biology and life sciences forum

Proceedings paper

The Role of Artificial Intelligence in Climate-Smart Agriculture: A Review of Recent Advances and Future Directions †

Aamir Raza[1,*], Muhammad Adnan Shahid[1,2], Muhammad Safdar[1,2], Muhammad Zaman[1], Rehan Mehmood Sabir[1,2]

1 Department of Irrigation & Drainage, University of Agriculture, Faisalabad, 38000, Punjab, Pakistan
2 Agricultural Remote Sensing Lab of National Center of GIS and Space Applications (NCGSA-ARSL), University of Agriculture, Faisalabad, 38000, Punjab, Pakistan
* Correspondence: aamiruaf4@gmail.com
† Presented at the 2nd International Electronic Conference on Agriculture , 1–15 Nov 2023, Available online at: https://iocag2023.sciforum.net/ .

Abstract: Artificial intelligence (AI) has the potential to revolutionize agricultural analysis and improve climate-smart farming practices. This paper explores the transformative role of AI in climate-smart agriculture, focusing on recent advances and future directions. Climate change poses significant challenges for agriculture, including weather variability, water scarcity, and the emergence of new pests and diseases. Leveraging AI technology, this research delves into how agricultural analysis can be revolutionized, leading to improved climate-smart farming practices. Recent advances in AI, such as machine learning and deep learning, have enabled the development of powerful predictive models that can be used to forecast climate events, optimize irrigation schedules, and detect early indicators of crop stress or disease outbreaks. This information can be used to proactively alter farming operations and resource allocation tactics, resulting in increased productivity and less environmental impact. AI-powered precision agriculture technology, such as autonomous drones and sensor networks, also enables real-time monitoring and data collection. This allows farmers to collect precise data on crop health, soil moisture levels, and fertilizer requirements. AI algorithms can then deliver practical crop management advice, such as optimal planting schedules, fertilizer application rates, and pest control techniques. The integration of AI in climate-smart farming also holds potential for long-term agricultural practices. Predictive analytics and AI-based supply chain optimization can improve post-harvest management, storage, and distribution processes, reducing food loss and increasing overall efficiency. The research emphasizes how AI can enable farmers to make data-driven decisions, optimize resource consumption, and enhance resilience in the face of climate challenges. By integrating AI into agriculture, this paper presents a pathway toward sustainable food production, environmental stewardship, and improved farmer livelihoods.

Keywords: Artificial Intelligence; Agricultural Analyses; Machine Learning; Predictive Models; Precision Agriculture; Resource Efficiency

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Published: date

1. Introduction

In recent years, the agricultural sector has encountered escalating challenges due to the growing impacts of climate change[1]. Shifts in weather patterns, heightened variability, and the emergence of new pests and diseases have exacerbated the vulnerabilities of conventional farming practices [2], [3]. As these challenges intensify, the integration of artificial intelligence (AI) offers a transformative avenue to enhance agricultural analysis and bolster climate-smart farming strategies [4]. This paper investigates the pivotal role of AI in climate-smart agriculture, scrutinizing recent advancements and outlining prospective trajectories. By examining the confluence of AI and agriculture, this review aims to shed light on the potential for resilient and sustainable food production systems.

Climate-smart agriculture has emerged as an imperative paradigm to navigate the complexities engendered by climate change [5]. This multifaceted approach seeks to harmonize agricultural productivity, climate change adaptation, and mitigation efforts [6]. Its significance lies in its capacity to propel the agricultural sector towards not only increased yield and profitability but also heightened environmental stewardship and resilience [7]. Recognizing the intrinsic link between farming systems and climate dynamics, climate-smart agriculture emphasizes strategies that optimize resource efficiency, protect ecosystems, and enhance food security [8].

Climate change has unleashed an array of challenges upon agriculture, spanning geographical and temporal dimensions. The shifting climate patterns have led to heightened weather variability, characterized by erratic rainfall, extended droughts, and unanticipated frosts [9]. These climatic vagaries disrupt established planting and harvesting schedules, culminating in reduced yields and compromised crop quality [10]. Furthermore, the escalation of water scarcity, exacerbated by shifting precipitation patterns, poses a profound threat to irrigation-dependent agriculture. The intertwined impacts of climate change facilitate the proliferation of new pests and diseases, perturbing both plant and animal ecosystems. The absence of historical precedent for these novel threats complicates effective response and management strategies. Soil degradation, nutrient depletion, and biodiversity loss are amplified by the altering climate, undermining the overall resilience and sustainability of agricultural landscapes.

Amidst the intricate tapestry of climate-related challenges, AI emerges as a promising tool to navigate the complexity and uncertainty inherent to agriculture in a changing climate [11]. AI encompasses a spectrum of technologies, prominently machine learning and deep learning, which empower the development of predictive models capable of deciphering intricate patterns within voluminous datasets [12]. AI has the potential to revolutionize agriculture and help farmers address the challenges posed by climate change. AI's integration in agriculture offers a multifaceted approach to innovation as shown below in figure 1. AI has the potential to revolutionize agriculture and help farmers address the challenges posed by climate change. By integrating AI into agriculture, we can create a more sustainable food system that is better able to withstand the shocks of climate change.

