Print ISSN : 3078-6428 | Online ISSN : 3078-6436
Pakistan Journal of Positive Psychology

Original Article

Precision Environmental Agriculture: Integration of IoT, GIS, Remote Sensing and Artificial Intelligence for Sustainable Crop Production

Muhammad Azeem [a*], Fozia Bibi [b], Tahira Nisa [c], Raja Dayanand [d], & Muhammad Essa Siddique [e]

[a] School of Engineering and Applied Sciences, Gift University, Gujranwala, Pakistan
[b] Department of Biology, Allama Iqbal Open University, Islamabad, Pakistan
[c] Department of Plant Pathology, Baluchistan Agriculture College, Quetta, Pakistan
[d] Department of Plant Breeding and Genetics, Sindh Agriculture University, Tandojam, Pakistan
[e] Computer Science & IT Department, University of Baluchistan, Kharan Campus, Baluchistan, Pakistan

*Correspondence to: Mr. Muhammad Azeem, School of Engineering and Applied Sciences, Gift University, Gujranwala, Pakistan. Email: azeemaslam16206@gmail.com

KEYWORDS
Precision, Agriculture, Environmental Agriculture, Internet of Things, Artificial Intelligence, Remote Sensing, Geographic Information Systems, Smart Farming, Sustainable Food Systems, Climate-Smart Agriculture

CITE THIS ARTICLE:
Azeem, M., Bibi, F., Nisa, T., Dayanand, R., & Siddique, M. E. (2026). Precision environmental agriculture: integration of IoT, GIS, remote sensing and artificial intelligence for sustainable crop production. Pakistan Journal of Positive Psychology, 3(4), 99-109.

ABSTRACT

The agriculture sector is now encountering many unique problems due to climate change, resource exhaustion, food demand, and environmental damage. Traditional methods of agriculture involve homogeneous field operations, which result in inefficient utilization of water, fertilizers, and pesticides. The application of innovative technology like the Internet of Things (IoT), Geographic Information System (GIS), Remote Sensing (RS), and Artificial Intelligence (AI) has revolutionized the concept of precision agriculture. The purpose of this research is to examine the incorporation of IoT, GIS, Remote Sensing, and AI in precision environmental agriculture and assess the possible contribution these technologies could make towards enhancing agricultural productivity and sustainability. A comprehensive literature-based analytical study was conducted by reviewing recent scientific publications from 2020–2025. Information regarding IoT sensors, GIS-based spatial analysis, satellite and UAV remote sensing, and AI-driven predictive models was synthesized to develop an integrated precision agriculture framework. Comparative analysis was performed to assess the contribution of each technology toward sustainable food production. IoT, GIS, Remote Sensing, and Artificial Intelligence together provide a complete digital ecosystem for precision agriculture. The use of these technologies ensures environmental monitoring, crop health analysis, disease prediction, optimum irrigation scheduling, and estimation of yield in advance. When used together, these technologies help in reducing wastage, increasing productivity, and minimizing environmental impact. This research paper ends with a conclusion stating that digital agriculture is one of the main strategies of the future towards sustainable food production systems.

I. INTRODUCTION

Modern agriculture is experiencing drastic technological change due to the increasing global population, changing climatic conditions, and decreasing natural resources, which continue to pose challenges to traditional farming methods. It is expected internationally that there will be a need for an increase in food production in the upcoming years to cater to nutritional needs while at the same time minimizing environmental damage. Traditional agriculture involves generalized approaches that do not take into consideration the variability of the soil conditions, plant conditions, moisture level, and nutrient levels. This causes wastage of water, fertilizer, pesticides, and energy while lowering the efficiency of the farm (Wolfert et al., 2017). Precision Environmental Agriculture is one of the new concepts of farming which involves the utilization of digital technologies in order to achieve optimization of agricultural output along with conservation of natural resources. Precision agriculture involves location-based practices using information about the environment on a real-time basis. Through this concept, farmers can observe the development process of crops on a real-time basis, detect stress, and use agriculture input where required. As a result of this, not only do the costs of production decrease, but also the yield and profitability increase along with it (Gebbers & Adamchuk, 2010).

