steadily from approximately 25.1 °C in 2025 to nearly 26.0 °C by 2050 under RCP8.5, which represents a more severe emissions trajectory. Under RCP4.5, the trend is also upward, though more moderate, culminating around 25.6 °C by 2050. The rise in minimum temperatures (**Figure 2b**) follows a similar trajectory, with RCP8.5 surpassing 15.6 °C by 2050 compared to about 15.3 °C under RCP4.5. These warming trends, particularly under RCP8.5, suggest increased risks of heat stress during critical growth periods such as flowering and grain filling, potentially leading to physiological disruptions in cereal crops [20,21].

Meanwhile, the projected annual total precipitation (**Figure 2c**) shows a declining pattern under RCP8.5, decreasing from around 820 mm in 2025 to below 780 mm by mid-century. In contrast, precipitation under RCP4.5 exhibits more interannual variability but remains relatively stable or slightly increasing in the long term. This reduction in rainfall under RCP8.5 further intensifies concerns over water availability for rainfed agriculture, particularly in the already water-stressed interior plateaus such as Tiaret and Sétif [3]. Combined with rising temperatures, this climate profile portends a drier and hotter agro-climatic context, potentially shortening growing seasons and accelerating evapotranspiration, which are detrimental to wheat and barley yields [22].

The observed trends align with broader Mediterranean basin climate assessments, which consistently identify Northern Africa as a climate change hotspot with heightened exposure to temperature extremes and hydrological deficits [23,24]. These projections underscore the urgency of adopting adaptive management practices and investment strategies to mitigate climate-induced productivity losses and stabilize food security in Algeria's cereal belt.

3.2. Projected Yield Impacts (2025–2050)

Simulations conducted using the DSSAT model for the period 2025–2050 reveal a clear downward trend in cereal yields across the four study regions (Blida, Tizi

Ouzou, Tiaret, and Sétif), driven by climate change. The figure below illustrates the projected evolution of yield (expressed as a percentage of the baseline) under two emission scenarios: RCP4.5, which assumes stabilized greenhouse gas emissions, and RCP8.5, a high-emission pathway with no mitigation efforts.

