Available online at www.agrifarming.org

DOI: http://dx.doi.org/10.18782/2582-7146.299

ISSN: 2582 – 7146

Curr. Rese. Agri. Far. (2024) *5*(2), 20-28

Current Research in
Agriculture and Farming

Peer-Reviewed, Refereed, Open Access Journal

Review Article

Role of Big Data Analytics in Agricultural Decision-Making and Farm Management

Amit Kumar[1], Suhas Shripati Mane[2], Ramdhan Ghaswa[3*], Naval Kishore Meena[4]
[1]Subject Matter Specialist, Department of Agricultural Extension,
Krishi Vigyan Kendra (ICAR-VPKAS) Bageshwar, UK.
[2]Assistant Professor, Department of Agricultural Extension Education,
Shri Vaishnav Institute of Agriculture, SVVV, Indore, Madhya Pradesh
[3]Subject Matter Specialist, Department of Agricultural Extension,
Krishi Vigyan Kendra, Jaora Ratlam, Madhya Pradesh
[4]Ph.D. Scholar, Department of Horticulture (Fruit Science), RCA, MPUAT, Udaipur, Rajasthan
*Corresponding Author E-mail: ramdhanhorti86@gmail.com

Received: 17.02.2024 | Revised: 28.03.2024 | Accepted: 10.04.2024

ABSTRACT

The rapid advancement of information and communication technologies has transformed modern agriculture into a data-intensive domain. Big data analytics (BDA) is emerging as a pivotal tool for enhancing agricultural decision-making and optimizing farm management practices. This review paper examines the role of big data analytics in agriculture, encompassing data sources such as Internet of Things (IoT) sensors, satellite imagery, weather databases, and geographic information systems (GIS). The paper explores key applications including crop yield prediction, precision irrigation, pest and disease surveillance, soil health monitoring, and supply chain optimization. Analytical frameworks leveraging machine learning, cloud computing, and distributed processing platforms such as Hadoop and Apache Spark are discussed. Challenges related to data quality, infrastructure limitations, digital literacy, and privacy concerns are critically evaluated. The review underscores the transformative potential of BDA in enabling sustainable, climate-smart, and resource-efficient agricultural systems.

Keywords: *Big Data Analytics; Precision Agriculture; Internet of Things (IoT); Machine Learning; Farm Decision Support Systems.*

INTRODUCTION

Agriculture is the backbone of global food security and rural livelihoods, employing over one billion people worldwide and contributing significantly to the economies of developing nations (FAO, 2023). However, the agricultural sector faces unprecedented challenges, including climate change, diminishing arable land, water scarcity, and the imperative to feed a projected global population of 9.7 billion by 2050 (United Nations, 2022).

Cite this article: Kumar, A., Mane, S.S., Ghaswa, R., & Meena, N.K. (2024). Role of Big Data Analytics in Agricultural Decision-Making and Farm Management, *Curr. Rese. Agri. Far.* *5*(2), 20-28. doi: http://dx.doi.org/10.18782/2582-7146.299

In this context, the integration of advanced technologies into farming practices has become essential for improving productivity, sustainability, and resilience. Big data analytics has emerged as a transformative force in agriculture, enabling data-driven decision-making that enhances every stage of the farming cycle, from planting to post-harvest management (Wolfert et al., 2017). The concept of big data in agriculture encompasses the vast volumes of structured and unstructured data generated from diverse sources, including IoT-enabled field sensors, unmanned aerial vehicles (UAVs), satellite remote sensing platforms, weather monitoring stations, soil databases, and market information systems (Kamilaris et al., 2017). The defining characteristics of agricultural big data align with the classical "5Vs" framework: Volume, Velocity, Variety, Veracity, and Value (Rijmenam, 2014). The volume of agricultural data has grown exponentially owing to the proliferation of precision agriculture technologies, with estimates suggesting that a single farm may generate over 500,000 data points per day (Sonka, 2014).

The application of big data analytics in farm management is facilitated by advances in cloud computing, machine learning (ML), artificial intelligence (AI), and distributed computing frameworks such as Apache Hadoop and Apache Spark (Ata et al., 2024). These technologies enable farmers, agronomists, and policymakers to extract actionable insights from complex datasets, supporting decisions related to crop selection, nutrient management, irrigation scheduling, pest control, and market timing (Thakur et al., 2024). Furthermore, big data analytics contributes to climate-smart agriculture by enabling predictive modelling of weather patterns, crop performance, and resource utilization under varying climatic scenarios (Delgado et al., 2019).