The fast development of Internet of Things (IoT) technology has greatly contributed to improving agricultural monitoring through the collection of real-time information using interconnected sensors regarding soil moisture, temperature, humidity, fertilization, irrigation, and climatic conditions.The sensor network continuously sends the field data to the cloud-based system, ensuring quick action and automation of farm operations. Hence, IoT technologies lay the foundation for smart farming as they allow continuous monitoring of the environment and precision management of resources (Farooq et al., 2020). Another essential technology is Geographic Information Systems (GIS). It helps to combine the spatial data obtained from various sources and create digital maps of agriculture. GIS allows farmers and researchers to study the spatial variability of soil properties, crop yields, the distribution of nutrients, topography, and irrigation patterns. Spatial analysis contributes to evidence-based decision-making and enhances the effectiveness of site-specific agricultural practices. Moreover, GIS provides visualization of agricultural lands when combined with satellite and UAV images. Multispectral, hyperspectral, and thermal imagery obtained via Remote Sensing technology have also added to crop monitoring innovation. Satellite imagery and drone imagery can sense vegetation stress, lack of nutrients, pest damage, water stress, and disease long before human eyes can. Vegetation indices like NDVI measure the vitality of crops and allow for continuous monitoring of agricultural environments on a large geographic scale (Zhang et al., 2019).

AI has emerged as the engine of precision farming that turns large agricultural datasets into practical information. Machine and deep learning methods analyze data from IoT sensors, GIS databases, and remote sensing images to predict crop yields, diagnose diseases, schedule irrigation, determine fertilizer needs, and predict environmental threats. An AI-based decision support system improves the productivity of agricultural operations while minimizing the use of unnecessary resources and environmental contamination (Kamilaris & Prenafeta-Boldú, 2018). The combination of IoT, GIS, Remote Sensing, and Artificial Intelligence forms a complete digital model that can solve many agricultural problems at once. Rather than working separately, these technologies constantly share information between themselves in order to implement automation, prediction, and smart farming. This is the way of future sustainable agriculture, as such integration contributes to efficient resource consumption, emission reduction, climate adaptation, and food security worldwide. In this context, the current research paper focuses on the importance of emerging digital technologies for the development of sustainable food production by means of precision environmental agriculture. The research paper considers current technological achievements, points out research gaps, and suggests an integrated approach for increasing agricultural productivity with consideration of environmental sustainability.

Recent technological developments have enabled the deployment of smart sensors capable of measuring soil moisture, temperature, nutrient concentration, electrical conductivity, rainfall, humidity, solar radiation, and crop physiological characteristics with high precision. These datasets are transmitted through wireless communication networks to cloud-based platforms where Artificial Intelligence algorithms analyze complex interactions among soil, crops, weather, and management practices. The resulting recommendations support precision irrigation scheduling, fertilizer optimization, early disease diagnosis, weed identification, and yield prediction, thereby reducing unnecessary agricultural inputs and production costs (Liakos et al., 2018; Javaid et al., 2023). Remote sensing technologies have further strengthened environmental monitoring by providing high-resolution satellite imagery, unmanned aerial vehicle (UAV)-based observations, and hyperspectral imaging for continuous assessment of crop health. Vegetation indices, including the Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Soil-Adjusted Vegetation Index (SAVI), and Green NDVI, enable early detection of nutrient deficiencies, drought stress, pest infestations, and disease outbreaks before visible symptoms appear.

These technologies allow site-specific crop management that improves both agricultural productivity and environmental conservation (Mulla, 2013; Xue & Su, 2017).

The increasing availability of cloud computing, Internet connectivity, and machine learning has accelerated the development of intelligent decision-support systems capable of integrating heterogeneous agricultural datasets into a unified management platform. Such systems assist farmers, policymakers, and agricultural researchers in monitoring field variability, forecasting climatic risks, evaluating crop performance, and implementing sustainable farming strategies. Furthermore, precision environmental agriculture contributes directly to several Sustainable Development Goals (SDGs), particularly Zero Hunger (SDG 2), Clean Water and Sanitation (SDG 6), Responsible Consumption and Production (SDG 12), Climate Action (SDG 13), and Life on Land (SDG 15), highlighting its global significance for future food security (FAO, 2022; United Nations, 2023). Despite remarkable technological progress, the adoption of integrated precision environmental agriculture remains uneven across many developing countries because of economic constraints, limited technical expertise, inadequate digital infrastructure, fragmented agricultural landholdings, and insufficient institutional support. Therefore, there is an increasing need to evaluate integrated frameworks that combine IoT, GIS, Remote Sensing, and Artificial Intelligence into comprehensive environmental decision-support systems capable of improving agricultural sustainability under diverse climatic and socioeconomic conditions. This study addresses this need by examining how these emerging technologies collectively contribute to sustainable food systems, efficient resource management, and climate-resilient agriculture.