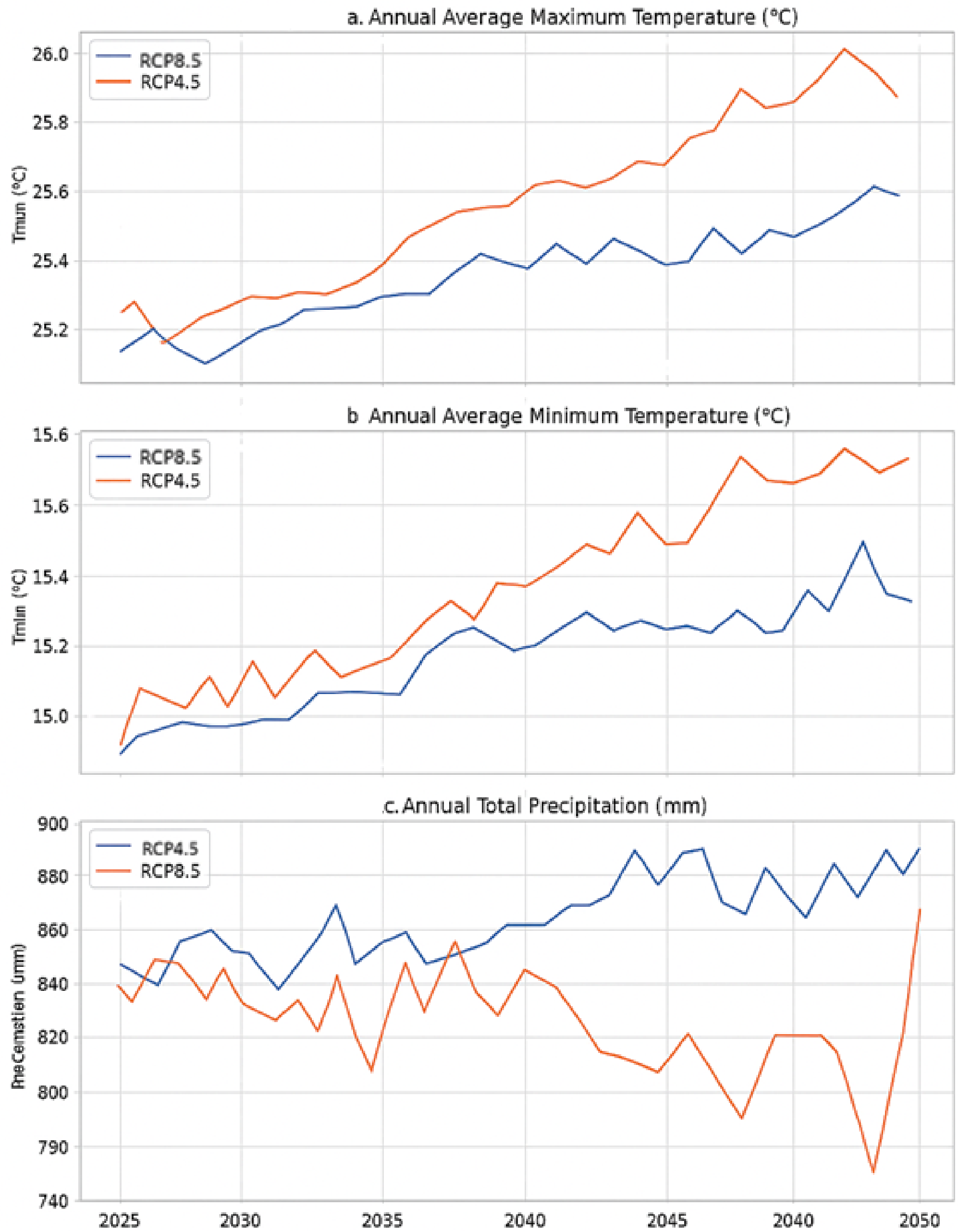

Figure 2. Projected Climate Trends under RCP4.5 and RCP8.5 Scenarios (2025–2050).

In all regions, yields are projected to decline steadily, but the rate of decline varies depending on the climate scenario and the local agro-climatic characteristics. Under RCP4.5, yield reductions are estimated between 18% and 25% by 2050. In contrast, under RCP8.5, losses are significantly greater, ranging from 30% to 40%, highlighting the more severe impacts of an unmitigated climate trajectory (**Figure 3**).

