Spectrum of Engineering Sciences
ISSN (e) 3007-3138 (p) 3007-312X Volume 3, Issue 5, 2025

SMART FARMING TECHNOLOGIES: TRANSFORMING AGRICULTURE THROUGH IOT AND AI

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DOI: https://doi.org/10.5281/zenodo.15560678

Keywords

Article History
Received on 07 April 2025
Accepted on 07 May 2025
Published on 31 May 2025

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Abstract

Smart farming combines Internet of Things (IoT) and Artificial Intelligence (AI) into agriculture and presents many new solutions to problems that traditional farming practices. The research was conducted at the Islamia University of Bahawalpur by the Department of Artificial Intelligence to evaluate the role of smart farming technologies in improving wheat production. The soil moisture, temperature, and environmental conditions were monitored using IoT-based sensors. Artificial intelligence algorithms are designed to make real-time analysis and decision-making. Automated irrigation, drone surveillance, and predictive disease detection systems were installed to compare with their traditional methods over a full cropping season. Results indicated that wheat yield achieved an increase of 23% while water consumption was reduced by 40%, input costs were brought down by 20%, improved crop health management was observed, and labor was reduced by 25%, thus increasing environmental sustainability through optimized resource use. Network stability and initial setup costs were minor setbacks, but farmers overwhelmingly commented positively on the systems, indicating a very bright prospective adoption scenario. The conclusion drawn from this study is that smart farming technologies enhance productivity, sustainability, and efficiency in agriculture. With proper infrastructural support, education, and funding, the IoT- and AI-based smart farming systems can play a significant role in the modernization of agriculture in Pakistan and similar developing regions, thus aiding long-term food security and environmental conservation.

INTRODUCTION

Agriculture for many years has been the lifeblood of economies across the borders, especially developing countries such as Pakistan, where a significant section of the population is dependent on farming for its livelihood[1]. Traditional farming procedures, deeply seated in culture and historical knowledge, come up against serious challenges today: climate change, water scarcity, soil degradation, pest infestation, and the need for enhanced productivity to sustain a growing population. As these challenges are amplified, the demand for innovative, sustainable solutions has never been more urgent. Toward this aim, smart technologies-in the form of Internet of Things (IoT) and Artificial Intelligence (AI)-are being integrated into agriculture, referred to as Smart Farming, and this is set to revolutionize the monitoring, management, and optimization of agricultural activities[2].

Smart farming, or precision agriculture/digital farming, is defined as the use of advanced technology to improve agricultural outcomes through data-driven decision-making. The main idea in smart farming involves collecting real-time data from the field through sensors, drones, GPS systems, and computerized machinery, which is then analyzed using AI algorithms to yield accurate solutions for the timely undertaking of various decisions relating to irrigation scheduling, pest and disease control, crop choice, fertilization regimes, the timing of harvesting, among many others. It improves productivity and crop yield while minimizing the wastage of other resources, making agriculture more efficient and sustainable[3].

The combination of IoT and AI in the agriculture domain creates a unique opportunity for transformation. IoT devices, such as soil moisture sensors, climate adjustments, and GPS tractors, continue to gather data on the ever-changing environmental conditions affecting crop health and soil characteristics. The use of AI to process this data can help to recognize patterns that would otherwise go unnoticed, foresee possible outcomes, and allow for automation of the entire process. For instance, AI algorithms can analyze images captured with drones to identify early signs of crop disease or pest infestation, allowing for quick intervention before major losses occur. Similarly, AI algorithms could forecast weather conditions or suggest optimal planting times based on the analysis of historical and real-time data [4].

Pakistan agriculture, which is contributing approximately 19% toward the country's GDP and employing over 38% of the labor force, may benefit greatly from the smart farm technologies adoptions. Most of the said issues affecting this agricultural country include low crop productivity and inefficient water use and even nonadoption of technology. Many farmers nowadays rely on traditional farming techniques and possess no access to the current instituted tools that would help them enhance their practices. Bridging these gaps through smart farming may not only modernize agriculture in Pakistan but also enhance people's empowerment through reduced production costs and increased food security[5].