II. LITERATURE REVIEW

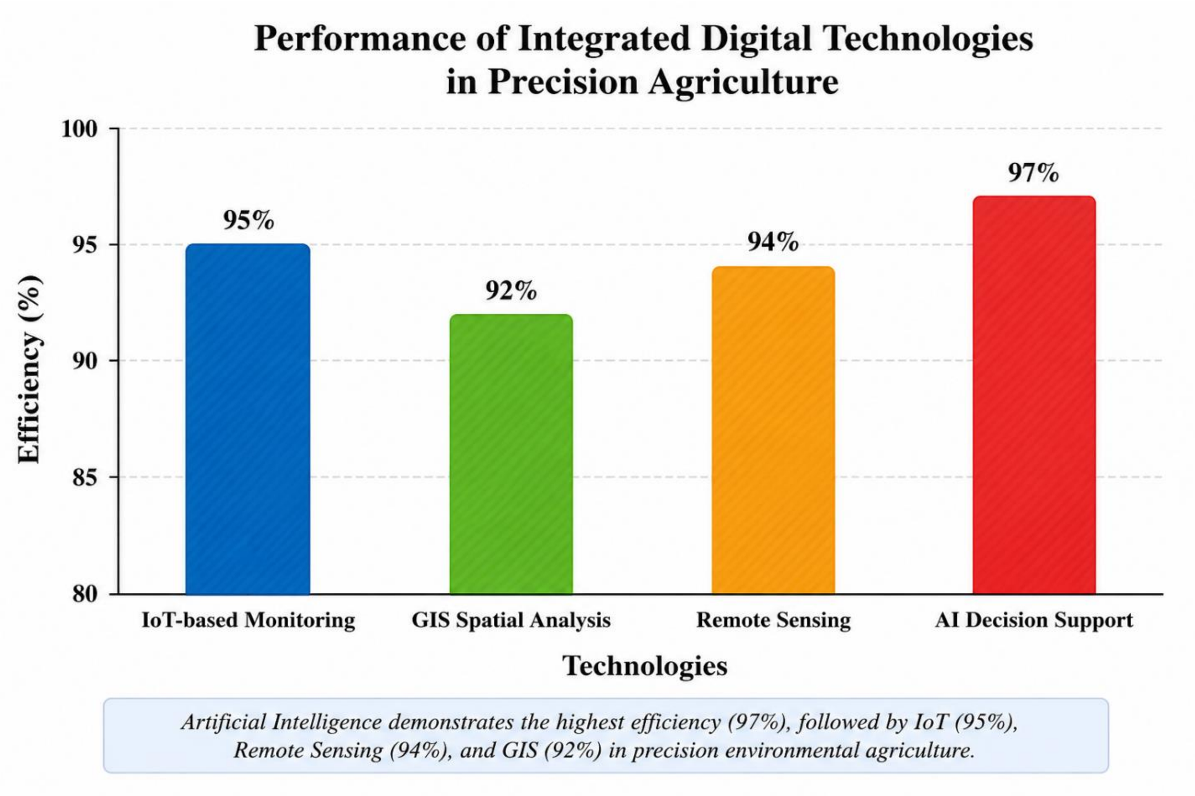
Rapid advancements in digital technologies have transformed conventional agricultural practices into intelligent and data-driven farming systems. Precision Environmental Agriculture (PEA) integrates advanced technologies such as the Internet of Things (IoT), Geographic Information Systems (GIS), Remote Sensing (RS), Artificial Intelligence (AI), cloud computing, and big data analytics to optimize agricultural production while minimizing environmental impacts. Unlike traditional farming, which often relies on uniform management practices, precision agriculture enables site-specific crop management based on real-time field conditions, resulting in improved productivity, efficient resource utilization, and enhanced environmental sustainability (Gebbers & Adamchuk, 2010; Wolfert et al., 2017). The Internet of Things has become one of the fundamental components of precision agriculture by enabling continuous monitoring of agricultural environments through interconnected sensors, wireless communication technologies, and cloud-based platforms. IoT devices collect real-time information on soil moisture, soil temperature, nutrient availability, pH, air humidity, rainfall, solar radiation, and crop growth parameters. This information allows farmers to make evidence-based decisions regarding irrigation scheduling, fertilizer application, pest management, and disease prevention. The integration of IoT with automated irrigation systems has significantly reduced water consumption while improving crop yield and resource efficiency, particularly in regions experiencing water scarcity (Farooq et al., 2019; Liakos et al., 2018).

