Climate Change Impact on 2024 Agriculture

Willow Westbrook, Matthew Kolovsky, Drew Kryzan

Loyola Marymount University

Programming for Data Analytics: BSAN 6030

Contact Us:

wwestbro@lion.lmu.edu, mkolovsk@lion.lmu.edu, akryzan@lion.lmu.edu

Executive Summary

This report examines the most effective strategies for maintaining agricultural productivity under changing climate conditions. The objective was to analyze how factors like

irrigation access, soil health, pesticide and fertilizer use, and adaptation strategies impact crop yields and economic outcomes. The study aimed to identify practices that enhance resilience to temperature and precipitation variability while promoting sustainable productivity. The analysis used regional crop yield data alongside climate and adaptation variables. Data cleaning and visualizations, including scatter plots and bar charts, were performed using Python. Correlations between temperature, precipitation, and crop yields were explored, along with the economic impacts of different adaptation strategies. The methodology provided a comprehensive understanding of the factors driving agricultural outcomes.

Key findings highlight that irrigation access is vital in regions with high precipitation variability, where it significantly improves yields. Soil health enhances resilience but shows limited direct correlation with productivity. Overuse of pesticides reduces effectiveness, making it crucial to apply them only when needed, in precise amounts, and for specific pests or growth stages. Crop rotation and drought-resistant crops emerged as the most effective strategies, delivering high yields and economic benefits, while water management showed mixed results due to regional challenges.

Our report recommends prioritizing irrigation infrastructure in vulnerable regions, promoting practices to enhance soil health, and adopting efficient pesticide strategies. Tailored combinations of crop rotation, drought-resistant crops, and optimized water management are suggested to maximize productivity based on regional needs. These measures provide a roadmap for adapting agriculture to climate change while ensuring economic and environmental sustainability.

Table of Contents

Introduction

      Agriculture is one of the most critical sectors impacted by climate change, with shifts in temperature, precipitation, and extreme weather events directly affecting crop yields and

economic outcomes. This report focuses on analyzing the effectiveness of various adaptation strategies, including irrigation access, soil health improvement, and optimized pesticide and fertilizer use, in enhancing agricultural resilience and productivity. The primary goal is to identify actionable solutions that ensure sustainable yields while addressing the challenges posed by climate variability.

The importance of this analysis lies in the agricultural sector's central role in global food security and economic stability. Agriculture accounts for approximately 10% of global GDP and sustains millions of livelihoods worldwide (FAO, 2023). Climate change has already caused annual crop yield reductions of 5-10%, with vulnerable regions disproportionately affected (FAO, 2023). Without effective adaptation measures, these trends threaten not only food supply but also broader economic and social stability. This report aims to provide evidence-based insights for policymakers, farmers, and agribusinesses to mitigate these impacts and promote sustainable practices.

The dataset used in this analysis includes regional information on crop yields, temperature, precipitation, extreme weather events, and adaptation strategies. It also provides detailed metrics such as irrigation access rates, soil health indices, and pesticide and fertilizer usage. These variables were analyzed to understand their relationships with agricultural productivity and to evaluate the economic impacts of various strategies.

Our workflow involved extensive data cleaning to ensure accuracy and consistency in the dataset, followed by exploratory data analysis to uncover key trends and relationships. We visualized multiple variables through scatter plots, bar charts, and heatmaps to provide a comprehensive understanding of the dataset. Correlation studies, regional comparisons, and economic impact evaluations were conducted to identify effective practices. By combining robust analytical methods with actionable recommendations, this report serves as a call to action for stakeholders to invest in sustainable agricultural strategies that address the challenges of climate change.

Methodology

This study aimed to analyze the relationships between climate variables, adaptation strategies, and agricultural productivity. To ensure the analysis was systematic and reproducible, the methodology included three main stages: data collection, data cleaning, and analysis. Each

stage was carefully executed using Python and associated libraries to prepare and process the data for meaningful insights.

The dataset was collected in CSV format and contained detailed information about regional and temporal agricultural practices. It included variables such as crop yields (measured in metric tons per hectare), climate factors (temperature and precipitation), soil health indices, irrigation access percentages, pesticide and fertilizer use, and the economic impacts of various adaptation strategies. The dataset spanned multiple regions and years, providing a comprehensive view of agricultural productivity under diverse conditions.