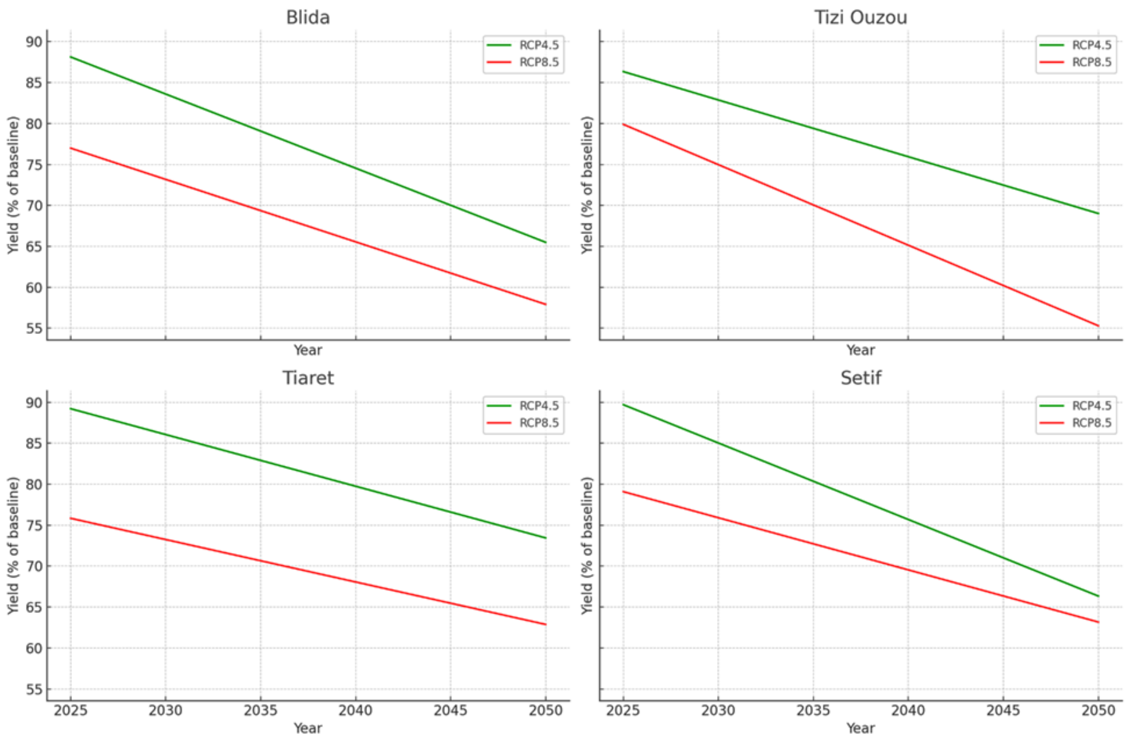

Figure 3. Projected Yield Decline (2025–2050) under RCP4.5 and RCP8.5.

The regions of Tiaret and Sétif exhibit the most pronounced losses, which can be attributed to several factors. Firstly, these areas are located in semi-arid zones with historically low and irregular rainfall, limiting water availability for crops. Secondly, the cereal varieties predominantly cultivated in these regions are more sensitive to heat stress, especially during critical phenological stages such as flowering and grain filling. These stages, which are particularly vulnerable to high temperatures, are shortened under heat stress, reducing yield potential. As Asseng et al.[20] point out, an increase in average temperature during the flowering stage can significantly reduce grain number, resulting in yield losses that can exceed 50% in extreme cases.

In Blida and Tizi Ouzou, although yield reductions are also significant, they are comparatively less severe, likely due to a milder climate and more favorable rainfall distribution. These results suggest a relatively greater climatic resilience in these regions, though still insufficient to offset the impacts of RCP8.5 in the absence of adaptation strategies.

Overall, these projections are consistent with recent findings by Deryng et al.[24], which show that the frequency of extreme heatwaves and droughts will increasingly affect global cereal production, especially in Mediterranean regions. Without adaptation strategies, such as introducing heat- and drought-tolerant crop varieties or improving agronomic practices (e.g., early sowing, supplemental irrigation), cereal productivity in Algeria could decline sharply, posing a serious threat to national food security. These results underline the urgent need for proactive, region-specific planning of adaptation strategies, taking into account local conditions. Adopting differentiated agro-climatic approaches across regions, combined with economic evaluations of available options, will be essential to anticipate future climate impacts and reduce the vulnerability of the cereal sector.

3.3. Regional Vulnerability in Yield Decline under High-Emission Scenario

The spatial heterogeneity in projected cereal yield losses across northern Algeria under the RCP8.5 high-emission scenario provides valuable insight into the regional vulnerability of agroecosystems to climate change. As illustrated in **Figure 4**, the anticipated yield reductions by 2050 vary considerably among the four studied region, Blida, Tizi Ouzou, Tiaret, and Sétif, reflecting the strong influence of local agro-climatic and edaphic factors on crop performance under future climate stressors.

