Scientific Research Timelines Journal (2025), 3(1):15-18
Online Bimonthly Publication Frequency
https://scientificrtj.com/

Review Paper **Open Access**

AI-DRIVEN DIGITAL TWIN MODELS FOR HYBRID CROP SELECTIO AND CLIMATE-RESILIENT YIELD PREDICTION

Sheeza Ahmad[1*]

[1]*Department of Computer Science, Faculty of Computing, The Islamia University of Bahawalpur, Bahawalpur 63100, Pakistan*
[*]**Corresponding authors e-mail:** Sheezaahmad26@outlook.com

ABSTRACT Advancements in climate change have launched major hurdles against worldwide agricultural systems which diminish plant production alongside food distribution stability. This paper evaluates the application of AI-based digital twin systems in hybrid crop decisions along with climate-resistant yield estimation. The combination of IoT sensors along with AI algorithms and virtual farm replicas ensures both environmental measurement precision and resource optimization and crop management prediction enhancement. The document presents insights about how digital twin and artificial intelligence tech bring advantages for soil health improvement and pest control and weather prediction. This research demonstrates how machine learning technology chooses specific hybrid species that adapt to multiple climate zones as well as predicts harvest outputs during environmental transformations. The realization of AI benefits depends on solving issues with data precision and system costs and flexibility to make sure all farming levels acquire equal technological opportunity. The paper ends with a discussion about how AI and digital twins represent future potential to built sustainable agricultural systems which resist climate change and provides actionable guidance for farmers together with policymakers seeking improvements in agricultural sustainability and productivity.
Keywords: *Digital twin technology; Climate resilience; Crop yield; Hybrid crop selection; Machine learning.*

INTRODUCTION The effects of global climate change pose major problems for agricultural production because they boost weather fluctuations and boost strong climate events while endangering food supplies and threatening natural ecosystem sustainability. Traditional farming practices find it difficult to adjust to emerging conditions thus resulting in decreased operational performance levels along with lower yields (Hadeed et al., 2024). The Figure 1 presents evidence of how AI technology alongside digital twins creates effective climate resilience which enhances yield prediction abilities. Machine learning algorithms coupled with IoT sensor networks through artificial intelligence technology make it possible to monitor agricultural data precisely such as tracking weather patterns together with soil health details and crop productivity metrics. The technologies equip farmers to use data-based choices which help them optimize their resource consumption and control pests and diseases for better harvest results (Ametefe et al., 2024, Ullah et al., 2022, Rashid et al., 2022). Farm efficiency improves through digital twin technology since it develops exact farm representations for real-time monitoring and operational simulation. AI models produce precise crop yield forecasts through processing wide datasets that contain historical yield data and environmental factors besides the information shown in Table 1. The approach enables immediate responsive actions that help reduce yield reductions (Gul and Banday, 2024). The use of AI-powered predictive systems enables farm owners to foresee disastrous weather conditions thus enabling them to plan responses that reduce the effects of devastating weather occurrences. Small farmers faced with data quality problems alongside inadequate infrastructure and expensive costs prevent them from benefiting fully from these recent technological advances in developing regions. The solution of these barriers depends on combined efforts from farmers along with researchers and technology developers for equal access to AI technologies (Ametefe et al., 2024). The combination of AI with digital twin modeling has emerged as an innovative method for developing resilient climate systems while improving yield forecasts which results in better food security across the globe and enhanced sustainability of environmental resources.