Before analysis, the data underwent a thorough cleaning process to ensure accuracy and consistency. Missing values were identified and addressed systematically. Numerical variables, such as crop yields and soil health indices, were input with averages based on regional or global data our team collected. Records with extensive missing data that could not be reasonably corrected were excluded. Units of measurement were standardized to maintain consistency; for instance, all crop yields were converted to metric tons per hectare, and temperature values were standardized to degrees Fahrenheit. Outliers were detected using interquartile ranges and visualized with box plots to determine whether they were valid data points or errors. Invalid outliers were removed or corrected. Additionally, categorical variables, such as adaptation strategies, were reviewed for uniformity and consistency. Inconsistent labels or duplicate categories were consolidated to ensure reliable grouping for analysis.

Following data cleaning, the dataset was analyzed to uncover relationships between variables and to evaluate the effectiveness of adaptation strategies. Exploratory data analysis was conducted to identify patterns and correlations. For instance, correlation matrices revealed the relationships between temperature, precipitation, and crop yields. Scatter plots, such as one depicting *Temperature vs. Crop Yield by Region*, were used to visualize regional differences in productivity under varying climate conditions. These visualizations helped identify regions that performed better under specific temperature ranges and informed the analysis of strategy effectiveness.

Continuous variables, such as temperature and precipitation, were categorized into bins using Python's pandas.cut function. This allowed for a more detailed examination of trends within specific bin ranges, such as the impact of moderate versus extreme temperature levels on crop yields. Grouping and aggregation techniques were utilized to compare the performance of different adaptation strategies, including crop rotation, drought-resistant crops, and water

management. Bar charts and heatmaps were created to visualize differences in crop yields and economic impacts across strategies and regions.

The analysis was conducted entirely in Python within Jupyter Notebook. Tools such as pandas and NumPy were used for data cleaning and manipulation, while matplotlib and seaborn facilitated the creation of clear and informative visualizations. The structured workflow ensured that the process was reproducible and that the insights derived were both accurate and actionable. Through these steps, the project provided evidence-based recommendations for improving agricultural resilience and productivity under the impacts of climate change.

Findings

The analysis revealed several critical insights into the relationships between climate variables, adaptation strategies, and agricultural productivity. These findings, supported by numerical evidence, tables, and visualizations, highlight the importance of region-specific strategies to mitigate the impacts of climate change on agriculture.

One of the key findings was the impact of temperature on crop yields. The scatter plot *Temperature vs. Crop Yield by Region* demonstrated that regions with average temperatures between 10°C and 20°C consistently achieved higher yields, indicating that this range is optimal for crop growth. In contrast, regions with extreme temperatures, either below 10°C or above 30°C, experienced significant reductions in yield, suggesting that temperature extremes place stress on crops. This pattern underscores the need for strategies that mitigate the effects of temperature variability, such as the adoption of climate-resilient crops.

Irrigation access emerged as a significant factor influencing productivity. The scatter plot *Irrigation Access vs. Crop Yield by Temperature Range* revealed that regions with irrigation access exceeding 60% consistently outperformed those with less access, particularly in moderate temperature ranges (10°C–30°C). This finding highlights the critical role of water infrastructure in stabilizing yields under variable climate conditions. Regions lacking irrigation access often experienced yield stagnation, reinforcing the need for investments in irrigation systems, especially in areas prone to drought or irregular precipitation.

Soil health was another crucial determinant of agricultural productivity. The scatter plot *Soil Health vs. Crop Yield by Precipitation Range* showed that regions with healthier soils (indices above 70) performed better across all levels of precipitation. However, in areas with low precipitation (below 500 mm), even high soil health could not fully counteract the negative

impacts of water scarcity. This suggests that soil management practices, such as crop rotation and organic amendments, should be combined with improved water management to achieve optimal productivity.

The analysis also assessed the effectiveness of various adaptation strategies. The bar chart *Average Crop Yield by Adaptation Strategy* revealed that crop rotation and drought-resistant crops were the most effective measures, achieving average yields of 2.27 MT/HA and 2.24 MT/HA, respectively. These strategies outperformed others, such as water management, which showed slightly lower yields due to regional challenges in implementation. This finding suggests that a combination of strategies tailored to regional conditions can maximize productivity.

Economic impacts of adaptation strategies varied significantly across regions. The heatmap *Economic Impact by Region and Adaptation Strategy* revealed that regions like Southwest and Tamil Nadu experienced the highest economic benefits, with average impacts exceeding $800 million under crop rotation strategies. In contrast, regions such as Pampas and Nouvelle-Aquitaine exhibited lower economic outcomes, reflecting challenges in applying adaptation measures effectively. This disparity highlights the importance of tailoring strategies to the specific needs and capabilities of each region.

The analysis of long-term trends in crop yields, depicted in the line plot *Average Crop Yield Over Time*, showed that yields have remained relatively stable over the past three decades, with occasional fluctuations. Peaks in yields often coincided with years of favorable climate conditions and effective strategy implementation, emphasizing the role of consistent adaptation efforts in sustaining productivity over time.