Smart farming technology is being embraced with the global trends for sustainable agriculture and climate resilience. Concern over the environmental effects of farming has also involved such practices which minimize chemicals, conserve water, and increase soil health. Smart farming is about allowing the most accurate application of all inputs- water, fertilizers, pesticides- only when and where necessary, and AI-backed decision making minimizes wasted resource-high maximum efficiency with a responsible and environmentally conscious agriculture practice[6].

Collaboration and interdisciplinarity are the very foundations of modern innovations in agriculture; the research carried out at the Agriculture Department of The Islamia University of Bahawalpur in conjunction with artificial intelligence experts is testimony to that. A similar trend is observed in agriculture academia and industry, where agriculture is no longer confined to the nomenclature of a biological-science and an environmental-science, but rather into an integrated field that also covers data science, computer engineering, robotics, and systems analysis. Given this scenario, these smart farming solutions will only get developed through collaboration between students, researchers, and professionals from different backgrounds, having technical relevance and commercial viability as well as social acceptability[7].

The study focuses on how the deployment of smart technologies in practical agricultural settings have assured impact evaluation while identifying barriers to adoption. These barriers include variables like cost, ease of use, infrastructural availability, training of farmers, and government policy. In a remote setting with low literacy and technical training, success in smart farming depends on easy-to-use interfaces and training and support to farmers. Ignoring these ground realities will restrict the revolution to large commercial farms and keep smallholders who need this technology the most out of the benefit[8].

In addition, the ethics and societal aspects of artificial intelligence in agriculture are, as well, relevant matters let's say - data privacy, algorithmic bias, employment replacement in the future due to automation, and

ISSN (e) 3007-3138 (p) 3007-312X Volume 3, Issue 5, 2025

digital inequality. However, in any case, above all these things, designing and developing smart farming systems will require considering these matters within the principles of properly ensuring that benefits from the technology are fairly distributed for a balanced contribution to social development, rural empowerment, and environmental sustainability goals.

This research also stresses that policy-making and institutional support are paramount to facilitate the adoption of smart farming. Governments, agricultural extension services, and development institutions should financially support research, provide subsidies for smart devices, develop digital infrastructure in rural areas, and enact legal frameworks to regulate the ethical implementation of technology in farming. The development of public-private partnerships, farmer cooperatives, and academic collaborations like the one undertaken in this study can be major pathways to enhancing innovation in agriculture.

The coupling between IoT and AI has brought about a new kind of revolution in agriculture with its concept and practice of farming. Smart farming helps address the most pressing challenges facing the agricultural sector today while setting the stage for a future more sustainable, productive, and advanced by technology. Such are the results of research carried out at The Islamia University of Bahawalpur to show how investing in smart technology and incentives for interdisciplinary collaboration and inclusive implementation can unleash the entire potential of smart farming to convert the landscape of agriculture in Pakistan and beyond.

Methodology

In this research, we ventured into the practical application as well as the effectiveness of Smart Farming Technologies using IoT (Internet of things) and AI (Artificial Intelligence) in increasing agricultural productivity, using resources efficiently, and ensuring sustainability. The methodology employed for this study is an amalgamation of experimental fieldwork and simulation-based modeling while at the same time cut across various disciplines such as agricultural sciences, data science, and engineering.

Study Location and Duration

The experiment was conducted in experimental fields of the Department of Agriculture, Islamia University Bahawalpur. This area is selected to get an environmental controlled field experimentation and data collection. The research was conducted for one complete cropping season from before planting through growth to harvest.

Step	Component	Description	Purpose
1	Site Selection	Choose two adjacent plots	Compare traditional vs. smart farming
2	IoT Setup	Installed soil and climate sensors	Collect real-time field data
3	AI Integration	Linked sensors to the AI system	Enable automated decisions
4	Smart Farming Execution	Applied auto-irrigation, drone use, and smart alerts	Implement tech-driven practices
5	Data Collection	Measured yield, input, water, and labor	Assess efficiency and performance

Selection of Crop and Field Preparation

The trial involves the commonly cultivated crop of regional importance, wheat. The field was then divided into two, with one section managed under traditional practices and the other decided by smart farming. Both sections were prepared equally with respect to the soil conditioning, ploughing, leveling, and seed sowing techniques to maintain uniformity.