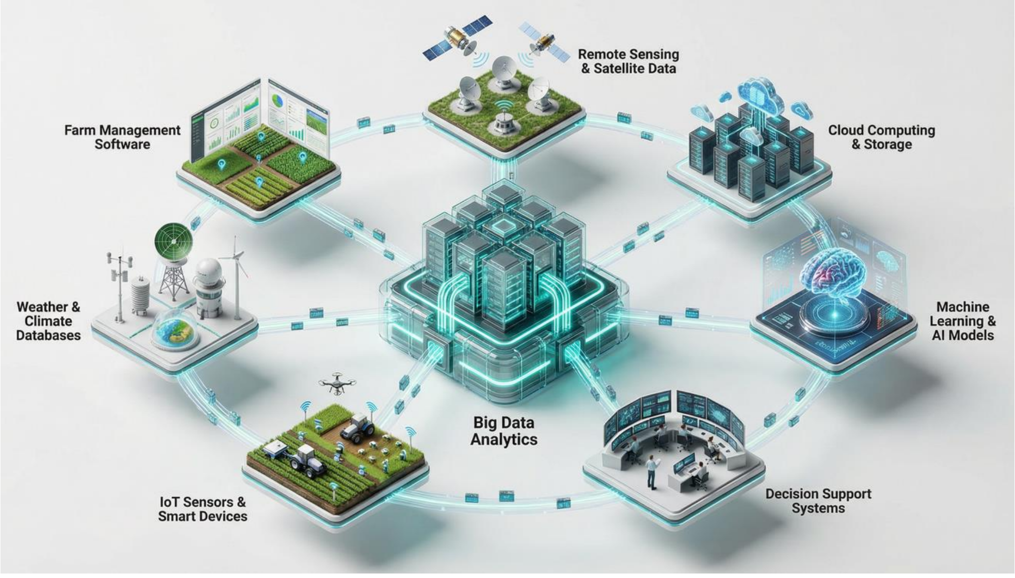

Figure 1: Big Data Ecosystem in Agriculture

2. Sources of Big Data in Agriculture

Agricultural big data originates from a multiplicity of sources that collectively capture the spatial, temporal, and environmental dimensions of farming systems. Understanding these data sources is fundamental to designing effective analytics pipelines and decision support systems (Charania & Li, 2020).

2.1 IoT Sensors and Field Devices

The Internet of Things has revolutionized agricultural data collection by enabling the deployment of networked sensors that monitor soil moisture, temperature, humidity, pH, and nutrient levels in real time (Zhai et al., 2020). These sensors transmit data wirelessly to cloud-based platforms, where it is aggregated, processed, and analysed to inform field-level management decisions. Precision irrigation systems, for example, utilize soil moisture sensors to dynamically adjust water application rates, thereby conserving water and preventing crop stress (Bwambale et al., 2022). Advanced sensor technologies, including multispectral and hyperspectral sensors, are also employed for monitoring plant health and detecting physiological stress indicators (Khanal et al., 2020).

2.2 Satellite and Drone Imagery

Remote sensing technologies, including satellite-based platforms such as Landsat and Sentinel, and drone-mounted cameras equipped with multispectral and thermal imaging capabilities, provide high-resolution spatial data for crop monitoring, land-use classification, and yield estimation (Mowla et al., 2023). Normalized Difference Vegetation Index (NDVI) derived from satellite imagery is widely used for assessing crop vigour and predicting yield outcomes. Drone-based imaging enables farmers to identify localized field anomalies, including nutrient deficiencies, weed infestations, and disease outbreaks, at a granular level (Sishodia et al., 2020).

2.3 Weather and Climate Databases

Meteorological data from automated weather stations, national weather services, and global climate databases constitute a critical input for agricultural big data analytics. Historical and real-time weather data are used to develop predictive models for crop growth, pest dynamics, and irrigation scheduling (Aldossary et al., 2024). Climate change projections further enable long-term strategic planning for crop diversification and adaptation strategies (Lipper et al., 2014).