Finally, the study explored the diminishing returns from agricultural inputs such as pesticides and fertilizers. The scatter plot *Fertilizer Use vs. Pesticide Use and Crop Yield* revealed that excessive use of inputs did not consistently lead to higher yields. Beyond a threshold—approximately 60 KG/HA for fertilizers and 30 KG/HA for pesticides—yields plateaued. This finding highlights the importance of optimizing input use to enhance efficiency and reduce unnecessary costs.

In summary, these findings provide a comprehensive understanding of how climate variables and adaptation strategies influence agricultural productivity and economic outcomes. The results underscore the importance of region-specific approaches that integrate water management, soil health improvements, and optimized input use to enhance resilience and

sustainability in agriculture. The major tables and graphs presented here directly support these conclusions, while additional analyses and results are included in the appendix for further context.

Interpretation & Analysis

The analysis provided critical insights into the relationships between climate variables, adaptation strategies, and agricultural productivity. These findings directly address the research questions and offer actionable interpretations that are crucial for understanding and addressing the business problem of improving agricultural resilience and sustainability.

The analysis of temperature impacts revealed that regions with average temperatures between 10°C and 20°C achieve the highest crop yields, as shown in *Temperature vs. Crop Yield by Region*.
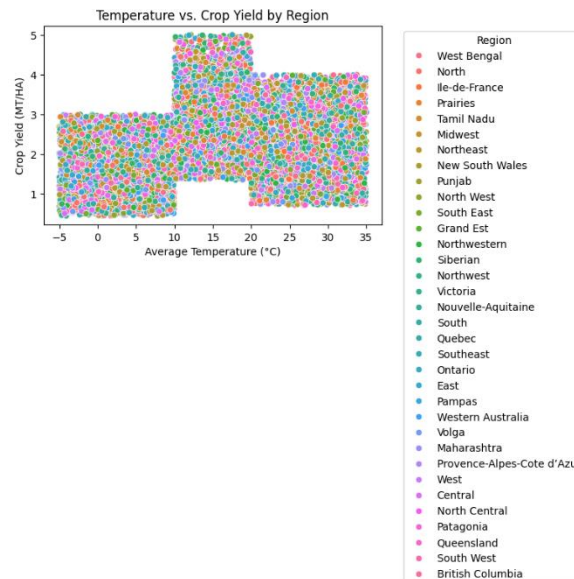

This finding highlights the importance of moderate temperatures for optimal crop growth. However, regions experiencing extreme temperatures (<10°C or >30°C) showed marked reductions in yield, emphasizing the adverse effects of temperature extremes. For stakeholders, this underscores the need for temperature-resilient strategies, such as climate-smart crops or adjustments in planting schedules, to buffer against such variability.

Irrigation access played a pivotal role in sustaining productivity, particularly in regions with significant temperature fluctuations. The scatter plot *Irrigation Access vs. Crop Yield by Temperature Range*
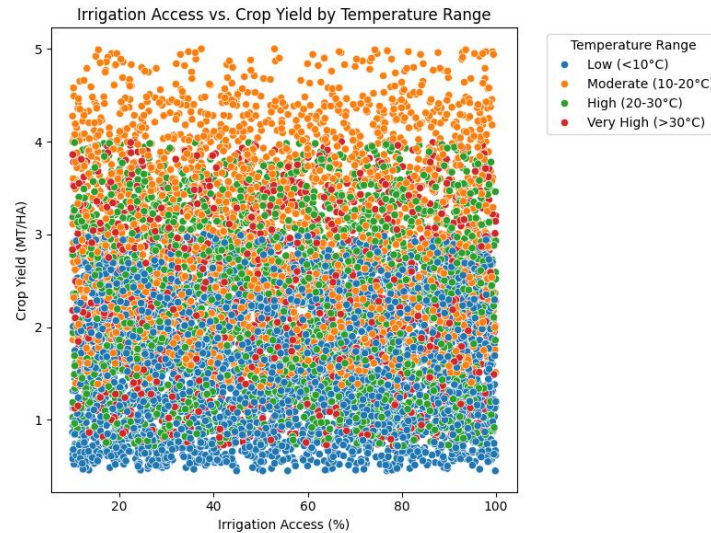
demonstrated that regions with high irrigation access (above 60%) consistently achieved higher yields, even in challenging temperature conditions. This finding highlights the value of reliable water infrastructure in mitigating climate-induced water stress. Businesses and policymakers must prioritize investments in irrigation development, especially in drought-prone regions, to stabilize yields and support agricultural sustainability.