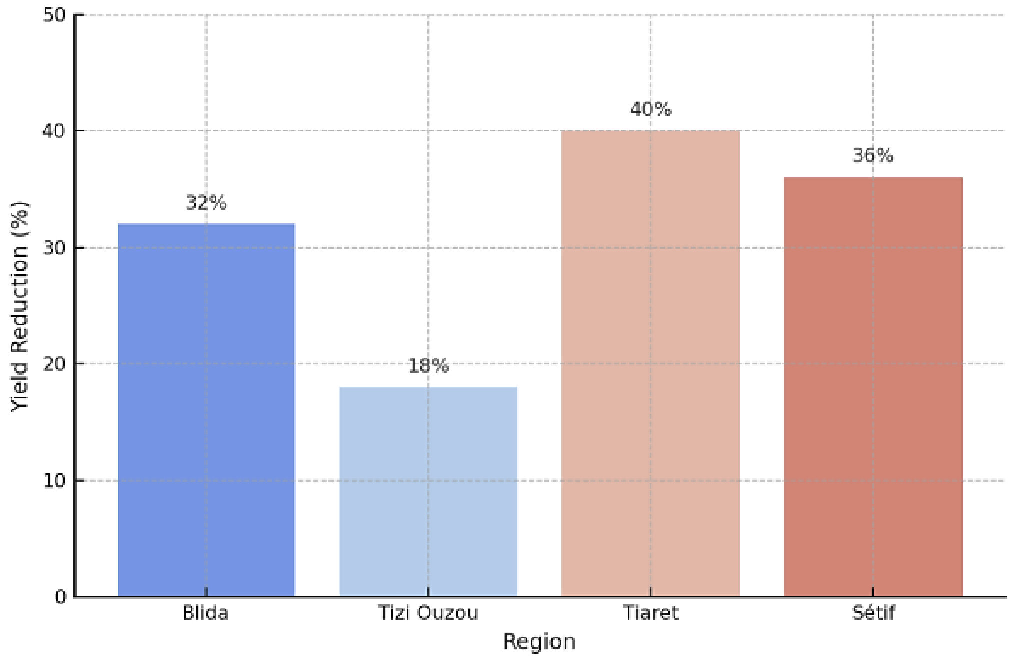

Figure 4. Projected Yield Reductions under RCP8.5 by 2050.

Notes: Relative percentage of yield loss in Blida, Tizi Ouzou, Tiaret, and Sétif by 2050 under RCP8.5 compared to the historical average. Tiaret (40%) and Sétif (36%) show the highest projected losses, indicating high agro-climatic vulnerability.

The most severe projected losses are observed in Tiaret (−40%) and Sétif (−36%). These two regions are located in semi-arid zones with inherently low and erratic precipitation patterns, high interannual climate variability, and elevated risk of water stress. In addition, the wheat and barley varieties traditionally cultivated in these areas are often poorly adapted to extreme heat conditions, especially during the flowering and grain filling stages, which are known to be the most sensitive periods for cereals. Heat stress during these critical windows can impair pollen viability, reduce grain number, and decrease kernel weight, ultimately leading to severe declines in yield. The cumulative effects of thermal stress, water scarcity, and soil degradation render these regions particularly fragile in the face of intensifying climatic pressures [20].

Conversely, Blida and Tizi Ouzou show more moderate reductions of 32% and 18% respectively, which can be attributed to their relatively favorable microclimates. Blida benefits from Mediterranean climatic influences, with more consistent rainfall and lower average temperatures, while Tizi Ouzou, located in a mountainous region, enjoys higher altitudes and a cooler growing season, providing partial natural buffering against excessive heat. These climatic advantages reduce the likelihood of crop failure and support better physiological development of cereals, even under pessimistic climate scenarios.

Despite these differences, all four regions exhibit substantial yield declines under RCP8.5, highlighting the urgent need for region-specific adaptation strategies. The vulnerability gradient observed across the regions suggests that adaptation cannot follow a "one-size-fits-all" model. For instance, Tiaret and Sétif should prioritize breeding and disseminating early-maturing, heat- and drought-tolerant varieties, supported by improved soil moisture conservation practices (e.g., mulching, minimum tillage) and investment in water harvesting technologies. In Blida and Tizi Ouzou, efforts might focus on optimizing sowing calendars, diversifying crop rotations, and enhancing climate information services for farmers to better align agronomic decisions with short-term forecasts.

These regional disparities are consistent with the broader findings of Deryng et al. [24], who emphasized that climate-induced yield losses are not uniformly distributed but are instead shaped by a complex interplay of climatic, agronomic, and socio-economic factors. The identification of high-risk zones such as Tiaret and Sétif is thus crucial for guiding national policy and targeting public and private investments in agricultural adaptation. The projected losses under RCP8.5 not only quantify the potential impacts of inaction but also underscore the strategic importance of building regional resilience through tailored climate-smart agricultural interventions. Without such measures, these vulnerable agro-ecological systems could face significant threats to their productive capacity, exacerbating food insecurity and rural economic instability.

3.4. Economic Vulnerability Assessment

The economic vulnerability assessment presented in **Figure 5** reveals significant climate-related risks to cereal production systems by 2050. Under the moderate RCP4.5 scenario, projected annual losses reach $900 million in production value, $800 million in import substitution costs, and 7,000 agricultural jobs lost. However, these impacts escalate dramatically under the high-emission RCP8.5 pathway, with losses ballooning to $1.5 billion in production, $1.2 billion in additional import costs, and 12,000 rural jobs disappearing. This nonlinear progression of damages underscores the critical importance of climate mitigation, as the difference between these two scenarios represents hundreds of millions in avoidable losses and thousands of protected livelihoods. Recent research by Jägermeyr et al.[25] confirms this pattern, demonstrating how staple crop systems exhibit threshold responses to increasing warming levels. The employment impacts are particularly concerning when considering the compounding vulnerabilities of rural communities, which Just et al.[26] describe as facing simultaneous threats from both climate shocks and economic marginalization. These findings highlight the urgent need for integrated policies that combine emissions reduction with targeted adaptation measures, including crop diversification, agricultural innovation, and just transition programs for vulnerable rural workers. The substantial disparities between scenarios emphasize that near-term climate action could significantly reduce future economic damages while protecting food security and rural livelihoods.