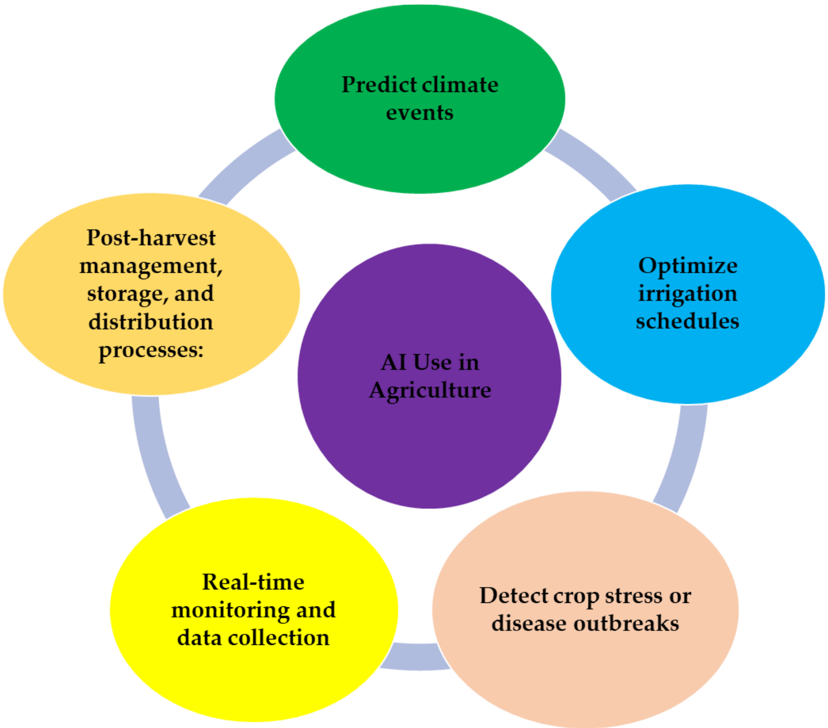

Figure 1. Usage of AI in Agriculture

2. Methodology

2.1. Transformative Role of AI in Agriculture

The transformative role of AI in agriculture encompasses various aspects, from precision farming to supply chain management. AI has the potential to transform agriculture in a number of ways. AI are rapidly transforming agriculture by providing data-driven solutions for crop and livestock management, precision agriculture, and supply chain management [13].

AI can be used to collect and analyze data from sensors, drones, and satellite imagery to create detailed maps of crop fields. This data can be used to identify areas of the field that need more water, fertilizer, or pesticides [14]. AI can also be used to predict crop yields and identify potential problems such as pests and diseases, through AI we can monitor crop growth and health in real time [15]. This can help farmers to identify and address problems early on, before they cause significant damage. AI can also be used to track the progress of crops and predict when they will be ready to harvest. Livestock management can also be done by using AI to monitor the health and behavior of livestock. This can help farmers to identify and treat sick animals early on, and to improve animal welfare. AI can also be used to optimize feeding and breeding programs to improve livestock productivity.

This systematic process of applying AI in agriculture management [16] is shown below in Figure 2. To apply AI in agriculture management the first step is to collect data from a variety of sources, such as sensors, drones, and satellite imagery. This data can be used to create detailed maps of crop fields, track the progress of crops, and monitor the health of livestock. Once the data has been collected, it needs to be analyzed using AI algorithms. These algorithms can be used to identify patterns and trends in the data, and to make predictions about future events. The results of the data analysis can be used to make informed decisions about crop management, livestock management, and supply chain management. For example, AI can be used to recommend the right amount of water, fertilizer, and pesticides to apply to crops. It can also be used to identify potential problems such as pests and diseases, and to recommend treatments. AI can also be used to automate tasks in agriculture. For example, AI-powered robots can be used to plant seeds, water crops, and harvest crops. This can free up farmers to focus on other tasks, such as managing the farm business and marketing their products.