Soil health was another critical factor influencing crop productivity. The scatter plot *Soil Health vs. Crop Yield by Precipitation Range*
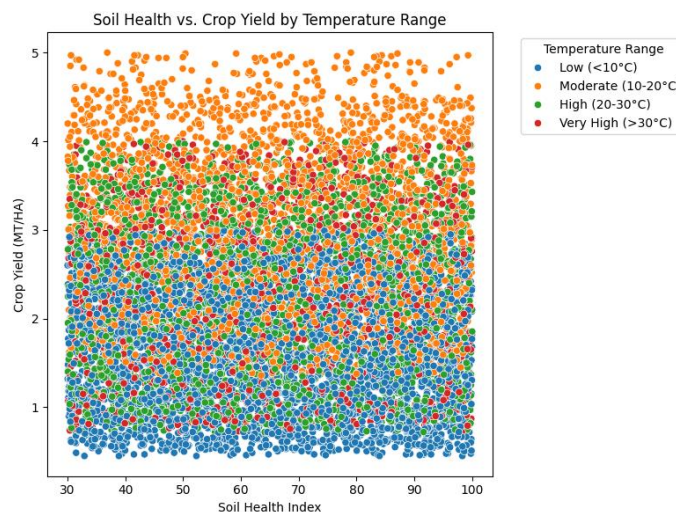
revealed that regions with higher soil health indices (above 70) performed better across all precipitation levels. However, in areas with limited rainfall (<500 mm), even healthy soils could not fully mitigate the impact of water scarcity. This finding highlights the need for integrated strategies that combine soil management practices, such as crop rotation and organic

amendments, with improved irrigation systems to maximize productivity under varying climate conditions.

The effectiveness of adaptation strategies was evaluated using *Average Crop Yield by Adaptation Strategy*.
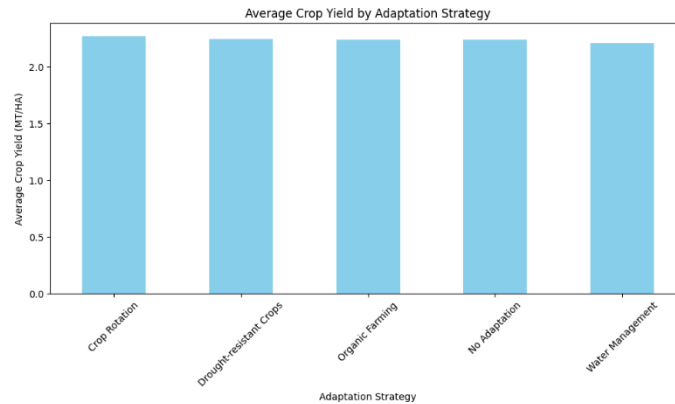

Crop rotation and drought-resistant crops emerged as the most effective strategies, achieving average yields of 2.27 MT/HA and 2.24 MT/HA, respectively. These strategies outperformed water management, which faced challenges in implementation in some regions. This finding underscores the importance of focusing on proven, scalable strategies that can be adapted to regional needs. Encouraging the adoption of these strategies is essential for improving resilience and sustaining agricultural outputs in the face of climate challenges.

Economic impacts of adaptation strategies varied significantly across regions, as illustrated in *Economic Impact by Region and Adaptation Strategy*.
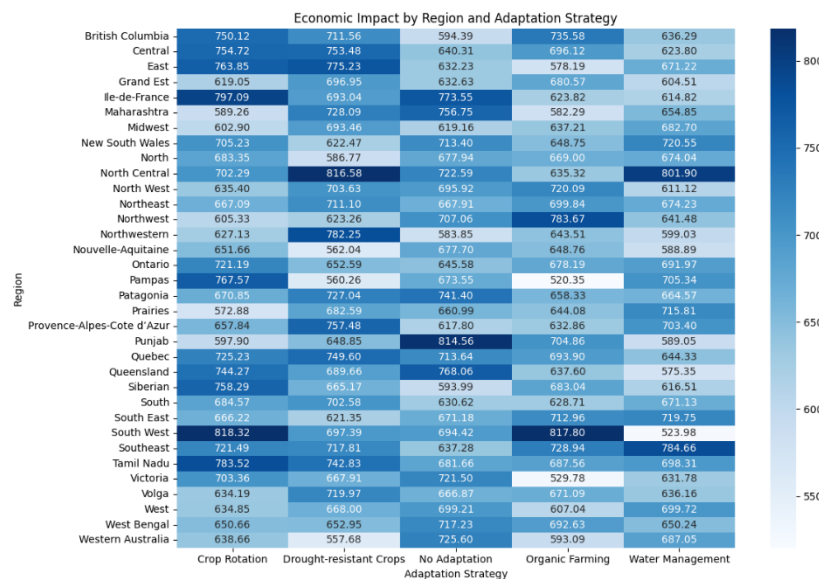
Regions such as Southwest and Tamil Nadu experienced the highest economic benefits, exceeding $800 million under crop rotation strategies, emphasizing the financial viability of these measures. In contrast, regions like Pampas and Nouvelle-Aquitaine experienced lower economic returns, reflecting challenges in scaling adaptation practices. This finding suggests that businesses and policymakers should focus on tailored strategies to maximize economic outcomes while addressing regional constraints.