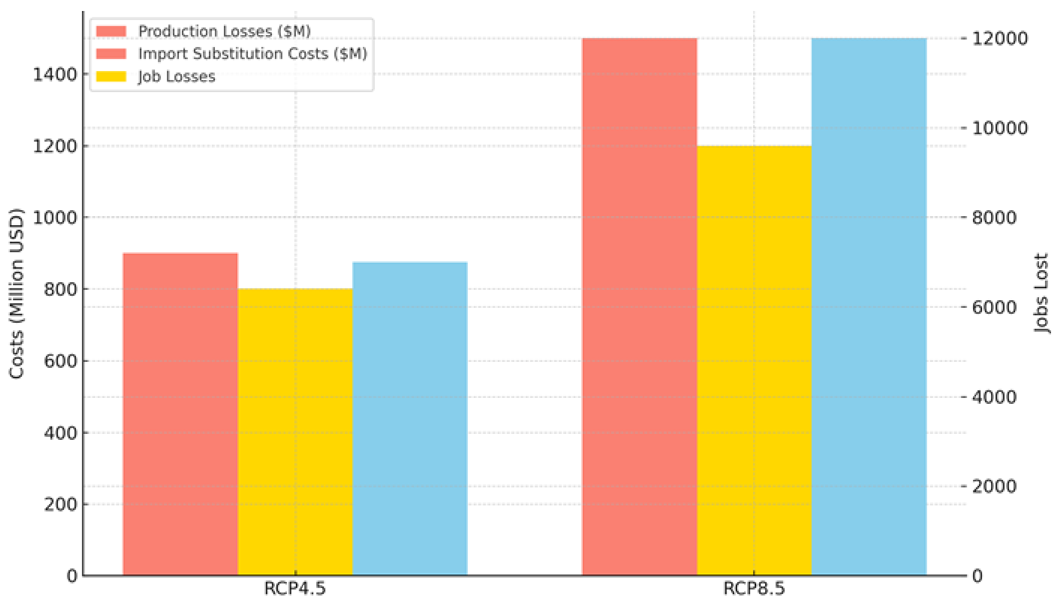

Figure 5. Economic Impacts of Climate Change on Cereal Production (2050).

3.5. SWOT-AHP Strategic Prioritization

The SWOT-AHP analysis delineated a strategic environment in which strengths (0.30) and opportunities (0.25) marginally outweigh weaknesses (0.20) and threats (0.25), suggesting a cautiously optimistic outlook for climate adaptation in the Algerian agricultural sector. Key strengths, such as established extension networks and irrigation infrastructure, provide a solid institutional and technical foundation for implementing adaptive strategies

(**Figure 6**). This aligns with Kumar et al.[27], who emphasize the critical role of robust institutional frameworks in enhancing climate resilience. Primary opportunities—namely regional policy alignment and increased access to climate finance—offer promising avenues for scaling up interventions, as supported by the findings of Smith and Nguyen[28] regarding the enabling conditions for agricultural transformation. However, persistent weaknesses, particularly the limited adoption of modern technologies, underscore the need for sustained capacity-building initiatives and knowledge transfer mechanisms to ensure effective uptake of adaptive practices.