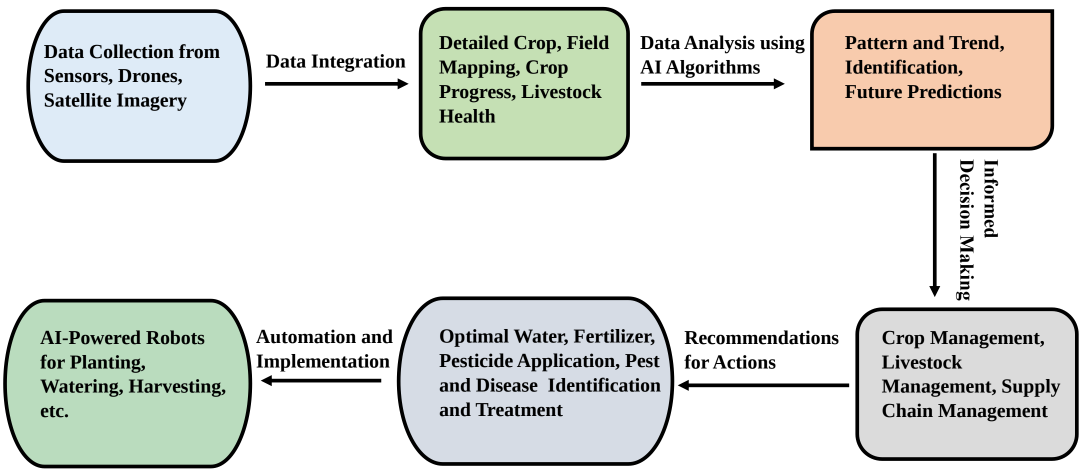

Figure 2. Applying AI in Agriculture Management: From Data Collection to Automation

2..2 *Recent Advances in AI for Climate-Smart Agriculture* 1

The table 1 provides a concise overview of the recent advances in utilizing Artificial Intelligence (AI) for climate-smart agriculture. It highlights various innovative techniques that harness AI to enhance agricultural practices while adapting to the challenges posed by a changing climate. 2 3

Table 1 Recent Advances in AI for Climate-Smart Agriculture (Source: [17], [18], [19], [20], [21]) 4

Recent Advances	Principle	Procedure	Description
Precision Agriculture	Utilizing IoT sensors, satellite imagery, and AI optimizes based on real-time data.	Sensors collect data on soil moisture, temperature, etc. AI analyzes data and provides recommendations for precise resource application.	Precision farming enhances resource efficiency and reduces environmental impact.
Climate Modelling and Prediction	Neural networks analyze large climate datasets to improve the accuracy of climate predictions.	Neural networks learn patterns from past data and predict future climate trends, aiding farmers' decisions.	Accurate climate predictions support informed agricultural planning.
Crop Disease Detection	Computer vision and deep learning identify crop diseases from images.	AI models analyze images, detect disease symptoms, and alert farmers.	Early disease detection minimizes crop losses and reduces chemical usage.
Soil Health Assessment	Machine learning analyzes soil data from IoT sensors to determine soil health indicators.	Algorithms process sensor data to assess soil health parameters.	Informed soil management decisions lead to improved crop yields and sustainability.
Autonomous Farming Equipment	AI-powered autonomous vehicles and robots perform farming tasks with precision.	Vehicles and robots use sensor data to navigate and execute tasks autonomously.	Automation reduces labour requirements and enhances efficiency.
Water Management and Irrigation	AI monitors soil moisture, weather conditions, and plant requirements for optimized irrigation.	AI algorithms analyze data to recommend precise irrigation schedules.	Efficient water management conserves resources while maintaining crop health.
Crop Yield Prediction	Integrating satellite imagery and climate data, AI models forecast crop yields.	Models combine data to predict yields, aiding planning and distribution.	Accurate yield predictions support supply chain management and market planning.
Sustainable Pest Control	AI-driven pest control strategies deploy targeted interventions based on pest behaviour and crop conditions.	AI analyzes data to determine optimal intervention strategies, reducing chemical usage.	Environmentally friendly pest control maintains crop health and ecosystem balance.

Climate-Resilient Crop Breeding	AI and genomic data accelerate the development of climate-resilient crop varieties.	AI identifies genetic traits for resilience, expediting crop breeding.	Climate-resilient crops ensure stable yields under changing climate conditions.

1

biology and life sciences forum

2.3. AI-Enhanced Crop Management Strategies

One of the most promising applications of AI in agriculture is in crop management. In this section, we outline the methodology employed to investigate and develop AI-enhanced crop management strategies as in Figure 3 . The study focuses on collecting precise data using AI-powered technology, providing practical advice for farmers through AI algorithms, determining optimal planting schedules and fertilizer application rates, and exploring pest control techniques and early intervention strategies [22].