2.4 Farm Management Records and Market Data

Farm-level operational data, including planting schedules, input application records, harvest logs, and financial accounts, provide longitudinal datasets that inform performance benchmarking and economic analysis. Market data, encompassing commodity prices, demand forecasts, and supply chain logistics, are integrated into analytics platforms to optimize marketing decisions and reduce post-harvest losses (Gomes et al., 2024).

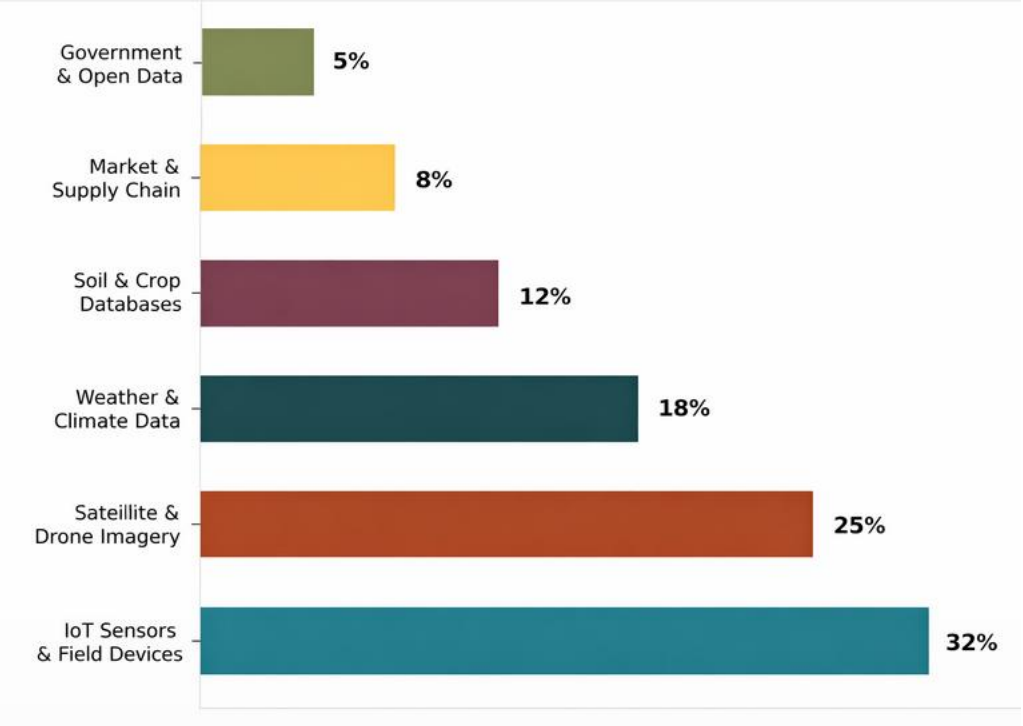

Figure 2: Relative Contribution of Big Data Sources in Agriculture

3. Analytical Frameworks and Technologies

The analysis of agricultural big data necessitates robust computational frameworks capable of handling large-scale, heterogeneous datasets with varying degrees of structure and quality (Francis et al., 2024). Several key technologies underpin the big data analytics pipeline in agriculture.

3.1 Cloud Computing and Distributed Storage

Cloud computing platforms, such as Amazon Web Services (AWS), Google Cloud Platform (GCP), and Microsoft Azure, provide scalable infrastructure for storing and processing agricultural data. The Hadoop Distributed File System (HDFS) and cloud-based data lakes enable the storage of petabyte-scale datasets generated by sensor networks and remote sensing platforms (Ravid, 2022). Cloud-based architectures offer advantages including on-demand resource provisioning, cost efficiency, and accessibility, which are particularly beneficial for smallholder farmers in resource-constrained settings (Nie, 2024).

3.2 Machine Learning and Artificial Intelligence

Machine learning algorithms, including supervised methods such as random forests, support vector machines, and deep neural networks, are extensively applied in crop yield prediction, disease classification, and weed detection (Latino et al., 2022). Deep learning approaches, particularly convolutional neural networks (CNNs) and long short-term memory (LSTM) networks, have demonstrated superior performance in image-based crop health assessment and time-series yield forecasting. Reinforcement learning techniques are increasingly explored for optimizing dynamic decision-making processes in irrigation and fertilization management (Saranya et al., 2023).