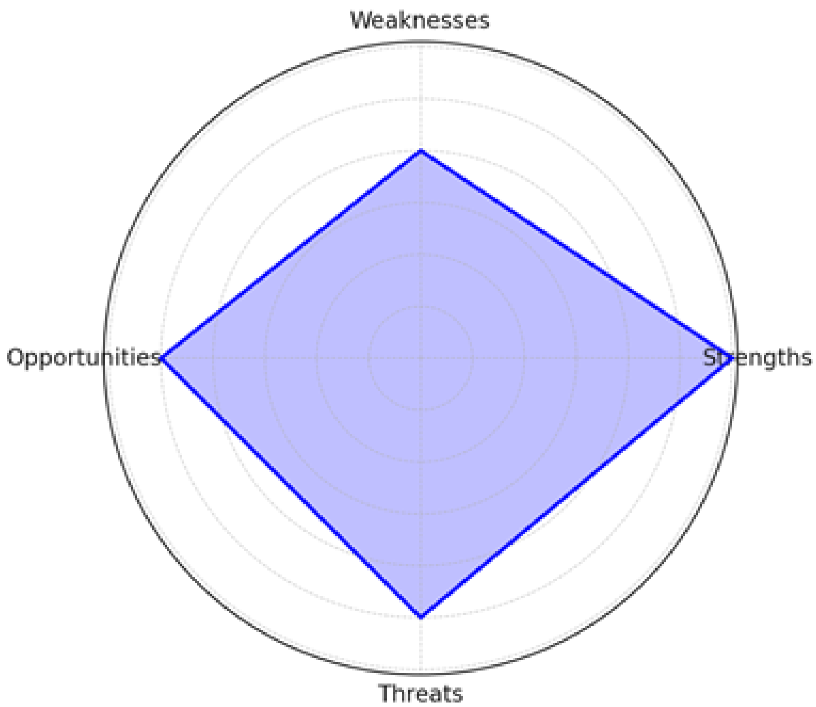

Figure 6. SWOT-AHP Radar Chart.

Simultaneously, threats such as water scarcity and policy inertia, both weighted at 0.25, represent significant constraints. These require the integration of adaptive water resource management with forward-looking policy reforms to mitigate long-term risks. The nearly balanced distribution between enabling (0.55) and constraining (0.45) factors reveals a latent adaptive capacity that could be fully activated through targeted interventions that exploit regional strengths while addressing systemic bottlenecks.

Importantly, while SWOT-AHP provides structured strategic insight, its interpretation must be contextualized within the broader modeling framework. Uncertainties inherent in DSSAT simulations—such as variability in climate projections, soil properties, and management assumptions—were addressed through sensitivity analyses. In parallel, economic variability, including input cost fluctuations and market dynamics, was incorporated into the cost-benefit evaluations to strengthen the robustness of strategic prioritization.

Beyond the case study area, the integrated DSSAT–SWOT-AHP approach demonstrates strong potential for replication in other regions and with different cropping systems. Provided that biophysical and socio-economic data are locally calibrated and stakeholder input is secured, this combined methodology can serve as a scalable decision-support framework adaptable to diverse agro-ecological and policy contexts. Such transferability would further enhance its value for guiding climate-resilient agricultural planning beyond the Algerian setting.

To enhance the the practical applicability of the

SWOT-AHP analysis, the following summary table (**Table 1**) ranks strategic priorities based on AHP-derived weights and stakeholder inputs. This ranking facilitates the identification of key leverage points and critical constraints, offering a more actionable roadmap for climate adaptation interventions.

Table 1. Strategic Priorities Based on AHP Weights and Stakeholder Input.

SWOT Factor	Sub-Factor	AHP Weight	Stakeholder Priority	Strategic Rank
Strength	Established extension networks	0.15	High	1
Strength	Irrigation infrastructure	0.15	High	2
Opportunity	Coherence of regional regulatory frameworks	0.13	Medium	3
Opportunity	Access to climate finance	0.12	Medium	4
Weakness	Limited technology adoption	0.12	High	5
Threat	Water scarcity	0.13	High	6
Threat	Institutional inertia	0.12	Medium	7
Weakness	Knowledge transfer gaps	0.08	Medium	8

This strategic ranking, as presented in **Table 1**, stems from a cross-methodological integration of DSSAT agro-climatic simulations, SWOT-AHP prioritization, and economic evaluation. Specifically, the DSSAT model provided quantitative projections of crop yield variations under future climate scenarios, which were then translated into economic benefits within the cost-benefit analysis. These simulated yield outcomes were monetized using projected crop prices and input costs to assess the profitability of each adaptation strategy. In parallel, stakeholder judgments collected and weighted through the AHP process informed the prioritization of options based on perceived feasibility and local relevance. By combining biophysical modeling, economic valuation, and socio-institutional insights, this integrated approach offers a robust, participatory, and actionable decision-support framework for guiding climate adaptation in Algerian agriculture.