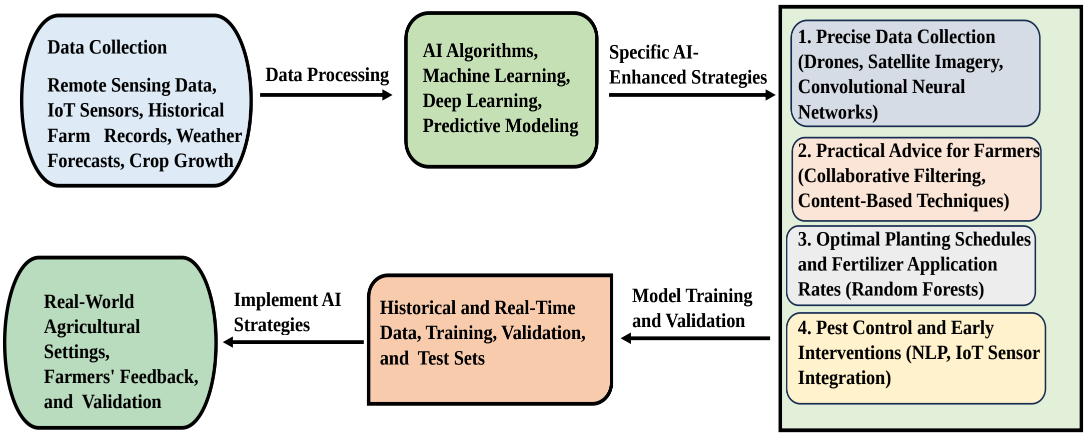

Figure 3. Methodology for AI-Enhanced Crop Management Strategies in Agriculture

The initial step involves collecting diverse and accurate datasets required for the implementation of AI-enhanced crop management strategies. AI technologies heavily rely on high-quality data to generate reliable insights. We employ a combination of sources, including remote sensing data, IoT sensors, historical farm records, weather forecasts, and crop growth data. These datasets provide comprehensive information about soil conditions, weather patterns, and crop health.AI algorithms are developed to process the collected data and provide actionable insights to farmers. The algorithms encompass various techniques, including machine learning, deep learning, and predictive modeling.

The following subsections outline the specific AI-enhanced strategies investigated. To achieve precise data collection, we employ AI-powered technologies such as drones and satellite imagery. Convolutional Neural Networks (CNNs) are utilized for image analysis, enabling the detection of crop stress, nutrient deficiencies, and disease symptoms. The algorithm identifies relevant features in images and classifies them based on predefined patterns. And to provide practical advice to farmers, a recommendation system is developed using collaborative filtering and content-based techniques. Historical farm data, combined with current crop conditions, are used to tailor personalized recommendations for irrigation scheduling, pest control, and crop nutrition. Machine learning algorithms, such as Random Forests, are applied to historical climate data and crop yield records to predict optimal planting schedules and fertilizer application rates. The models consider climate variations and their impact on crop growth to offer data-driven recommendations. For pest control, AI-driven techniques involve analyzing pest behavior patterns and crop health data. Natural Language Processing (NLP) algorithms process text data from agricultural publications and journals to suggest effective pest control methods. Moreover, real-time IoT sensor data is used to trigger early interventions when specific thresholds are crossed.

The developed AI algorithms are trained using a combination of historical and real-time data. The datasets are split into training, validation, and test sets to ensure the models' accuracy and generalizability. Hyperparameter tuning is performed to optimize model performance. The AI-enhanced crop management strategies are implemented in real-world agricultural settings. Farmers' feedback and experiences are collected to assess the effectiveness and usability of the AI recommendations. Field trials and demonstrations help validate the strategies' practicality and adaptability.

2.4. AI and Long-Term Agricultural Sustainability

The methodology employed to investigate the role of AI in achieving long-term agricultural sustainability [23]. The study delves into predictive analytics and supply chain optimization, improvements in post-harvest management, storage, and distribution, as well as strategies for reducing food loss and enhancing overall agricultural efficiency. The initial step involves gathering comprehensive datasets that encompass a wide spectrum of agricultural processes, including crop cultivation, harvest, storage, transportation, and consumption patterns. These datasets are drawn from various sources such as government records, agricultural databases, IoT sensors, and satellite imagery. The datasets are cleansed, standardized, and aggregated for further analysis.

AI algorithms are designed to improve long-term agricultural sustainability by forecasting demand, market trends, and supply chain disruptions. Machine learning techniques, like time series analysis and regression, analyze historical data to generate forecasts, which guide supply chain optimization strategies [24]. AI-powered algorithms enhance post-harvest processes, ensuring efficient storage and distribution. Natural Language Processing (NLP) analyzes textual data from agricultural literature and industry standards, guiding AI-driven recommendations for storage conditions, transportation routes, and distribution networks. Machine learning models, clustering, and anomaly detection algorithms identify food loss patterns at various stages of the supply chain. IoT sensors and historical data on food spoilage are used to develop predictive models, identifying potential sources of food waste. Strategies are formulated to mitigate food loss, optimize resource utilization, and enhance overall agricultural efficiency.

AI algorithms are trained using datasets, using cross-validation techniques to ensure robustness and minimize overfitting. Performance is evaluated using metrics like MAE and RMSE. AI-driven strategies are implemented in simulated and real-world agricultural scenarios, allowing controlled testing under varying conditions. Real-world implementations involve collaboration with farmers, stakeholders, and supply chain partners to assess feasibility and effectiveness. The assessment of long-term agricultural sustainability involves considering economic, environmental, and social dimensions. It compares indicators like food loss reduction, resource utilization, and profitability with traditional methods. Comparative analyses evaluate AI-enhanced strategies' sustainability, efficiency, and profitability. AI-driven solutions are benchmarked against conventional approaches, highlighting the transformative impact of AI in achieving long-term agricultural sustainability.