AI and Digital Twin Architectures for Agricultural Modeling
AI-driven architectures with digital twin models improve agricultural modeling while selecting hybrid crops through integration of advanced IoT sensors with cloud computing and AI algorithms to achieve climate resilience. Farms obtain virtual duplicates through digital twins to detect agricultural procedures in real-time while optimizing resource management and enhancing soil quality according to the representation shown in Figure 1 (Peladarinos et al., 2023). The newly constructed models receive IoT sensor-generated data on plant health together with environmental factors and soil conditions to

achieve full farming status visibility. The storage capabilities of cloud computing systems enable large-scale processing of IoT sensor data to generate current visualizations that let managers decide about water distribution and pest control operations (Kothuri et al., 2024). AI enables precise selection of hybrid crops by examining environmental data together with weather outlooks as well as harvest history data to identify ideal crops for particular situations. Offsetting the vulnerabilities of climate change AI-based predictive analytics provides advanced environmental change as well as pest outbreak and planting yield predictions to activate protective plans that enhance efficiency of resources and decrease risk exposure. The combination of AI algorithms Support Vector Regression (SVR) and Multilayer Perceptron (MLP) successfully predicts reference evapotranspiration (ETo) parameters because they exhibit higher precision in estimation (Bali and Singh, 2024). The incorporation of AI into digital twins leads to better crop yields through 15-20% increases while resources decrease by 25% thus promoting sustainable agriculture with proof demonstrated in Table 1. These technological tools create an agricultural system that succeeds under climate uncertainties through sustainable practices which ensure food security. The successful implementation of digital farming systems depends on solving issues related to data reliability as well as solving problems with equipment basics and digital equipment gaps. Digital twin models integrated with AI architectures offer a revolutionary path for advancing agricultural practices that addresses environmental challenges and maximizes crop output performance (Gul and Banday, 2024).

Hybrid Crop Selection and Yield Prediction

Digital twin models combined with AI algorithms improve the selection of hybrid crops as well as forecast their yield performance under conditions of climate change. The analysis of substantial data through machine learning (ML) together with neural networks plays a vital role in hybrid crop selection by identifying crop varieties suitable for resisting climate-related dangers. Random Forest along with Decision Tree and Gradient Boosting Regressor serve as ML algorithms to make crop and fertilizer recommendations by using environmental data and they produce optimized yield results that appear in Table 1 (Vaddi et al., 2024, Ahmed et al., 2022, Ahmed, 2021, Ullah et al., 2020). Genomic selection that utilizes neural networks alongside other ML models helps breed resilient crops by forecasting breeding values and analyzing genotype-by-environment interactions during the development process for climbing climate changes. Digital twin models enhance yield prediction efforts through their creation of simulated crop representations that predict outcomes from different climatic scenarios. The technology combines IoT sensor data with drone information to provide real-time supervision along with accurate interventions for improved prediction results together with optimized resource utilization (Landivar-Bowles et al., 2023). Under different climatic conditions XGBoost proved its superiority as an AI-based predictive model for yield forecasting which led to effective climate adaptation strategies revealed by Figure 1. The merging of AI and digital twin technologies presents transformative solutions for agriculture which provide strong decision-making capabilities to farmers and policymakers for better production and adaptation to climate changes (Zidan and Febriyanti, 2024).

Technological Innovations in Agricultural Systems

The agricultural revolution stems from AI and IoT collaboration which enhances predictions and increases crop climate toughness as depicted in Figure 1. The precise data collection abilities of IoT devices including sensors and drones enable monitored soil conditions along with plant and environmental factors which serves as critical information for better irrigation management as well as fertilization and pest control methods (Sharma and Shivandu, 2024). The combination of satellite observations with remote sensing techniques produces detailed land use evaluation together with exact crop monitoring requirements needed to detect environmental threats. Through machine learning (ML) analysis and deep learning (DL) techniques the data is analyzed to extract useful decision patterns as shown in Table 1. Deep learning models such as CNNs perform analysis of crop diseases yet SVMs and regression algorithms play vital roles through crop yield predictions alongside market estimate forecasts (Uma et al., 2025). AI together with IoT technology enables developers to create predictive drought and climate models which process large volumes of information through cloud-based systems. SARIMA/ARIMA forecasting models give organizations real-time crop tracking capabilities to optimize their food supply chains because they allow better resource monitoring. Model scalability problems along with data quality challenges occur together with security concerns in shortage of data conditions (Dhal and Kar, 2024, Mushtaq et al., 2024). Public-private cooperation with government policies plays a vital role in resolving current technology difficulties to expand their use in developing sustainable climate-resistant agricultural systems.