Finally, the diminishing returns of agricultural inputs were evident in *Fertilizer Use vs. Pesticide Use and Crop Yield*.
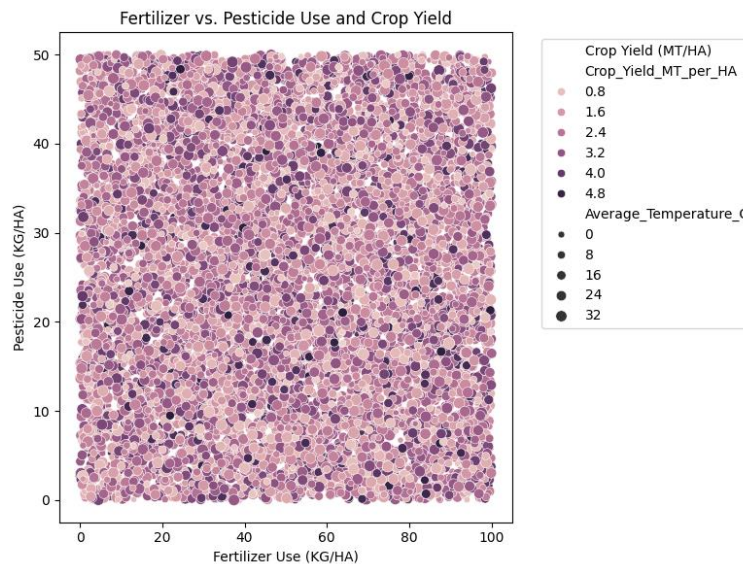
Beyond specific thresholds—60 KG/HA for fertilizers and 30 KG/HA for pesticides—yields plateaued, indicating that additional inputs did not translate into higher productivity. This underscores the need for precision agriculture techniques to optimize input use, reduce costs, and minimize environmental impacts.

In conclusion, these findings provide actionable insights into how climate variables and adaptation strategies influence agricultural productivity and economic outcomes. The key visualizations presented here underscore the importance of prioritizing water infrastructure, improving soil health, and adopting effective adaptation strategies to enhance resilience and ensure sustainable agricultural practices in the face of climate change. Additional supporting analyses and graphs are included in the appendix to provide further context.

Interpretation & Analysis

The findings of this analysis provide a strong foundation for developing actionable recommendations to address the challenges of climate change in agriculture. These recommendations are tailored to the realities of regional diversity, resource availability, and the need for sustainable solutions, ensuring that they are both practical and impactful.

One of the most critical recommendations is to invest in irrigation infrastructure. The analysis revealed that regions with higher irrigation access (above 60%) consistently achieved better crop yields, even under challenging temperature and precipitation conditions. This underscores the importance of reliable water availability in mitigating climate-induced stress. Managers should prioritize expanding irrigation networks and developing water storage systems, particularly in drought-prone regions. In areas with limited water resources, efficient irrigation methods, such as drip or sprinkler systems, should be adopted to maximize water use efficiency and ensure stable crop yields.

Another key recommendation is to promote crop rotation and the adoption of drought-resistant crop varieties. The data showed that these strategies were the most effective in maintaining high crop yields, with averages of 2.27 MT/HA and 2.24 MT/HA, respectively. These practices not only improve soil health and resilience but also enhance productivity in regions facing extreme climate conditions. Managers should encourage farmers to integrate crop rotation into their farming systems and provide access to drought-resistant seeds. Subsidies, training programs, and awareness campaigns can be effective tools to facilitate the widespread adoption of these strategies.

Improving soil health is another crucial area for intervention. The findings demonstrated that regions with healthier soils consistently performed better across all precipitation levels. To achieve this, managers should promote sustainable soil management practices, such as the use of organic amendments (e.g., compost and green manure), reduced tillage, and cover cropping. These practices enhance soil fertility, improve water retention, and reduce erosion. Investment in soil testing facilities and advisory services can further help farmers monitor and manage soil health effectively.