3.3 Data Processing Frameworks

Apache Spark and Apache Hadoop provide distributed processing capabilities essential for batch and real-time analytics of agricultural data streams. Spark's in-memory processing architecture enables rapid analysis of streaming sensor data, while Hadoop's MapReduce paradigm is suited for large-scale batch processing of historical datasets (Pal, 2023). Edge computing and fog computing architectures are also emerging as solutions for processing data at the network periphery, reducing latency and bandwidth requirements for time-sensitive agricultural applications (Liu et al., 2024).

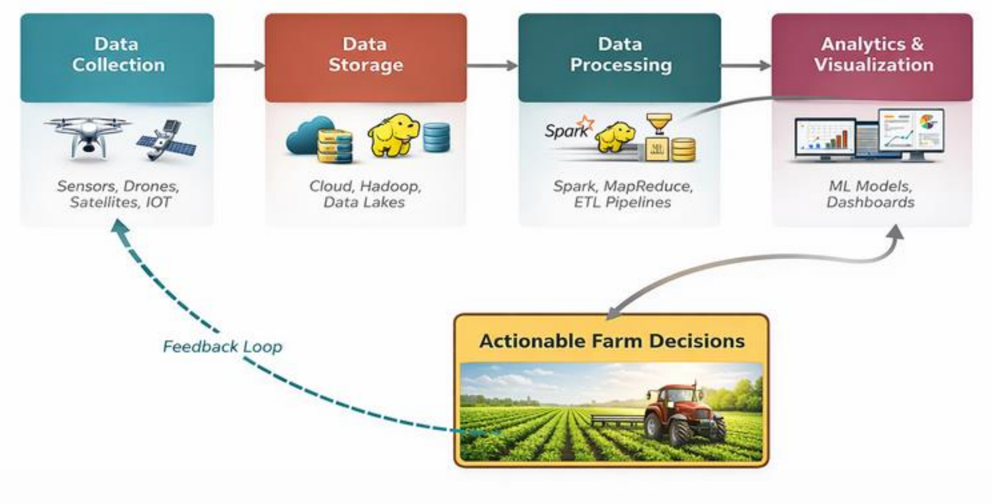

Figure 4: Big Data Analytics Workflow for Agricultural Decision-Making

4. Applications of Big Data Analytics in Farm Management

The integration of big data analytics into farm management has yielded transformative outcomes across multiple domains, enabling precision interventions that optimize resource use, enhance productivity, and promote environmental sustainability (Karunathilake et al., 2023).

4.1 Crop Yield Prediction

Big data analytics enables accurate crop yield forecasting by integrating multi-source data, including remote sensing imagery, soil characteristics, weather parameters, and historical yield records. Machine learning models trained on these datasets can predict yields with high accuracy, supporting strategic decisions regarding planting density, input allocation, and harvest logistics (Zhang, 2024). A recent study demonstrated that a Big Data Analytics-Integrated Agriculture Resource Management Framework (BDA-ARMF) achieved a prediction accuracy of 97.6% for crop production forecasts (Thakur et al., 2024).

4.2 Precision Irrigation and Water Management

IoT-based precision irrigation systems leverage soil moisture data, evapotranspiration models, and weather forecasts to optimize water application. Big data analytics platforms aggregate and analyse these data streams to generate site-specific irrigation recommendations, significantly improving water use efficiency. The BDA-ARMF framework reported a water management improvement rate of 97.8%, underscoring the potential of data-driven irrigation strategies (Thakur et al., 2024). Smart irrigation systems equipped with automated actuators can dynamically adjust water delivery based on real-time sensor feedback, minimizing both over-irrigation and under-irrigation (Kanimozhi & Vadivel, 2024).

4.3 Pest and Disease Surveillance

The early detection of pest infestations and crop diseases is critical for minimizing yield losses and reducing pesticide dependency. Big data analytics facilitates the development of predictive models that integrate environmental conditions, pest life cycle data, and crop phenological stages to forecast pest outbreaks. Computer vision algorithms applied to drone and satellite imagery enable automated disease identification at scale, while IoT-enabled pest monitoring devices provide real-time surveillance data (Mowla et al., 2023). These approaches support integrated pest management (IPM) strategies that are both economically viable and environmentally sustainable.