Challenges and Future Directions

The implementation of AI-based digital twin models for agricultural use encounters various obstacles because of data standards and system complexity, project expenses, multidisciplinary requirements and ethical issues. Effective simulations together with accurate predictions need precise high-quality data procured from diverse sources such as environmental sensors as well as plant and soil conditions. Purchasing AI technologies such as digital twins proves expensive and this barrier blocks fair access to these advances mainly for smallholder farmers who belong to a digital access divide. The challenge of scalability emerges during integration because rural areas face limitations in existing agricultural frameworks as well as a shortage of both required technical expertise and robust infrastructure. Protecting farmer privacy together with preventing unauthorized data access requires strong cybersecurity policies because of the large amounts of gathered information. The successful integration of AI technology into agriculture requires teams from different discipline backgrounds since this process requires coordinated analysis of technology systems with agronomic principles alongside social-economic elements (Aggarwal et al., 2024). A large number of future opportunities exist for AI to revolutionize agricultural systems despite the present difficulties. Research confirms that AI-powered digital twins boost production yields and resource management and reduce pest-caused loss as well as source wastage simultaneously. The field of research integrates AI systems with IoT devices and blockchain technology to achieve better product tracking capabilities as well as real-time decision implementation due to recent advancements in edge computing for local data management. The strategic partnership between innovation and AI allows it to bring forth agricultural advancements which build lasting food security networks and ecologically friendly agricultural procedures (Rattan, 2023).

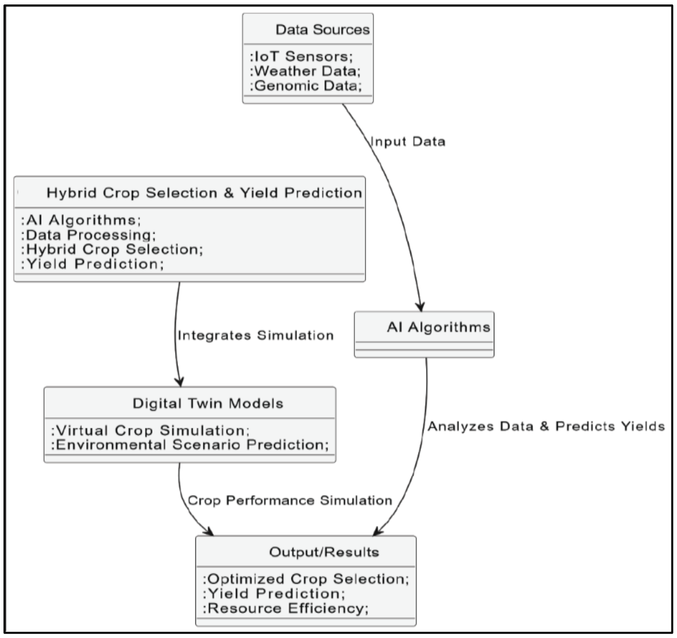

Figure 1: Workflow of AI-Driven Hybrid Crop Selection and Yield Prediction Using Digital Twin Models

Table 1: Overview of Technologies and Strategies in AI-Driven Digital Twin Models for Agricultural Modeling and Hybrid Crop Selection