Optimizing the use of agricultural inputs is also vital. The analysis showed that excessive application of fertilizers and pesticides did not yield proportional benefits, with diminishing returns observed beyond specific thresholds. Managers should advocate for precision agriculture techniques, which use data-driven tools to apply inputs efficiently based on crop and soil needs.

This approach not only reduces input costs for farmers but also minimizes environmental impacts, contributing to sustainable agricultural practices.

Additionally, the economic analysis revealed regional disparities in the effectiveness of adaptation strategies. For example, regions like Southwest and Tamil Nadu experienced the highest economic benefits from crop rotation, while others, such as Pampas, faced challenges in scaling adaptation measures. This suggests the need for region-specific strategies tailored to local conditions and constraints. Managers should conduct localized assessments to identify the most suitable adaptation practices for each region and allocate resources accordingly.

Finally, long-term planning and continuous adaptation are essential to sustaining agricultural productivity. The analysis of historical trends highlighted the importance of consistent efforts in implementing and refining climate-resilient practices. Managers should establish programs for ongoing research and development to innovate and adapt strategies as climate conditions evolve. Collaborations with research institutions, government agencies, and non-governmental organizations can provide additional support in developing and disseminating effective solutions.

In summary, these recommendations emphasize the importance of investing in irrigation, promoting effective adaptation strategies like crop rotation and drought-resistant crops, improving soil health, optimizing input use, tailoring solutions to regional needs, and fostering long-term resilience through continuous innovation. By implementing these measures, agricultural stakeholders can enhance productivity, mitigate the impacts of climate change, and ensure sustainable farming practices for the future.

Summary & Conclusion

This analysis explored the relationships between climate variables, adaptation strategies, and agricultural productivity to identify actionable measures for improving resilience and sustainability in agriculture. The findings revealed that moderate temperatures (10°C–20°C/50°F–68°F), irrigation access, and soil health were critical factors influencing crop yields. Adaptation strategies such as crop rotation and drought-resistant crops were shown to be the most effective in maintaining productivity, while excessive input use demonstrated diminishing returns.

A comprehensive recommendation derived from this analysis include investments in irrigation infrastructure, promotion of crop rotation and drought-resistant crops, adoption of

sustainable soil management practices, optimization of input use, and the implementation of region-specific strategies. These measures aim to enhance agricultural resilience to climate change while ensuring economic viability for farmers and stakeholders.

Our team undertook a rigorous process to clean, enrich, and analyze the dataset, ensuring the results were as precise and actionable as possible. By addressing every facet of the data preparation and analysis process, we maximized the reliability and relevance of the findings to inform strategies for addressing climate change impacts on agriculture.

Given additional time, the scope of the analysis could be broadened to explore further dimensions of agricultural challenges. For instance, incorporating detailed cost data would enhance the economic analysis, allowing for a more comprehensive assessment of the feasibility and scalability of adaptation strategies. Additionally, integrating qualitative insights, such as farmer surveys or regional case studies, would provide a richer understanding of local challenges and preferences, further contextualizing the recommendations.

This analysis represents a strong foundation for addressing the impacts of climate change on agricultural systems. The findings and recommendations presented are derived from a meticulous and methodical approach, offering evidence-based strategies to enhance resilience and sustainability. With continued refinement and expansion of this work, stakeholders can implement these strategies to effectively support agricultural systems and ensure their long-term viability amidst evolving climate conditions.

References

Bouteska, Ahmed, et al. "Impacts of the Changing Climate on Agricultural Productivity and
      Food Security: Evidence from Ethiopia." *Journal of Cleaner Production*, 2024,
          https://doi.org/10.1016/j.jclepro.2024.141793. Accessed 23 Nov. 2024.

Food and Agriculture Organization of the United Nations. *The State of Food and Agriculture*

     2023: Climate Change Impacts on Agriculture. FAO, 2023.

Frontiers. "Climate Change and Crop Yield: A Comprehensive Analysis." *Frontiers in Plant*

     Science, https://www.frontiersin.org/journals/plant-

     science/articles/10.3389/fpls.2022.925548/full. Accessed 8 Nov. 2024.

Heifer International. "How Climate Change Affects Agriculture." *Heifer International*,

     https://www.heifer.org/blog/how-climate-change-affects-agriculture.html.

     Accessed 15 Nov. 2024.

The Nature Conservancy. "Growing Threats: How Climate Change Will Exacerbate

     Environmental Impacts on Agriculture." *The Nature Conservancy*,

     https://www.nature.org/en-us/newsroom/growing-threats-how-climate-change-will-

     exacerbate-environmental-impacts-agriculture/. Accessed 17 Nov. 2024.