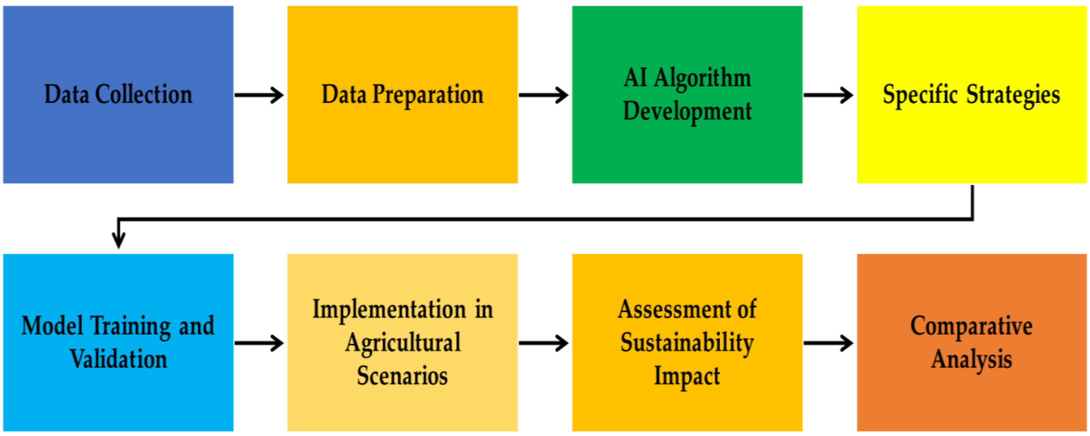

Figure 4. Methodology for Investigating AI's Role in Achieving Long-Term Agricultural Sustainability

2.5. Data-Driven Decision Making and Resilience

The study investigates the role of data-driven decision-making in enhancing resilience in agriculture [25]. It aims to empower farmers, optimize resource consumption, minimize environmental impact, and improve resilience in climate challenges. Data sources include remote sensing, IoT sensors, historical records, climate data, and crop performance metrics. Figure 5 illustrates the sequential progression of a meticulously structured methodology aimed at leveraging data-driven approaches to fortify agricultural resilience. Beginning with data collection and integration, the process advances through the development of an interactive decision support system, AI-powered resource optimization, prediction of climate challenges, model training and validation, real-world implementation, comparative analysis, and culminates in an assessment of resilience.

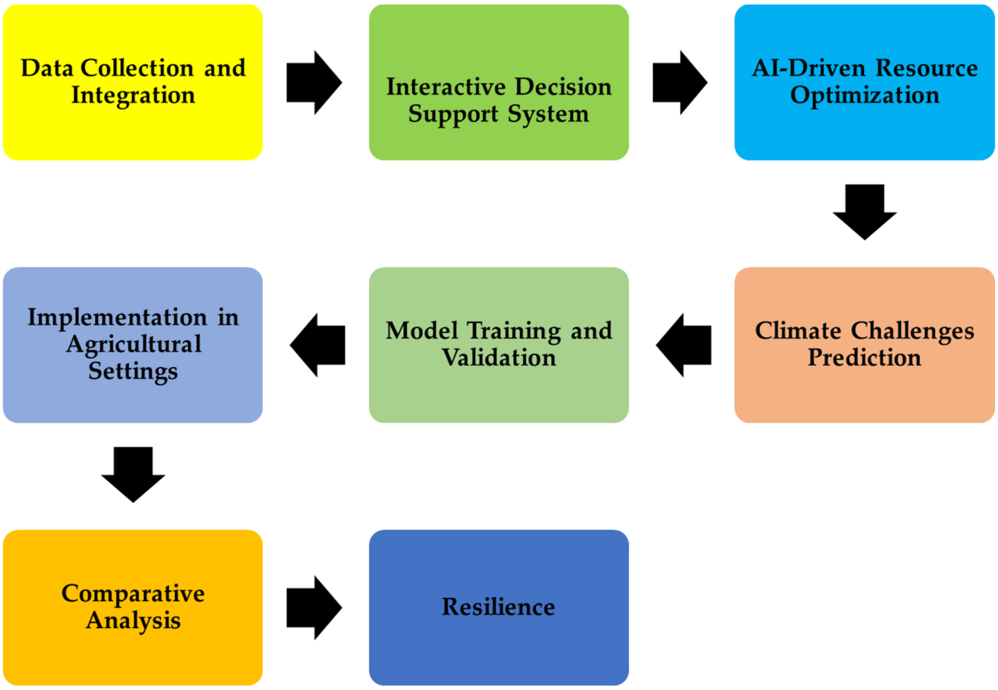

Figure 5. Sequential Stages of Data-Driven Agricultural Resilience: From Data Integration to Comparative Analysis

An interactive decision support system is developed to empower farmers with data-driven decisions. Machine learning algorithms process integrated data, offering insights and recommendations on crop health, weather forecasts, and resource availability. AI-driven optimization models balance resource consumption and environmental impact, using linear programming and genetic algorithms to suggest optimal resource allocation strategies. Machine learning techniques, including ensemble models and neural networks, predict climate challenges on agricultural productivity, using historical crop yields and soil characteristics. These predictions help develop strategies to enhance resilience, such as crop diversification and dynamic planting schedules.