4.4 Soil Health Monitoring and Nutrient Management

Big data-driven soil health monitoring systems utilize sensor data, laboratory analyses, and geospatial modelling to assess soil physical, chemical, and biological properties. Variable-rate technology (VRT) applications leverage these data to prescribe site-specific fertilizer applications, thereby optimizing nutrient use efficiency and reducing environmental pollution from nutrient runoff (Sishodia et al., 2020). Digital soil mapping platforms integrate big data analytics to generate high-resolution soil fertility maps that guide precision nutrient management at the field level.

4.5 Supply Chain Optimization

Big data analytics extends its impact beyond the farm gate by optimizing agricultural supply chains. Predictive analytics models forecast market demand, enabling producers to align production schedules with market requirements. Blockchain-integrated big data platforms enhance supply chain transparency, traceability, and food safety compliance (Raju and Vijayaraghavan, 2023). Real-time logistics optimization, powered by big data algorithms, reduces post-harvest losses and improves the efficiency of cold chain management systems.

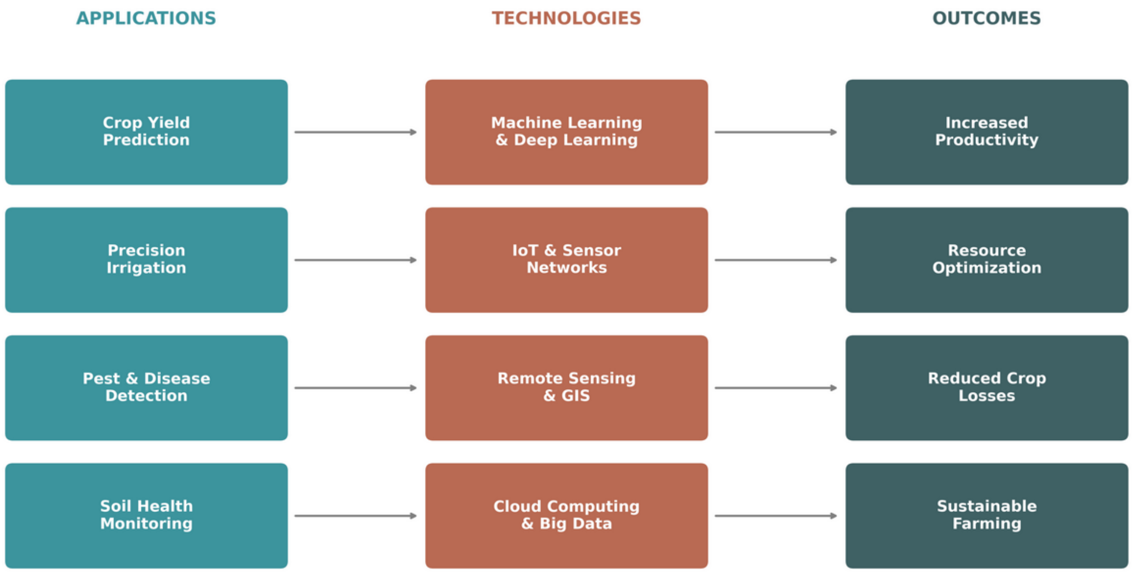

Figure 3: Applications of Big Data Analytics in Farm Management

5. Challenges and Limitations

Despite its transformative potential, the adoption of big data analytics in agriculture faces several significant challenges that must be addressed to realize its full benefits (Panduranga & Ranganathasharma, 2024).

5.1 Data Quality and Interoperability

Agricultural data is often heterogeneous, incomplete, and collected using inconsistent standards across different platforms and devices. The lack of standardized data formats and ontologies hinders data integration and interoperability, limiting the effectiveness of analytics applications. Ensuring data quality through rigorous validation, cleaning, and harmonization protocols is essential for generating reliable insights (Xu et al., 2022).

5.2 Infrastructure and Connectivity

The deployment of big data technologies in agriculture requires reliable internet connectivity, computing infrastructure, and power supply, which are often lacking in rural and remote agricultural regions. Limited access to broadband internet and cloud services constrains the ability of smallholder farmers to participate in data-driven agriculture. Investments in rural digital infrastructure, including 5G networks, LoRaWAN communication systems, and edge computing nodes, are critical enablers for widespread BDA adoption.