Waqi786. *Climate Change Impact on Agriculture.* Kaggle,

     https://www.kaggle.com/datasets/waqi786/climate-change-impact-on-agriculture/data.

     Accessed 14 Nov. 2024.

Appendices

Our research questions:

i. What are the most effective adaptation strategies for maintaining agricultural productivity in the face of climate change?

ii. How is climate change affecting agricultural productivity across different regions?

iii. How does irrigation access correlate with crop yields in regions experiencing temperature increases or changes in precipitation patterns?

iv.   What is the relationship between soil health index and crop yields, and how does this relationship change under different climate conditions?

v.   How do pesticide and fertilizer use relate to crop yields in the context of changing climate patterns across different regions?

vi.   What is the economic impact of various adaptation strategies on agricultural productivity in different countries and regions?

The appendices provide supplementary charts and analyses that complement the findings presented in the main report. While these visualizations are not essential for understanding the primary conclusions, they offer additional depth and context, supporting the practical recommendations and enriching the overall analysis.

One key visualization is the scatter plot showing *Extreme Weather Events vs. Crop Yields*. This plot demonstrates how yields vary with the frequency and severity of extreme weather. The data reveals that regions experiencing moderate levels of extreme events exhibit higher resilience, likely due to the effectiveness of existing adaptation strategies. This insight reinforces the need for implementing and scaling climate-smart practices in vulnerable regions.
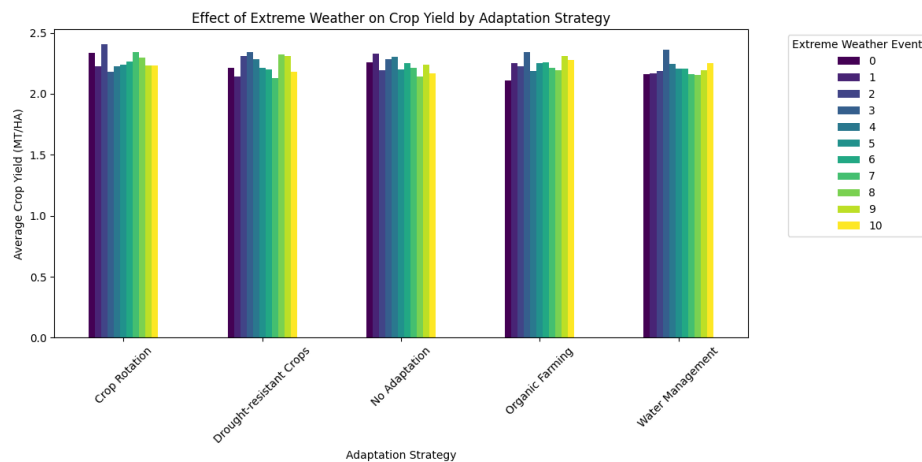

The analysis of crop yields over time reveals significant trends that provide context for understanding agricultural productivity's evolution. By examining the trajectory of average crop yield across decades, we gain insights into how various factors, such as climatic conditions, technological advancements, and socio-economic policies, have influenced agricultural outcomes. One key observation from this data is the overall upward trend in crop yields, punctuated by periods of volatility and fluctuation.

The graph showcasing average crop yield over time highlights several critical moments. For instance, peaks in the early 2010s may correlate with advancements in agricultural
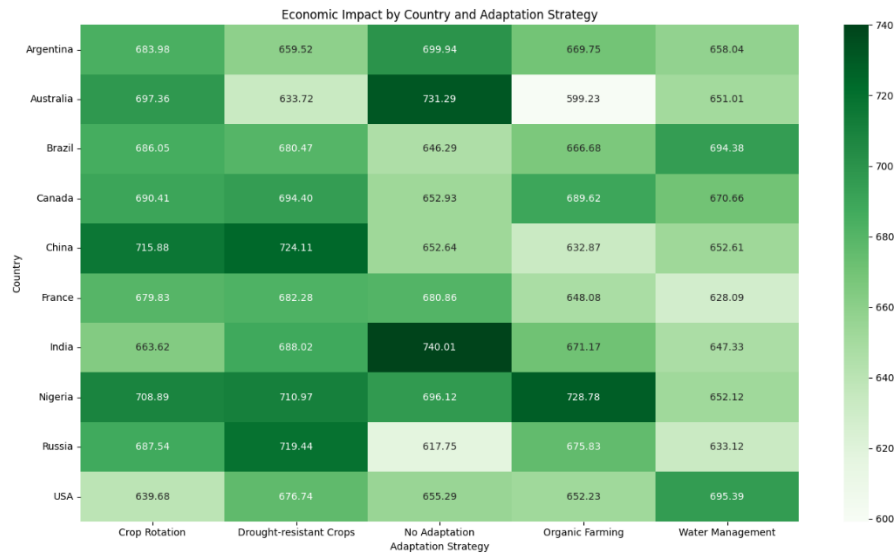
technologies or favorable weather patterns. Conversely, troughs, such as the sharp decline in the early 2020s, likely point to the adverse impacts of extreme climatic events, including droughts or flooding, or other socio-economic disruptions. These observations underscore the challenges faced by farmers and policymakers in maintaining consistent productivity levels amidst an unpredictable climate.