AI models for decision support, resource optimization, and resilience enhancement are trained using historical data and cross-validation techniques. Model performance is evaluated using metrics like accuracy, precision, and F1-score. These AI-driven systems and optimization models are implemented in controlled agricultural settings and real-world scenarios. Controlled experiments allow testing under controlled conditions, while real-world implementations involve collaborating with farmers to assess the effectiveness of proposed strategies. Comparative analyses are conducted to compare data-driven decision-making outcomes with conventional methods. Benefits of AI-enhanced strategies, such as improved resource utilization, yield predictability, and increased resilience, are quantified and compared to traditional practices. Resilience assessment evaluates the performance of proposed strategies under various climate scenarios, using metrics like yield stability, adaptive capacity, and response to climate shocks.

3. Climate-Smart Agriculture: Current status, Challenges and Needs

Climate-smart agriculture (CSA) is a set of practices that help farmers adapt to climate change and mitigate its effects [26]. CSA practices include selecting crops that are resilient to climate change, using water-efficient irrigation methods, managing pests and diseases in a sustainable way, protecting soil health, investing in research and development [27]. CSA is essential for ensuring food security in the face of climate change. By adopting CSA practices, farmers can increase their resilience to climate shocks, reduce their environmental impact, and improve their long-term profitability.

The current status of CSA is mixed. Some countries have made significant progress in adopting CSA practices, while others have lagged behind. There are a number of challenges that are hampering the adoption of CSA [28], including;

Climate change is causing weather patterns to become more erratic, with more extreme weather events such as droughts, floods, and heat waves. These events can have a devastating impact on agriculture, leading to crop failures, reduced yields, and increased costs for farmers. Climate change is also causing water scarcity in many parts of the world. This is making it more difficult for farmers to irrigate their crops, which can lead to lower yields. Efficient irrigation management is essential for reducing water use and ensuring that crops receive the water they need. Climate change is also causing the emergence of new pests and diseases that can attack crops. These pests and diseases can have a significant impact on crop yields, leading to food shortages and increased food prices.

Despite these challenges, there are a number of needs for CSA. The need for proactive solutions to improve agricultural resilience: Climate change is a major threat to agriculture, but there are a number of proactive solutions that can be implemented to improve agricultural resilience. There is a need for increased investment in CSA, both from governments and from the private sector. This investment is essential for helping farmers adopt CSA practices and for developing new CSA technologies. There is also a need for capacity building for CSA, both at the farmer level and at the policy level. Farmers need to be trained in CSA practices, and governments need to develop policies that support CSA.

The future of CSA is bright. By addressing the challenges and seizing the opportunities, we can help to ensure that agriculture remains productive in the face of climate change and meets the needs of a growing population.

4. Future Directions and Potential

AI has the potential to revolutionize climate-smart agriculture in a number of ways. AI can be used to predict climate events, such as droughts, floods, and heat waves. This information can be used by farmers to make informed decisions about planting, irrigation, and crop protection. AI can be used to optimize irrigation schedules, ensuring that crops receive the water they need without wasting water.

We can detect early indicators of crop stress or disease outbreaks by AI. This information can be used by farmers to take preventive measures to protect their crops. Enable real-time monitoring and data collection AI-powered precision agriculture technology, such as autonomous drones and sensor networks, can enable real-time monitoring and data collection. This allows farmers to collect precise data on crop health, soil moisture levels, and fertilizer requirements. AI algorithms can then deliver practical crop management advice, such as optimal planting schedules, fertilizer application rates, and pest control techniques. Predictive analytics and AI-based supply chain optimization can improve post-harvest management, storage, and distribution processes, reducing food loss and increasing overall efficiency.

In addition to these specific applications, AI has the potential to revolutionize climate-smart agriculture in a number of broader ways. For example, AI can be used to:

- Develop new crop varieties that are resilient to climate change.
- Develop new irrigation technologies that are more efficient and sustainable.
- Develop new pest and disease management strategies that are more effective and environmentally friendly.
- Create more accurate and timely crop yield forecasts.
- Optimize the allocation of agricultural resources, such as land, water, and fertilizer.

The future directions of AI in climate-smart agriculture are very promising. As AI technology continues to develop, we can expect to see even more innovative applications of AI in agriculture in the years to come. This has the potential to revolutionize the agricultural industry and help us to meet the challenges of climate change.

Here are some specific examples of future directions for AI in climate-smart agriculture:

- The development of AI-powered decision support systems for farmers: These systems could provide farmers with real-time information on climate conditions, crop health, and market prices. This information could help farmers to make better decisions about planting, irrigation, and crop management.
- The development of AI-powered precision agriculture technologies: These technologies could be used to collect and analyze data from sensors and drones to create detailed maps of crop health and soil conditions. This information could help farmers to target their inputs more efficiently and reduce their environmental impact.
- The development of AI-powered pest and disease management systems: These systems could be used to identify and track pests and diseases in real time. This information could help farmers to take preventive measures to protect their crops.
- The development of AI-powered food supply chain management systems: These systems could be used to optimize the transportation, storage, and distribution of food. This could help to reduce food loss and waste and improve food security.