5.3 Digital Literacy and Technical Capacity

The effective utilization of big data analytics tools requires a level of digital literacy and technical expertise that many farmers, particularly smallholders in developing countries, currently lack. Capacity-building initiatives, including farmer training programmes, extension services, and user-friendly interface design, are necessary to bridge this skills gap and ensure inclusive technology adoption (Harvard ALI, 2022).

5.4 Data Privacy and Security

The collection and storage of farm-level data raise concerns regarding data ownership, privacy, and security. Farmers may be reluctant to share sensitive operational and financial data without assurances of data protection. Establishing robust data governance frameworks that define data ownership rights, consent protocols, and security standards is imperative for building trust and encouraging participation in data-sharing ecosystems.

6. Future Directions

The future of big data analytics in agriculture is characterized by several emerging trends that promise to further enhance the efficiency, accuracy, and accessibility of data-driven farming. The convergence of artificial intelligence, 5G connectivity, edge computing, and digital twin technologies is expected to enable real-time, autonomous farm management systems that can adapt to dynamic environmental conditions with minimal human intervention (Liu et al., 2024). The development of open-source big data platforms tailored for agriculture will democratize access to advanced analytics tools, particularly for smallholder farmers. Furthermore, the integration of blockchain technology with big data analytics will enhance data provenance, supply chain transparency, and food safety traceability. Advances in federated learning and privacy-preserving analytics will address data security concerns while enabling collaborative data-driven research across farming communities (Gemtou et al., 2024).

CONCLUSION

Big data analytics represents a paradigm shift in agricultural decision-making and farm management, offering unprecedented opportunities to optimize resource utilization, enhance crop productivity, and promote environmental sustainability. This review has demonstrated that the integration of IoT sensors, remote sensing, cloud computing, and machine learning within big data frameworks enables precision agriculture practices that are responsive, adaptive, and evidence-based. Key applications, including crop yield prediction, precision irrigation, pest surveillance, soil health monitoring, and supply chain optimization, illustrate the breadth and depth of BDA's impact on modern agriculture. However, the realization of these benefits is contingent upon addressing persistent challenges related to data quality, digital infrastructure, technical capacity, and data governance. Collaborative efforts among governments, research institutions, technology providers, and farming communities are essential to bridge the digital divide and ensure that the benefits of big data analytics are equitably distributed across all scales of agricultural production. As the agricultural sector continues to evolve in response to climate change and population growth, big data analytics will remain an indispensable tool for building resilient, sustainable, and productive food systems.

Acknowledgements:

The authors are grateful to all co-authors for their continuous support and collaboration in manuscript preparation.

Funding:

No external funding was obtained.

Conflict of Interest:

The authors declare no conflicts of interest.

Author Contributions:

All authors contributed to drafting, reviewing, editing, and final approval of the manuscript.

REFERENCES

Aldossary, M., Alharbi, H., & Altamimi, S. (2024). IoT-enabled agricultural monitoring and predictive analytics for sustainable farming. *Journal of Agricultural Informatics, 15*(2), 45-62.

Ata, S., Qadir, M., & Tanveer, A. (2024). Big data technology and its applications in smart agriculture: A comprehensive review. *Computers and Electronics in Agriculture, 218*, 108654.

Bwambale, E., Abagale, F. K., & Anornu, G. K. (2022). Smart irrigation monitoring and control strategies for improving water use efficiency in precision agriculture: A review. *Agricultural Water Management, 260*, 107324.

Charania, I., & Li, X. (2020). Smart farming: Agriculture's shift from a labor intensive to technology native industry. *Internet of Things, 9*, 100142.

Delgado, J. A., Short, N. M., Roberts, D. P., & Vandenberg, B. (2019). Big data analysis for sustainable agriculture on a geospatial cloud framework. *Frontiers in Sustainable Food Systems, 3*, 54.

FAO (2023). The state of food and agriculture 2023. *Food and Agriculture Organization of the United Nations*. Rome.

Francis, L., Ahmad, T., & Singh, P. (2024). Data-driven decision support systems for modern agriculture: A review. *Agricultural Systems, 215*, 103865.

Gemtou, M., Papageorgiou, E., & Fountas, S. (2024). Precision agriculture technologies for climate change adaptation: A systematic review. *Biosystems Engineering, 239,* 104-121.