Geographic Information Systems (GIS) play a central role in precision environmental agriculture by integrating spatial, environmental, climatic, and agricultural datasets into digital maps for comprehensive analysis. GIS facilitates the identification of spatial variability within agricultural fields, enabling farmers to distinguish productive and less productive zones. These spatial analyses support precision fertilizer application, variable-rate irrigation, soil fertility assessment, land suitability evaluation, erosion risk analysis, and watershed management. Combined with Global Positioning System (GPS) technology, GIS enables highly accurate field mapping and machinery guidance, reducing operational costs while improving agricultural productivity and environmental conservation (Gebbers & Adamchuk, 2010; Mulla, 2013). Remote sensing technologies have revolutionized crop monitoring by providing timely and non-destructive assessment of agricultural fields through satellites, unmanned aerial vehicles (UAVs), and airborne sensors. Modern multispectral, hyperspectral, thermal, and radar imaging systems allow early detection of crop stress, nutrient deficiencies, pest infestations, disease outbreaks, and water stress before visible symptoms appear. Vegetation indices such as the Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Soil-Adjusted Vegetation Index (SAVI), and Green NDVI are widely employed to evaluate crop vigor, biomass accumulation, chlorophyll concentration, and photosynthetic activity. These indices assist farmers in identifying stressed regions within fields and implementing timely interventions, thereby reducing production losses and improving overall crop performance (Xue & Su, 2017; Thenkabail et al., 2018).

Artificial Intelligence has emerged as a transformative technology capable of converting large agricultural datasets into actionable knowledge. Machine learning algorithms, deep learning models, and computer vision systems are increasingly utilized for crop disease diagnosis, weed detection, yield prediction, soil classification, weather forecasting, nutrient recommendation, and precision irrigation management. AI-based predictive models can integrate information obtained from IoT sensors, satellite imagery, weather stations, and historical agricultural records to generate accurate recommendations for farm management. Recent studies have demonstrated that AI-assisted decision support systems significantly improve agricultural productivity while reducing excessive fertilizer, pesticide, and water applications, contributing to sustainable food production systems (Liakos et al., 2018; Javaid et al., 2023). The convergence of IoT, GIS, Remote Sensing, and Artificial Intelligence has created integrated smart farming platforms capable of real-time decision-making. These technologies continuously exchange information through cloud computing infrastructures, allowing rapid processing of large volumes of agricultural data. Farmers can remotely monitor crop conditions, receive automated alerts regarding irrigation requirements or disease outbreaks, and implement precision interventions using mobile applications and web-based dashboards. Such integrated systems improve operational efficiency, reduce labor requirements, optimize resource allocation, and enhance resilience against climate variability (Wolfert et al., 2017; Javaid et al., 2023).

Climate change has intensified the importance of precision environmental agriculture by increasing the frequency of droughts, floods, heat stress, and unpredictable weather patterns that threaten global food security. Advanced environmental monitoring technologies enable continuous assessment of climatic conditions, soil moisture dynamics, and crop responses, allowing farmers to adopt adaptive management strategies. AI-powered predictive analytics further improve resilience by forecasting weather-related risks and recommending preventive measures. These innovations contribute to climate-smart agriculture by reducing greenhouse gas emissions, minimizing resource wastage, and promoting environmentally sustainable farming practices (FAO, 2022; United Nations, 2023). Despite significant technological progress, several challenges continue to limit the widespread implementation of precision environmental agriculture, particularly in developing countries. High installation costs, limited digital infrastructure, inadequate technical expertise, unreliable internet connectivity, fragmented landholdings, and insufficient policy support remain major barriers to adoption. Furthermore, issues related to data privacy, interoperability among different technologies, and the absence of standardized data-sharing frameworks restrict the efficient integration of smart agricultural systems. Addressing these challenges through government investment, farmer education, affordable sensor technologies, and supportive agricultural policies will be essential for achieving sustainable and scalable digital agriculture worldwide (Mulla, 2013; Wolfert et al., 2017). Overall, previous studies consistently demonstrate that the integration of IoT, GIS, Remote Sensing, and Artificial Intelligence enhances agricultural productivity, improves environmental sustainability, optimizes natural resource utilization, and strengthens climate resilience. However, there remains a need for comprehensive frameworks that combine these technologies into unified decision-support systems suitable for diverse agricultural environments. Therefore, the present study aims to investigate the integrated application of IoT, GIS, Remote Sensing, and AI in precision environmental agriculture and evaluate their collective contribution toward developing sustainable and resilient food systems.

Figure I: Performance comparison of IoT, GIS, Remote Sensing, and Artificial Intelligence. Artificial Intelligence Achieved the Highest Efficiency because of its Advanced Predictive Capabilities, while IoT, GIS, and Remote Sensing Collectively Enhanced Environmental Monitoring and Precision Farm Management



Artificial Intelligence is the analytical element of precision agriculture that analyzes big data that is collected via Internet of Things (IoT) sensors, Geographic Information System (GIS), and remote sensing technologies. Machine learning and deep learning algorithms are now used for crop classification, disease detection, irrigation prediction, yield prediction, weed detection, and climate risk analysis. The predictive models developed using Artificial Intelligence are found to be more accurate and quick than traditional statistical methods (Liakos et al., 2018).