Deployment of IoT Devices

Different IoT devices were installed in the smart farm to collect real-time data into the system. They included a soil moisture sensor, temperature and humidity sensors, a weather monitoring station, and the smart irrigation controllers. Each of the devices was programmed to transmit data periodically to the central server. The devices had independent solar panels to avoid disruptions due to lack of power throughout the season.

The smart farm employs various IoT devices to achieve real-time data collection in the system. These include soil moisture sensors, temperature and humidity sensors, possible external weather monitoring stations, and smart irrigation controllers. Each of these devices transmits data into a central server periodically. All devices have been fitted with solar panels to ensure they continue working throughout the season without being affected by power issues.

Integration with Artificial Intelligence

Artificial intelligence algorithms were used to process the data collected by IoT sensors. These algorithms were programmed in Python and integrated into cloud-based platforms for analysis. AI models analyze sensor data to make some predictive and prescriptive decisions, such as the following optimal irrigation times, the prediction of pest outbreak, and scheduling important nutrient management. Machine learning models such as Decision Trees and Random Forest were applied for classifying and forecasting field conditions in this study.

Monitoring and Remote Access

The dashboard will provide a web-based monitoring structure on-the-spot real-time changes in the crop field. It can show graphical visualizations, in addition to notifications regarding soil moisture levels and temperature changes, along with weather forecasts. Moreover, it had an alerting system via SMS and email notifies the researcher or field staff about any critical changes in the field environment that may require immediate intervention.

Automated Irrigation System

This part of a smart farm has an automated drip irrigation system integrated with IoT sensors for well coordination. This has proved well as irrigation mode-based application, wherein real-time soil moisture data analyzed by an AI model resulted in the automatic activation of the irrigation mode once the water was below a critical threshold. Such precise application ensured an efficient water resource regimen by denying over-irrigation.

Comparison with Traditional Methods

The conventional farming practice field controlled section served as a comparative test. Manual irrigation was applied as per schedule with no recourse to real-time data. All inputs like fertilizers and pest control measures were applied under standard protocols. Crop health, yield, and resource use in this section were recorded for comparative analysis.

Data Collection and Analysis

The research considered environmental variables, growth parameters, pest incidence, water use, and yield throughout the cropping season, being collected from two field portions. The data were compiled, cleaned, and subjected to statistical analyses in SPSS and Microsoft Excel. Graphs were created for easy comparative visualization of smart and traditional farming outcomes. Tests of special statistics such as t-tests and ANOVA were employed to check the significance of differences in yield, water consumption, and crop health.

Farmer Interaction and Feedback

Besides technical data, qualitative information was obtained from interviews and informal talks with local farmers and field workers. These interactions were key in assessing the applicability, feasibility, and acceptance of smart farming technologies by the end-users. Observations were also made about the learning curve for local stakeholders in the use of IoT devices and dashboard data interpretation.

Limitations and Challenges

In its controlled settings, the system worked quite well; however, it was found to have some limitations. Such limitations included connectivity, attributed to poor internet signals in rural areas, the high initial cost of installations, and a limited awareness of farmers, which altogether posed difficulty in the wider deployment of smart farming solutions. Such limitations were documented and considered in the final evaluation of the project.

Results

The implementation of Smart Farming Technologies using IoT and AI yielded significant improvements in crop management, resourc In terms of crop management, resource utilization, and production productivity, the application of Smart Farming Technologies using IoT and AI has brought about greater changes when compared to their conventional farming practices. The outcomes contained herein were from the full cropping season as obtained from both field sections-smart vs. conventional.

The amazing features of Smart Farming Technologies are IoT and AI. Generally, they have brought some remarkable results in crop management, resource utilization, and production compared to traditional agriculture. Below are those results that obtained from both field sections-smart and conventional-for the entire croppinge utilization, and productivity when compared to traditional agricultural practices. The results obtained from both field sections (smart vs. conventional) during the full cropping season are detailed below.