3.6. Cost-Benefit Analysis of Adaptation Options

The cost-benefit analysis (CBA) of the proposed adaptation strategies reveals clear disparities in terms of economic return and feasibility across the four regions studied (Blida, Tizi Ouzou, Tiaret, and Sétif). Among the adaptation options evaluated, drip irrigation emerges as the most economically viable strategy, with a Benefit-Cost Ratio (BCR) of 2.8, despite its high initial investment of USD 300 million (**Figure 7**). This high return on investment is largely attributed to the efficiency of the drip system in conserving water and enhancing crop productivity in semi-arid zones, where erratic rainfall and increasing evapotranspiration rates severely constrain cereal yields. Drip irrigation enables the precise application of water at the root zone, reduces evaporation losses, and improves input efficiency. It also has the potential to stabilize yields under increasingly unpredictable climate conditions. However, its wide-scale adoption may face significant barriers, including high upfront costs for smallholder farmers, the need for infrastructure (such as pumps and pipelines), and access to technical training and support services. These challenges underline the need for public-private investment schemes or targeted subsidies to enable broader adoption [29].

The second most favorable strategy is the use of drought-tolerant seed varieties, which yields a BCR of 1.9 with a comparatively lower investment of USD 200 million (**Figure 7**). This option represents a well-balanced adaptation measure that enhances crop resilience without necessitating large infrastructure or system overhauls. Drought-tolerant varieties are particularly suitable for rain-fed systems and are effective in reducing yield losses during dry spells—a common phenomenon in Algeria's high plateau and mountainous regions. Moreover, this strategy aligns with the goals of sustainable intensification and may be deployed through national seed programs. However, its success is contingent on the presence of robust agricultural research and extension systems capable of developing, testing, and distributing improved cultivars that are tailored to the agro-ecological zones of northern Algeria. Furthermore, the long-term performance of such seeds needs to be continually evaluated under changing climate scenarios, which adds a layer of complexity to their deployment [30].

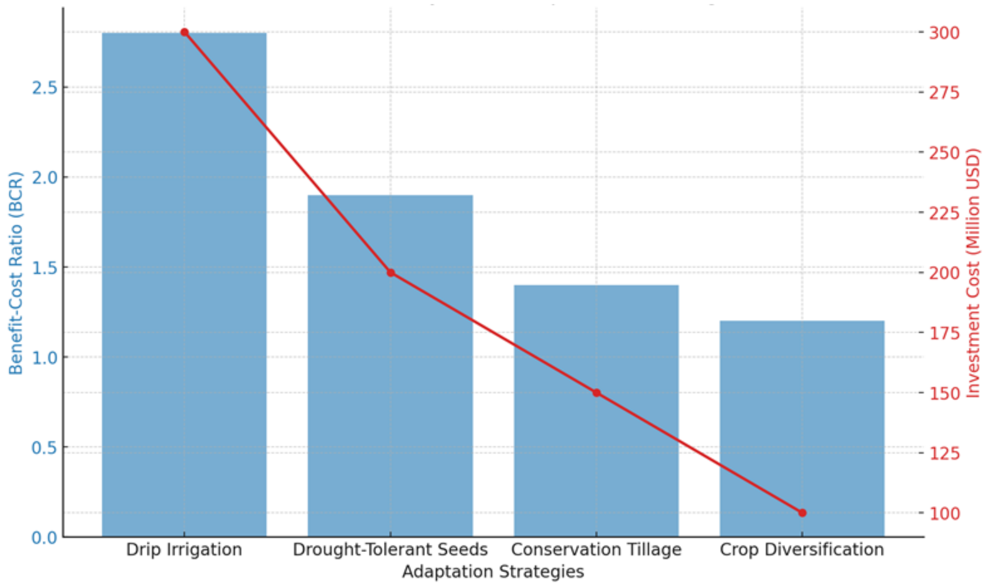

Figure 7. BCR and Investment Cost per Adaptation Strategy.

In contrast, strategies such as conservation tillage and crop diversification yield lower BCRs ranging from 1.2 to 1.4, making them less economically attractive in the short term. Nevertheless, their implementation costs are substantially lower, and they offer important co-benefits that extend beyond immediate profitability. Conservation tillage, for instance, improves soil organic matter, reduces erosion, and enhances moisture retention, factors that are crucial for maintaining long-term agricultural productivity under climate stress. Crop diversification reduces economic and biological risks by spreading vulnerability across different species and markets. Although their immediate returns are modest, these strategies play a critical role in increasing the resilience of agro-ecosystems, and they are more easily adoptable by resource-constrained farmers.