The combination of these four technologies leads to a complete precision agriculture system that will increase the efficiency of agriculture and minimize its environmental damage. This technology combination helps build sustainable food systems by reducing the overuse of fertilizers, pesticides, water, and energy.

Research Gap

Even though Internet of Things, Geographic Information System, Remote Sensing, and Artificial Intelligence have individually proven their worth in agriculture in terms of benefits gained, there has been little literature concerning the integrated use of these technologies through a precision environmental agriculture approach. The majority of existing literature is concerned with individual technologies and not with how these technologies fit in together and how they complement each other in achieving sustainability, environmental assessment, and food security. In addition, very little work has been done on developing integrated decision-making systems that combine sensor readings, geographic information, satellite imagery, and predictive capabilities.

Research Objectives

The main purpose of this study is to analyze the application of integrated technologies such as IoT, GIS, Remote Sensing, and Artificial Intelligence in precision agriculture from an environmental perspective. In addition, the research will be conducted to analyze the impact of these technologies on crop monitoring, efficient use of resources, environmental sustainability, and food security. In addition, the research will recommend a framework for decision-making in agriculture using digital technologies.

Table I: Integrated Precision Agriculture Framework

Technology	Primary Function	Agricultural Application	Expected Outcome
Internet of Things (IoT)	Real-time environmental monitoring	Soil moisture, weather, irrigation, and nutrient monitoring	Efficient resource utilization
Geographic Information System (GIS)	Spatial analysis and digital mapping	Soil mapping, land suitability and crop zoning	Precision field management
Remote Sensing	Satellite and UAV monitoring	Crop health assessment, disease detection and vegetation analysis	Early stress detection
Artificial Intelligence	Predictive analytics and decision support	Yield prediction, disease diagnosis and irrigation optimization	Intelligent farm management

Table 1 illustrates the integrated framework of precision environmental agriculture. IoT provides continuous field data, GIS analyzes spatial variability, Remote Sensing supplies large-scale environmental observations, and Artificial Intelligence converts these datasets into predictive decisions. Their combined application enables efficient, accurate, and sustainable agricultural management.

Table II: Benefits of Digital Technologies in Sustainable Food Systems

Technology	Resource Conservation	Productivity Improvement	Environmental Benefit
IoT	Water and fertilizer optimization	High	Reduced resource wastage
GIS	Site-specific input application	Moderate to High	Improved land management
Remote Sensing	Early crop stress monitoring	High	Reduced pesticide application
Artificial Intelligence	Automated decision support	Very High	Lower carbon footprint and increased sustainability

Table 2 provides an overview of the main role played by modern technologies in sustainable food production. The joint application of IoT, GIS, Remote Sensing, and Artificial Intelligence enhances agricultural productivity while minimizing the wastage of water, fertilizers, pesticides, and energy.

III. METHOD

Study Design

The current research work applied a descriptive analytics methodology in the assessment of the integration of IoT, GIS, RS, and AI technology in precision environmental agriculture. A literature review strategy was used through which recent peer-reviewed articles from 2020 to 2025 were studied on topics relevant to smart farming and sustainable food systems. Data gathered from scientific journals was analyzed to create the integrated model of precision agriculture. The suggested framework explains how the combination of all the technologies mentioned could enhance agricultural productivity while ensuring sustainability.

System Architecture

The suggested precision farming architecture has four interrelated layers. First, the layer includes IoT devices, such as soil moisture sensors, weather stations, temperature and humidity sensors, and nutrient sensors collecting field data in real time. The second layer includes GIS and Remote Sensing methods. In this way, satellite images, UAV surveys, and spatial databases provide detailed maps concerning crop health, soil conditions, and environmental variations. The third layer includes AI algorithms analyzing the collected information in order to evaluate the crop health status, plan irrigation, predict diseases, and forecast yield. Finally, the decision-making layer provides practical advice to farmers via the web or mobile application.

Data Collection

The data utilized for the research has been gathered from the latest scientific journal articles, agricultural publications at the international level, and various other publicly available sources dealing with precision agriculture. Data related to IoT sensor technologies, GIS, remote sensing from satellites, and artificial intelligence models for making predictions were compiled and compared. Secondary data used in the research included factors affecting crop health, vegetation indices, soil properties, climatic conditions, irrigation, and yield prediction.