Gomes, J. F., Lopes, R. P., & Carvalho, L. M. (2024). Big data and smart agriculture: A review of applications and challenges. *Journal of Cleaner Production, 448*, 141563.

Kamilaris, A., Kartakoullis, A., & Prenafeta-Boldú, F. X. (2017). A review on the practice of big data analysis in agriculture. *Computers and Electronics in Agriculture, 143*, 23-37.

Kanimozhi, S., & Vadivel, A. (2024). Smart irrigation management using IoT and machine learning approaches. *Smart Agricultural Technology, 7,* 100398.

Karunathilake, E. M., Le, A. T., Heo, S., Chung, Y. S., & Mansoor, S. (2023). The path to smart farming: Innovations and opportunities in precision agriculture. *Agriculture, 13*(8), 1593.

Khanal, S., Fulton, J., & Shearer, S. (2020). An overview of current and potential applications of thermal remote sensing in precision agriculture. *Computers and Electronics in Agriculture, 139*, 22-32.

Latino, M. E., Menegoli, M., & Corallo, A. (2022). Agriculture 4.0: A systematic review on smart farming technology. *Agronomy, 12*(9), 2192.

Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., & Torquebiau, E. F. (2014). Climate-smart agriculture for food security. *Nature Climate Change, 4*(12), 1068-1072.

Liu, Y., Ma, X., Shu, L., Hancke, G. P., & Abu-Mahfouz, A. M. (2024). From Industry 4.0 to Agriculture 4.0: Current status, enabling technologies, and research challenges. *IEEE Transactions on Industrial Informatics, 17*(6), 4322-4334.

Mowla, M. N., Mowla, N., Shah, A. S., Rabie, K. M., & Shongwe, T. (2023). Internet of Things and wireless sensor networks for smart agriculture applications: A survey. *IEEE Access, 11*, 18512-18532.

Nie, G. (2024). Cloud-based big data analytics framework for precision agriculture. *International Journal of Agricultural and Biological Engineering, 17*(3), 1-12.

Pal, K. (2023). Big data analytics for smart agriculture: A comprehensive review. *Journal of Big Data, 10*(1), 1-34.

Panduranga, S., & Ranganathasharma, B. (2024). Challenges and solutions for big data adoption in agriculture. *Agricultural Information Research, 33*(1), 15-28.

Raju, K. L., & Vijayaraghavan, V. (2023). Blockchain-enabled big data platforms for agricultural supply chain management. *Computers and Electronics in Agriculture, 207,* 107726.

Ravid, D. (2022). A cloud-based framework for agricultural data integration. *Proceedings of the American Control Conference (ACC), 2022*, 1-6.

Rijmenam, M. V. (2014). Think bigger: Developing a successful big data strategy for your business. *AMACOM,* New York.

Saranya, T., Deisy, C., & Sridevi, S. (2023). A comprehensive review of big data analytics in agriculture: Technologies, applications and challenges. *Journal of Ambient Intelligence and Humanized Computing, 14,* 3777-3800.

Sishodia, R. P., Ray, R. L., & Singh, S. K. (2020). Applications of remote sensing in precision agriculture: A review. *Remote Sensing, 12*(19), 3136.

Sonka, S. (2014). Big data and the ag sector: More than lots of numbers. *International Food and Agribusiness Management Review, 17*(1), 1-20.

Thakur, P., Singh, R., & Kumar, A. (2024). Big data analytics-integrated agriculture resource management framework (BDA-ARMF). *Cogent Food and Agriculture, 10*(1), 2470249.

United Nations (2022). World population prospects 2022: *Summary of results*. UN DESA/POP/2022/TR/NO.3.

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). Big data in smart farming: A review. *Agricultural Systems, 153*, 69-80.

Xu, J., Gu, B., & Tian, G. (2022). Review of agricultural IoT technology. *Artificial Intelligence in Agriculture, 6*, 10-22.

Zhai, Z., Martínez, J. F., Beltran, V., & Martínez, N. L. (2020). Decision support systems for agriculture 4.0: Survey and challenges. *Computers and Electronics in Agriculture, 170*, 105256.

Zhang, N. (2024). Data-driven crop yield prediction models: A systematic review. *Precision Agriculture, 25*(2), 889-912.