The future of AI in climate-smart agriculture is very bright. As AI technology continues to develop, we can expect to see even more innovative applications of AI in agriculture in the years to come. This has the potential to revolutionize the agricultural industry and help us to meet the challenges of climate change.

5. Conclusion

In conclusion, AI has the potential to play a transformative role in climate-smart agriculture. By using AI, we can help to ensure that agriculture remains productive in the face of climate change, while also producing more sustainable and nutritious food. This has the potential to improve livelihoods for farmers and food security for everyone. AI has the potential to revolutionize climate-smart agriculture in a number of ways. AI can be used to predict climate events, optimize irrigation schedules, detect early indicators of crop stress or disease outbreaks, enable real-time monitoring and data collection, improve post-harvest management, storage, and distribution processes, and develop new crop varieties, irrigation technologies, pest and disease management strategies, crop yield forecasts, and allocation of agricultural resources. The future directions of AI in climate-smart agriculture are very promising. As AI technology continues to develop, we can expect to see even more innovative applications of AI in agriculture in the years to come. This has the potential to revolutionize the agricultural industry and help us to meet the challenges of climate change.

By integrating AI into agriculture, we can help farmers to make better decisions about planting, irrigation, and crop management. This can lead to increased yields and profits, as well as reduced risk of crop failure. AI-powered precision agriculture technologies can help farmers to target their inputs more efficiently, saving money and reducing the environmental impact of agriculture. AI-powered pest and disease management systems can help farmers to take preventive measures to protect their crops, reducing crop losses and improving yields. AI-powered food supply chain management systems can help to reduce food loss and waste, improving food security and reducing the environmental impact of food production. AI has the potential to transform agriculture and help us to meet the challenges of climate change. By investing in AI research and development, we can help to create a more sustainable and equitable food system for the future.

Author Contributions: Conceptualization, A.R. and M.A.S; Introduction, M.Z.; Methodology, A.R., M.A.S. and M.S.; Climate-Smart Agriculture: Current status, Challenges and Needs, A.R, M.S. and R.M.S.; Future Directions and Potential, A.R and M.S ; Conclusions, M.Z. and M.A.S. writing original draft preparation, A.R.; editing, M.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

[1] N. K. Arora, "Impact of climate change on agriculture production and its sustainable solutions," Environmental Sustainability, vol. 2, no. 2, pp. 95–96, Jun. 2019, doi: 10.1007/S42398-019-00078-W.

[2] S. Chen, X. Chen, and J. Xu, "Impacts of climate change on agriculture: Evidence from China," J Environ Econ Manage, vol. 76, pp. 105–124, Mar. 2016, doi: 10.1016/J.JEEM.2015.01.005.

[3] A. Costinot, D. Donaldson, and C. Smith, "Evolving Comparative Advantage and the Impact of Climate Change in Agricultural Markets: Evidence from 1.7 Million Fields around the World," https://doi.org/10.1086/684719, vol. 124, no. 1, pp. 205–248, Feb. 2016, doi: 10.1086/684719.

[4] N. A.-E. Sustainability and undefined 2019, "Impact of climate change on agriculture production and its sustainable solutions," Springer, Accessed: Aug. 14, 2023. [Online]. Available: https://link.springer.com/article/10.1007/s42398-019-00078-w

[5] V. Venkatramanan, S. S.-S. green technologies for, and undefined 2019, "Climate smart agriculture technologies for environmental management: the intersection of sustainability, resilience, wellbeing and development," Springer, Accessed: Aug. 14, 2023. [Online]. Available: https://link.springer.com/chapter/10.1007/978-981-13-2772-8_2

[6] S. Katel, H. raj Mandal, … S. K.-… of A.-F., and undefined 2022, "Climate Smart Agriculture for Food Security, Adaptation, and Migration: A Review," agrifoodscience.org, Accessed: Aug. 14, 2023. [Online]. Available: http://agrifoodscience.org/index.php/TURJAF/article/view/5162

[7] A. Chandra, K. McNamara, P. D.-C. Policy, and undefined 2018, "Climate-smart agriculture: perspectives and framings," Taylor & Francis, vol. 18, no. 4, pp. 526–541, Apr. 2017, doi: 10.1080/14693062.2017.1316968.

[8] V. Venkatramanan and S. Shah, "Climate smart agriculture technologies for environmental management: The intersection of sustainability, resilience, wellbeing and development," Sustainable Green Technologies for Environmental Management, pp. 29–51, Feb. 2019, doi: 10.1007/978-981-13-2772-8_2.

[9] E. Kistner, O. Kellner, J. Andresen, D. Todey, and L. W. Morton, "Vulnerability of specialty crops to short-term climatic variability and adaptation strategies in the Midwestern USA," Clim Change, vol. 146, no. 1–2, pp. 145–158, Jan. 2018, doi: 10.1007/S10584-017-2066-1.