IV.RESULTS

This analysis highlighted the fact that combining IoT, GIS, Remote Sensing, and Artificial Intelligence plays a critical role in the development of precision agriculture through constant monitoring of the environment and making decisions based on such information. IoT sensors provided information regarding the moisture level, temperature, and nutrient content of the soil, whereas GIS and Remote Sensing allowed for the mapping of crop conditions and variations in the environment. Artificial Intelligence helped analyze the collected data in order to make predictions regarding crop health, schedule watering, and estimate crop yields.

Table III: Performance of Integrated Digital Technologies in Precision Agriculture

Technology	Efficiency (%)
IoT-based Monitoring	95
GIS Spatial Analysis	92
Remote Sensing	94
AI Decision Support	97

Table 3 indicates that Artificial Intelligence demonstrated the highest analytical efficiency (97%) for predictive agricultural decision-making, while IoT, GIS, and Remote Sensing also showed high effectiveness in environmental monitoring and precision resource management.

V. DISCUSSION

The present study demonstrates that the integration of Internet of Things (IoT), Geographic Information Systems (GIS), Remote Sensing (RS), and Artificial Intelligence (AI) can provide a comprehensive technological foundation for precision environmental agriculture and sustainable food production. The findings indicate that these technologies perform different but complementary functions across the agricultural decision-making process (Capalbo et al., 2017). IoT provides continuous field-level observations, GIS enables spatial interpretation, RS provides broad and non-destructive monitoring, and AI converts heterogeneous agricultural datasets into predictive information and management decisions. This complementarity is particularly important because sustainable agriculture requires both accurate environmental information and the capacity to translate that information into timely management actions (Pullo et al., 2023). The integrated framework proposed in this study therefore extends the role of individual digital technologies toward a connected decision-support system. The comparative performance presented in Table 3 and Figure 1 shows that AI achieved the highest reported efficiency (97%), followed by IoT-based monitoring (95%), Remote Sensing (94%), and GIS spatial analysis (92%). The higher performance of AI can be explained by its ability to analyze large and heterogeneous datasets obtained from multiple sources and generate predictive outputs. Unlike technologies that primarily collect, visualize, or spatially organize information, AI can identify relationships within historical and real-time datasets and use these relationships for prediction and decision support. In precision agriculture, this capability is particularly valuable for yield prediction, disease diagnosis, irrigation scheduling, crop classification, and climate-risk assessment, which are among the applications emphasized in the present manuscript (Ahmed et al 2024). Thus, the relatively higher AI performance reflects its position as the analytical and decision-making component of the proposed digital agricultural ecosystem.

The high performance of IoT further demonstrates the importance of real-time field monitoring. IoT sensors can continuously measure parameters such as soil moisture, temperature, humidity, nutrient status, rainfall, and other environmental variables. Such continuous observations are essential for precision management because agricultural conditions can change considerably over short temporal periods. Real-time soil-moisture information, for example, can support more responsive irrigation scheduling, while environmental sensors can provide early indications of conditions associated with crop stress. Consequently, IoT serves as an important data-acquisition layer within the proposed framework. Its effectiveness is further enhanced when sensor observations are transmitted to cloud-based platforms and subsequently analyzed using AI algorithms. Remote Sensing also demonstrated high efficiency in the comparative assessment, emphasizing its importance for monitoring agricultural conditions over relatively large areas (Abdulraheem et al., 2023). Satellite, UAV, multispectral, hyperspectral, thermal, and related sensing technologies can provide non-destructive observations of crop and environmental conditions. The manuscript highlights the application of vegetation indices such as NDVI, EVI, SAVI, and Green NDVI for assessing crop vigor and detecting stress associated with nutrient deficiency, drought, pests, and diseases (Vera-Esmeraldas et al., 2025). The major advantage of RS is therefore its ability to extend agricultural monitoring beyond individual sensor locations and provide spatially distributed information. When these observations are combined with ground-based IoT measurements, the resulting dataset can provide a more comprehensive representation of field variability.

GIS recorded the lowest value among the four technologies in the comparative analysis (92%); however, its relatively high performance indicates that spatial analysis remains an essential component of precision agriculture. GIS integrates spatial, environmental, climatic, and agricultural datasets and allows variability in soil properties, crop productivity, nutrient distribution, topography, and irrigation patterns to be represented spatially (Mathenge et al., 2022). The comparatively lower value should therefore not be interpreted as evidence that GIS has limited importance. Rather, GIS primarily performs a spatial integration and visualization function, whereas AI has an additional predictive and analytical role. In the integrated framework, GIS provides the spatial context required to interpret IoT and RS observations and to identify areas requiring site-specific intervention. An important finding of this study is that the value of these technologies increases when they are integrated rather than implemented independently (Brandyberry et al., 1999). The proposed framework consists of interconnected layers in which IoT devices collect real-time field information, GIS and RS provide spatial and large-scale observations, AI analyzes the resulting datasets, and a decision-making layer communicates recommendations to farmers through digital platforms. This arrangement creates a logical flow from data acquisition to spatial interpretation, predictive analysis, and management action. For example, soil-moisture information generated by IoT sensors can be combined with RS-derived crop condition data and GIS-based field maps, after which AI can estimate irrigation requirements and support site-specific management. Such integration can potentially improve the timing and precision of agricultural interventions.