While the Benefit-Cost Ratios (BCRs) provide valuable insights for ranking adaptation strategies based on economic efficiency, they do not fully reflect the multifaceted institutional, administrative, and social realities that condition implementation on the ground. In the Algerian context, numerous structural barriers may limit the deployment of even the most economically attractive measures. For instance, although drip irrigation shows a high BCR, its application demands significant initial capital, technical proficiency, and supportive infrastructure such as water conveyance and maintenance systems. However, small-scale farmers—especially those in semi-arid and mountainous areas—often face restricted access to financial services, lack formal land tenure, and are unable to provide guarantees, all of which impede investment in such technologies.

Similarly, the diffusion of drought-resistant seed varieties, while less capital-intensive, is hampered by limited breeding capacities, insufficient distribution frameworks, and farmers' reluctance to adopt formal seed systems. Enhancing adoption would require stronger collaboration between agricultural research centers, extension agents, and rural communities, as well as sustained efforts in testing, certifying, and distributing varieties adapted to diverse agro-ecological conditions.

Therefore, adaptation strategies with favorable economic indicators may remain ineffective without supportive measures such as tailored subsidies and local participatory mechanisms. On the other hand, approaches with lower immediate financial benefits—such as conservation tillage or crop diversification—may be more readily embraced due to their accessibility and consistency with traditional agricultural practices, especially when promoted through farmer associations and decentralized extension structures. Thus, beyond economic assessments, adaptation planning must account for social acceptability and implementation capacity to ensure tangible progress in building climate resilience in agriculture.

It is important to emphasize that the BCR is not the sole criterion to guide the selection of adaptation strategies. While it provides a useful economic metric for comparing options, it does not capture social, institutional, and environmental dimensions. For instance, strategies with high BCRs may not be feasible without strong institutional support, access to credit, or a favorable policy environment. Likewise, lower-BCR strategies may yield cumulative benefits in terms of soil conservation, biodiversity, and risk reduction that are not immediately reflected in economic metrics.

In this context, a hybrid adaptation approach may be the most effective pathway. Combining high-BCR interventions such as drip irrigation or improved seeds with broader resilience-building strategies like conservation practices and diversification could deliver both immediate economic gains and long-term sustainability. This integrated framework would not only maximize returns under current climate conditions but also reduce vulnerability to future shocks, making cereal production systems in northern Algeria more robust in the face of climate change.

4. Conclusions

This study provides a detailed assessment of the economic vulnerability of cereal production in northern Algeria under climate change, focusing on four key regions, Blida, Tizi Ouzou, Tiaret, and Sétif, selected for their agro-climatic diversity and strategic importance. Using a combined approach of DSSAT crop modeling, SWOT-AHP analysis, and cost-benefit evaluation, the research highlights both the risks posed by projected climate scenarios and the potential of targeted adaptation strategies.

Climate projections under RCP4.5 and RCP8.5 indicate significant yield reductions, between 18% and 40% by 2050, accompanied by major economic consequences, including an annual increase of up to $1.2 billion in import costs and the potential loss of 12,000 jobs. Heat stress during flowering was identified as the most critical yield-limiting factor, pointing to the urgency of developing and implementing effective adaptation strategies.

Among the options evaluated, drip irrigation and drought-tolerant seed varieties emerged as the most economically viable, with benefit-cost ratios of 2.8 and 1.9, respectively. However, their implementation depends on substantial initial investments and a reallocation of current cereal subsidies, which remain misaligned with climate resilience goals.

The findings underscore a fundamental trade-off in agricultural policy: maintaining current subsidy structures may provide short-term support but will increase vulnerability in the long run. In contrast, investing in climate-smart technologies offers a cost-effective pathway to safeguarding yields, reducing dependency on imports, and enhancing rural livelihoods. Ultimately, this study demonstrates that integrating crop simulation with participatory and economic analysis provides a powerful framework for guiding adaptation decisions. It offers valuable insights not only for Algeria but also for other semi-arid countries confronting similar climate-agriculture challenges.

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Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The author declares no conflict of interest.

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