Technology Strategy	Description	Technologies Used	Benefits
Digital Twin Models	Virtual replicas of farms that simulate agricultural processes, enabling real-time monitoring and management.	IoT sensors, cloud computing, AI algorithms, simulation software (e.g., Unity, Unreal Engine for modeling).	- Allows dynamic simulation of farming activities and environmental changes. - Optimizes resource allocation (water, fertilizers). - Improves operational efficiency.
IoT Sensors	Devices that collect real-time data on soil, crop health, and environmental factors, feeding into digital twin models.	Soil moisture sensors, temperature and humidity sensors, drone-mounted sensors, automated weather stations.	- Enables precise, real-time monitoring of soil health, temperature, humidity. - Provides early warnings for pest outbreaks and disease risks.
Cloud Computing	Distributed computing that stores and processes large datasets from IoT sensors, enabling remote data access.	Cloud platforms (e.g., AWS, Google Cloud), data storage solutions, edge computing for localized processing.	- Scalability for data storage and real-time analytics. - Supports collaboration and decision-making across teams. - Offers predictive capabilities in model deployment.
AI Algorithms	Machine learning and deep learning techniques used to analyze data, predict trends, and optimize farming practices.	Support Vector Regression (SVR), Multilayer Perceptron (MLP), Random Forest, Gradient Boosting, Neural Networks.	- Enhances prediction accuracy for crop yields, pest outbreaks, and climate shifts. - Improves hybrid crop selection and resource management.
Hybrid Crop Selection	Use of AI models to determine optimal crop varieties based on local climate, soil conditions, and historical data.	Random Forest, Decision Tree, Gradient Boosting, K-Nearest Neighbors (KNN), Genetic Algorithms.	- Maximizes yield potential by choosing the best-suited crop variety for specific environmental conditions. - Increases biodiversity and sustainability in farming.
AI-Driven Predictive Analytics	AI techniques to forecast environmental variables, pests, and yield under varying conditions.	Time series forecasting (e.g., ARIMA, SARIMA), deep learning models, Ensemble models (XGBoost, LSTM).	- Offers proactive measures to mitigate risks such as drought, pest infestations, or weather extremes. - Helps in resource allocation and planning.
Impact on Crop Yield	The improvements in crop productivity and resource efficiency through the combination of AI and digital twins.	Digital twin models, AI-driven resource allocation, IoT-enhanced crop management.	- Crop yield improvements by 15-20%. - Reduction in resource consumption (water, fertilizers) by 25%. - Enhanced climate resilience through real-time adaptive strategies.

CONCLUSION

Digital twin technology modified by AI brings important benefits to selecting crop hybrids and predicting yields under climates affected by global warming. Modern technology links IoT sensors with machine learning tools and virtual farms to track environmental factors plus soil quality and crop status closely. Our method helps find hybrid plants that resist different climate types and increase crop production results. This system lets farmers test operations live so they make better resource decisions. The combination of artificial intelligence with digital twins shows large potential but small farming operations find difficulties due to substandard information input, hardware needs and expensive setup expenses. Successful use of these innovations needs all parties to team up including government agencies technology creators and scientists. Through more development AI and digital twin technologies will enhance sustainable agriculture systems that boost production while building a stable source of food together with stable environment.

REFERENCES

Aggarwal, S., Bansal, S. & Goel, R. 2024. Ai In Agriculture: A Looming Challenge, A Gleaming Opportunity. International Journal of Engineering Science and Humanities, 14, 43-52.

Ahmed, H. G. M.-D. 2021. Combining Ability Analysis of Yield Traits in Hexaploid Wheat.

Ahmed, H. G. M.-D., Fatima, N., Owais, M., Faisal, A., Tariq, S., Ali, M., Irfan, M. & Ameen, M. 2022. Variability and correlation study of growth traits in bread wheat under non-stressed conditions. Journal of Applied Research in Plant Sciences, 3, 317-324.

Ametefe, D. S., Hussin, N., John, D., Dzorgbenya Ametefe, G., Adozuka Aliu, A. & Abdi Ali, Z. 2024. Revolutionising agriculture for food security and environmental sustainability: A perspective on the role of digital twin technology. CABI Reviews, 19.

Bali, M. K. & Singh, M. Farming in the Digital Age: AI-Infused Digital Twins for Agriculture. 2024 3rd International Conference on Sentiment Analysis and Deep Learning (ICSADL), 2024. IEEE, 14-21.