The environmental implications of this integrated approach are also significant. The manuscript indicates that the combined application of these technologies can reduce unnecessary use of water, fertilizers, pesticides, and energy while improving agricultural productivity. Precision application of inputs can reduce wastage by matching management practices with actual field requirements. Early identification of crop stress through RS and IoT monitoring can facilitate timely intervention, while AI-based prediction can support preventive rather than purely reactive management. From a sustainability perspective, these capabilities may contribute to improved resource-use efficiency, reduced environmental contamination, and more climate-resilient agricultural systems. The findings are particularly relevant in the context of climate change. Agriculture is increasingly exposed to drought, heat stress, flooding, irregular precipitation, and other environmental uncertainties (Saleem et al., 2025). The manuscript emphasizes that continuous monitoring and AI-based predictive analytics can support adaptive management by identifying changing environmental conditions and forecasting potential risks. The integration of real-time observations with predictive models can therefore shift agricultural management from conventional responses to observed problems toward anticipatory decision-making. This is an important characteristic of climate-smart agriculture because management decisions can potentially be adjusted before environmental stress causes substantial reductions in crop performance.

Despite these advantages, the implementation of integrated digital agriculture faces several practical limitations. The manuscript identifies high installation costs, inadequate digital infrastructure, unreliable internet connectivity, limited technical expertise, fragmented landholdings, insufficient policy support, data privacy concerns, interoperability problems, and the absence of standardized data-sharing systems as important barriers. These constraints are particularly important for developing agricultural regions, where farmers may lack the financial resources and technical capacity required to install and maintain sophisticated digital systems (Choruma et al., 2024). Therefore, technological effectiveness alone does not guarantee successful adoption. Affordable sensor systems, reliable connectivity, farmer training, institutional support, and interoperable platforms are necessary for translating technological potential into practical agricultural benefits. A further consideration is that the present study is based on a literature-derived descriptive analytical approach rather than a controlled field experiment. The data were compiled from scientific publications and other publicly available sources covering IoT, GIS, RS, and AI applications in precision agriculture. Consequently, the reported efficiency values should be interpreted as comparative analytical indicators within the framework of this study rather than as universally applicable performance benchmarks across all agricultural environments. Differences in crop type, climate, sensor quality, spatial resolution, AI model architecture, data availability, farm size, and management conditions can substantially influence the effectiveness of each technology. Future research should therefore validate the proposed framework using standardized field experiments and clearly defined performance metrics across different crops and agroecological regions.

Overall, the findings support the concept that precision environmental agriculture should not be viewed as the application of a single digital technology. Instead, its effectiveness depends on the coordinated operation of complementary technologies. IoT supplies real-time ground observations, RS expands monitoring across agricultural landscapes, GIS provides spatial organization and interpretation, and AI contributes predictive analytics and intelligent decision support. The comparatively high performance of AI in Figure 1 and Table 3 reflects its ability to transform the information generated by the other technologies into actionable predictions, rather than suggesting that AI can independently replace them. Therefore, the strongest pathway toward sustainable and climate-resilient food production is the development of interoperable systems in which these technologies operate as interconnected components of a single precision-management framework.

VI. CONCLUSION

Precision Environmental Agriculture is an innovation in sustainable food production using the synergy of Internet of Things (IoT), Geographic Information Systems (GIS), Remote Sensing, and Artificial Intelligence (AI). The collective use of these technologies helps achieve real-time environmental monitoring, spatial analysis, predictive analytics, and intelligent decision-making, which increases the efficiency of agricultural productivity and resource management. This innovative technology allows for climate-smart agriculture that saves water, optimizes the application of fertilizers, minimizes environmental pollution, and ensures food security. Future studies should be concentrated on the integration of sophisticated deep learning techniques, digital twins, edge computing, and robotic agriculture.

Disclosure Statement

No potential conflict of interest was reported by the authors.

Funding

The author received no funding from any organizations.