This analysis also brings to light the importance of adaptive strategies to mitigate risks. For instance, regions that contribute most to yield volatility could benefit from targeted interventions, such as enhanced irrigation systems or the introduction of climate-resilient crop varieties. Furthermore, examining specific years with dramatic changes in yields could offer valuable lessons for future agricultural planning and preparedness.
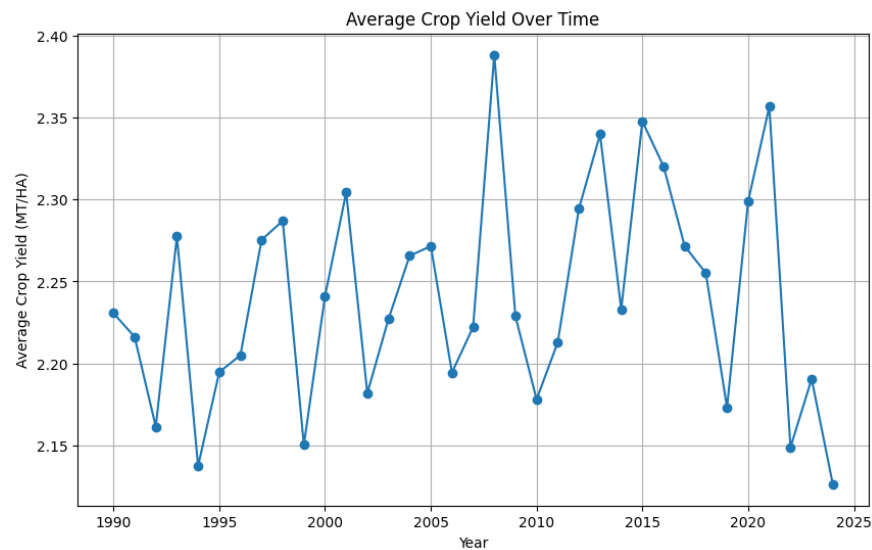
Understanding these trends is crucial for shaping future policies. The periodic declines emphasize the need for proactive measures to bolster agricultural resilience, while the overall upward trajectory is a testament to the potential of innovation and investment in the sector. This graph provides a foundational perspective for stakeholders to identify patterns, predict challenges, and implement effective strategies to sustain agricultural growth.

The heatmap showcasing the economic impact by country and adaptation strategy reveals key insights into the effectiveness of various agricultural practices across different nations. It highlights how strategies such as crop rotation, drought-resistant crops, organic farming, and water management yield varying economic benefits depending on the country's unique climatic and economic context.

Economic Impact by Country and Adaptation Strategy

Country	Crop Rotation	Drought-resistant Crops	No Adaptation Adaptation Strategy	Organic Farming	Water Management
Argentina	683.98	659.52	699.94	669.75	658.04
Australia	697.36	633.72	731.29	599.23	651.01
Brazil	686.05	680.47	646.29	666.68	694.38
Canada	690.41	694.40	652.93	689.62	670.66
China	715.88	724.11	652.64	632.87	652.61
France	679.83	682.28	680.86	648.08	628.09
India	663.62	688.02	740.01	671.17	647.33
Nigeria	708.89	710.97	696.12	728.78	652.12
Russia	687.54	719.44	617.75	675.83	633.12
USA	639.68	676.74	655.29	652.23	695.39

Notably, China and India demonstrate the highest economic impacts from drought-resistant crops, reflecting their challenges with water scarcity and extreme weather. Similarly, Brazil and Nigeria show substantial gains through organic farming, indicating the relevance of sustainable agricultural practices in these regions. Additionally, the USA displays consistent but moderate economic impacts across all strategies, suggesting a potential need for more innovative or targeted interventions.

This analysis emphasizes the necessity of tailoring adaptation strategies to each nation's specific conditions. It supports the recommendation for region-specific approaches that maximize economic returns while addressing local challenges, providing a roadmap for policymakers to enhance agricultural resilience and productivity in a changing climate.