Dhal, S. B. & Kar, D. 2024. Transforming Agricultural Productivity with AI-Driven Forecasting: Innovations in Food Security and Supply Chain Optimization. MDPI Forecasting, 6.

Gul, D. & Banday, R. U. Z. 2024. Transforming crop management through advanced AI and machine learning: Insights into innovative strategies for sustainable agriculture. AI, Computer Science and Robotics Technology.

Hadeed, M. Z., Ali, A., Malik, A., Raza, A. & Shoaib, M. 2024. Harnessing AI and GIS Technologies for Climate-Resilient Agriculture and Environmental Sustainability. Maintaining a Sustainable World in the Nexus of Environmental Science and AI. IGI Global.

Kothuri, S. N., Tanusree, M., Chaitanya, N. L. S. & Chaitanya, S. 2024. Precision Agriculture Advisor.

Landivar-Bowles, J., Pal, P., Bhandari, M. & Landivar-Scott, J. L. 2023. Digital Twins Models for Crop Phenotyping, Management and Yield Forecasting. Authorea Preprints.

Mushtaq, M. A., Ahmed, H. G. M.-D. & Zeng, Y. 2024. Applications of Artificial Intelligence in Wheat Breeding for Sustainable Food Security. Sustainability, 16, 5688.

Peladarinos, N., Piromalis, D., Cheimaras, V., Tserepas, E., Munteanu, R. A. & Papageorgas, P. 2023. Enhancing smart agriculture by implementing digital twins: A comprehensive review. Sensors, 23, 7128.

Rashid, M. A. R., Atif, R. M., Zhao, Y., Azeem, F., Ahmed, H. G. M.-D., Pan, Y., Li, D., Zhao, Y., Zhang, Z. & Zhang, H. 2022. Dissection of genetic architecture for tiller angle in rice (Oryza sativa. L) by multiple genome-wide association analyses. PeerJ, 10, e12674.

Rattan, P. 2023. Cultivating Agricultural Evolution: Revolutionizing Farming Through The Power of AI And Technology. Review of Artificial Intelligence in Education, 4 (00), e010.

Sharma, K. & Shivandu, S. K. 2024. Integrating artificial intelligence and Internet of Things (IoT) for enhanced crop monitoring and management in precision agriculture. Sensors International, 100292.

Ullah, A., Shakeel, A., Ahmed, H. G. M.-D., Naeem, M., Ali, M., Shah, A. N., Wang, L., Jaremko, M., Abdelsalam, N. R. & Ghareeb, R. Y. 2022. Genetic basis and principal component analysis in cotton (Gossypium hirsutum L.) grown under water deficit condition. Frontiers in Plant Science, 13, 981369.

Ullah, A., Shakeel, A., Ahmed, H. G. M.-D., Yar, M. M. & Ali, M. 2020. Evaluation of different cotton varieties against drought tolerance: A comparative analysis. International Journal of Cotton Research and Technology, 2, 47-53.

Uma, P., Gomathi, M., Gokulkumar, K., Monika, T. & Preethika, P. 2025. Empowering agriculture with AI: The smart agrohub initiative. Challenges in Information, Communication and Computing Technology. CRC Press.

Vaddi, H. R., Mandadhi, G. K., Ameer, S., Kumar, D. & Chittet, C. Smart Crop Advisor-Intelligent Crop and Fertilizer Recommendations with Crop Yield Prediction Using ML Algorithms. 2024 International Conference on Intelligent Systems for Cybersecurity (ISCS), 2024. IEEE, 1-6.

Zidan, F. & Febriyanti, D. E. 2024. Optimizing Agricultural Yields with Artificial Intelligence-Based Climate Adaptation Strategies. IAIC Transactions on Sustainable Digital Innovation (ITSDI), 5, 136-147

.