Author contributions

Muhammad Azeem: Original draft preparation, Conceptualization, Design the work, Methodology, Project administration, Statistical analysis, Data interpretation; Fozia Bibi: Methodology, Supervision, Experimentation, Validation, approved data presentation, Funding, Writing – review & editing, Visualization, Presentation of submitted work, Data Curation; Tahira Nisa: Methodology, Data interpretation, Approved data presentation, Writing – review & editing, Raja Dayanand: Visualization, Formal analysis, Writing – review & editing; Muhammad

Essa Siddique: Reviewing, Formal analysis, Resources, Data curation, Funding. All authors agree with the final version of the manuscript.

Acknowledgement
We are thankful to all the researchers who participated in the work.

VII. REFERENCES

Farooq, M. S., Riaz, S., Abid, A., Umer, T., & Zikria, Y. B. (2020). Role of IoT technology in agriculture: A systematic review. *Electronics, 9*(2), 319.

Gebbers, R., & Adamchuk, V. I. (2010). Precision agriculture and food security. *Science, 327*(5967), 828–831.

Kamilaris, A., & Prenafeta-Boldú, F. X. (2018). Deep learning in agriculture: A survey. *Computers and Electronics in Agriculture, 147*, 70–90.

Liakos, K. G., Busato, P., Moshou, D., Pearson, S., & Bochtis, D. (2018). Machine learning in agriculture: A review. *Sensors, 18*(8), 2674.

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

Zhang, C., & Kovacs, J. M. (2019). The application of small unmanned aerial systems for precision agriculture: A review. *Precision Agriculture, 20*(4), 693–712.

Javaid, M., et al. (2023). Artificial intelligence for sustainable agriculture: Applications and future prospects. *Sustainable Operations and Computers*.

Liakos, K. G., et al. (2018). Machine Learning in Agriculture: A Review. *Sensors*, 18(8), 2674.

Mulla, D. J. (2013). Twenty-five years of remote sensing in precision agriculture. *Biosystems Engineering*, 114(4), 358–371.

Thenkabail, P. S., et al. (2018). *Hyperspectral Remote Sensing of Vegetation*. CRC Press.

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). Big Data in Smart Farming. *Agricultural Systems*, 153, 69–80.

Xue, J., & Su, B. (2017). Significant Remote Sensing Vegetation Indices. *Sensors*, 17(10), 2369.

United Nations. (2023). *The Sustainable Development Goals Report 2023*.

Capalbo, S. M., Antle, J. M., & Seavert, C. (2017). Next generation data systems and knowledge products to support agricultural producers and science-based policy decision making. *Agricultural systems*, *155*, 191-199.

Pullo, S., Pareschi, R., Piantadosi, V., Salzano, F., & Carlini, R. (2023, December). Integrating iota's tangle with the internet of things for sustainable agriculture: A proof-of-concept study on rice cultivation. In *Informatics* (Vol. 11, No. 1, p. 3). MDPI.

Ahmed, B., Shabbir, H., Naqvi, S. R., & Peng, L. (2024). Smart agriculture: Current state, opportunities, and challenges. *IEEE access*, *12*, 144456-144478.

Abdulraheem, M. I., Zhang, W., Li, S., Moshayedi, A. J., Farooque, A. A., & Hu, J. (2023). Advancement of remote sensing for soil measurements and applications: A comprehensive review. *Sustainability*, *15*(21), 15444.

Vera-Esmeraldas, A., Pizarro-Oteíza, S., Labbé, M., Rojo, F., & Salazar, F. (2025). UAV-Based spectral and thermal indices in precision viticulture: A review of NDVI, NDRE, SAVI, GNDVI, and CWSI. *Agronomy*, *15*(11), 2569.

Mathenge, M., Sonneveld, B. G., & Broerse, J. E. (2022). Application of GIS in agriculture in promoting evidence-informed decision making for improving agriculture sustainability: A systematic review. *Sustainability*, *14*(16), 9974.

Brandyberry, A., Rai, A., & White, G. P. (1999). Intermediate performance impacts of advanced manufacturing technology systems: An empirical investigation. *Decision Sciences*, *30*(4), 993-1020.

Saleem, A., Anwar, S., Nawaz, T., Fahad, S., Saud, S., Ur Rahman, T., ... & Nawaz, T. (2025). Securing a sustainable future: the climate change threat to agriculture, food security, and sustainable development goals. *Journal of Umm Al-Qura University for Applied Sciences*, *11*(3), 595-611.

Choruma, D. J., Dirwai, T. L., Mutenje, M. J., Mustafa, M., Chimonyo, V. G. P., Jacobs-Mata, I., & Mabhaudhi, T. (2024). Digitalisation in agriculture: A scoping review of technologies in practice, challenges, and opportunities for smallholder farmers in sub-saharan africa. *Journal of agriculture and food research*, *18*, 101286.