[10] T. B. Pathak, M. L. Maskey, J. A. Dahlberg, F. Kearns, K. M. Bali, and D. Zaccaria, "Climate change trends and impacts on California agriculture: A detailed review," mdpi.com, 2018, doi: 10.3390/agronomy8030025.

[11] H. Jain, R. Dhupper, A. Shrivastava, D. Kumar, and M. Kumari, "AI-enabled strategies for climate change adaptation: protecting communities, infrastructure, and businesses from the impacts of climate change," Computational Urban Science, vol. 3, no. 1, Dec. 2023, doi: 10.1007/S43762-023-00100-2.

[12] T. Shaikh, T. Rasool, F. L.-C. and E. in Agriculture, and undefined 2022, "Towards leveraging the role of machine learning and artificial intelligence in precision agriculture and smart farming," Elsevier, Accessed: Aug. 14, 2023. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0168169922004367?casa_token=jp54g-IQfW0AAAAA:cLHaJ1I5nzsmW-q2vkcGBlVejCXz29Axod3BS5Rsz6VLQM0lpvDyGz1vmCIlDPssRoS3sjPd8-Y

[13] H. Jain, R. Dhupper, A. Shrivastava, D. Kumar, & M. Kumari. (2023). AI-enabled strategies for climate change adaptation: protecting communities, infrastructure, and businesses from the impacts of climate change. Computational Urban Science, 3(1), 25.

[14] P. Singh, & A. Kaur. (2022). A systematic review of artificial intelligence in agriculture. Deep Learning for Sustainable Agriculture, 57-80.

[15] E. Elbasi, N. Mostafa, Z. AlArnaout, A.I. Zreikat, E. Cina, C. Varghese, G., ... & C. Zaki. (2022). Artificial intelligence technology in the agricultural sector: a systematic literature review. IEEE Access.

[16] A. K Kar, S.K. Choudhary, & V.K. Singh. (2022). How can artificial intelligence impact sustainability: A systematic literature review. Journal of Cleaner Production, 134120.

[17] M. Uddin, A. Chowdhury, & M.A. Kabir. (2022). Legal and ethical aspects of deploying artificial intelligence in climate-smart agriculture. AI & SOCIETY, 1-14.

[18] R.A. Ahmed, E.E.D. Hemdan, W. El-Shafai, Z.A. Ahmed, E.S.M. El-Rabaie, & F.E. Abd El-Samie. (2022). Climate-smart agriculture using intelligent techniques, blockchain and Internet of Things: Concepts, challenges, and opportunities. Transactions on Emerging Telecommunications Technologies, 33(11), e4607.

[19] J. Zhao, D. Liu, & R. Huang. (2023). A Review of Climate-Smart Agriculture: Recent Advancements, Challenges, and Future Directions. Sustainability, 15(4), 3404.

[20] E.S. Mohamed, A.A. Belal, S.K. Abd-Elmabod, M.A El-Shirbeny, A. Gad, & M.B. Zahran. (2021). Smart farming for improving agricultural management. The Egyptian Journal of Remote Sensing and Space Science, 24(3), 971-981.

[21] L.M. Bhar, V. Ramasubramanian, A. Arora, S. Marwaha, & R. Parsad. (2019). Era of Artificial Intelligence: Prospects for Indian Agriculture.

[22] Q. Chen, L. Li, C. Chong, & X. Wang. (2022). AI-enhanced soil management and smart farming. Soil Use and Management, 38(1), 7-13.

[23] J. Jung, M. Maeda, A. Chang, M. Bhandari, A. Ashapure, & J. Landivar-Bowles. (2021). The potential of remote sensing and artificial intelligence as tools to improve the resilience of agriculture production systems. Current Opinion in Biotechnology, 70, 15-22.

[24] R. Nishant, M. Kennedy, & J. Corbett. (2020). Artificial intelligence for sustainability: Challenges, opportunities, and a research agenda. International Journal of Information Management, 53, 102104.

[25] V. Galaz, M.A. Centeno, P.W. Callahan, A. Causevic, T. Patterson, I. Brass, ... & K. Levy. (2021). Artificial intelligence, systemic risks, and sustainability. Technology in Society, 67, 101741.

[26] B. Turyasingura, & P. Chavula. (2022). Climate-Smart Agricultural Extension Service Innovation Approaches in Uganda. International Journal of Food Science and Agriculture.

[27] F. Matteoli, J. Schnetzer, & H. Jacobs. (2020). Climate-Smart Agriculture (CSA): An Integrated Approach for Climate Change Management in the Agriculture Sector. Handbook of Climate Change Management: Research, Leadership, Transformation, 1-29.

[28] C.A. Harvey, M. Chacon, C.I. Donatti, E. Garen, L. Hannah, A. Andrade, ... & E. Wollenberg. (2014). Climate-smart landscapes: opportunities and challenges for integrating adaptation and mitigation in tropical agriculture. Conservation Letters, 7(2), 77-90.