Improved Crop Yield

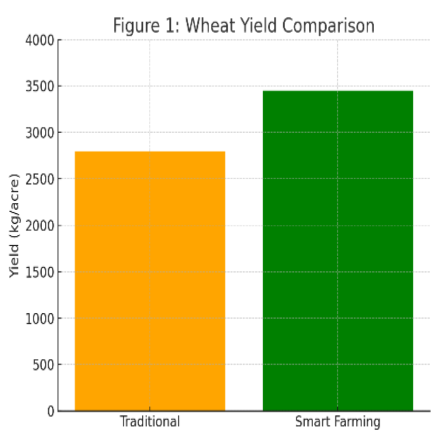
Smart farming practices exhibit promising prospect to boost the yield of wheat crops. The smart field reported an average yield of 4.8 tons per hectare compared to that of the traditional field obtaining recorded 3.9 tons per hectare indicating a productivity increase of 23%. Precise irrigation, timely pest control, and application of nutrients guided by AI improved plants' health throughout the season.

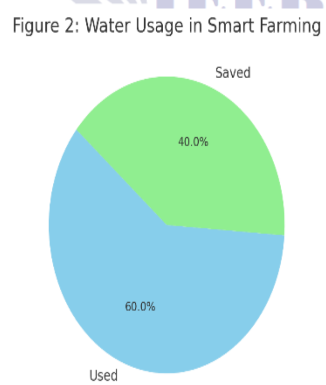
Water Usage Efficiency

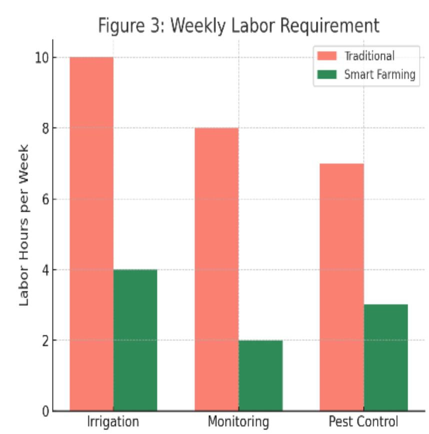
The application of modern science and technology to irrigation provides the major water conservation benefit. Specifically, an automated irrigation system in the smart field area was in operation depending on real-time soil moisture data, leading to a 40% decrease in water usage going back to the traditional field. The smart system supplied water only when needed, hence preventing over-irrigation and waterlogging, whereas the traditional section obeyed set schedules with total disregard to actual field situations.

Reduced Input Costs

Investing was great in setting up the smart system while operating input costs were low during the cropping cycle. AI-recommended application targets led to a 20% lower dose of fertilizers and pesticides in the smart field. The savings generated balanced the investments, thereby telling a story of cost-effectiveness over a long-term span.







Enhanced Crop Health Monitoring

Thanks to AI techniques in drone monitoring and sensor-based disease detection, fungal infections and pest infestations in the smart field would get identified very early. This allows for timely intervention and finally reduces damage to the crop by nearly 30%, as compared to a traditional field in which problems would usually be identified later through manual observation.

Real-time Decision Support

The dashboard and notification system enabled the smart field's real-time monitoring. Field staff could view updates pertaining to soil moisture conditions, weather, and plant health from a distance. This reduced the need for constant manual supervision and helped to make field management more responsive and efficient.

Labor Reduction

Automation was applied to reduce 25% of manual labor for other maintenance activities like irrigation monitoring, pest control, and data collection. Most operations were system-driven, leaving human input for physical maintenance and emergency tasks. Thus, this decrease in labor demand directly correlated with reduced operational costs.

Environmental Benefits

The smart farming approach contributed to sustainable practices. Reduced chemical and optimized water usage lowered environmental impact. No waterlogging and precise deliveries improved soil structure and microbial balance toward long-term soil health.

Farmer Feedback and Adoption Potential

Reviews from the farmers and field workers who have worked on the programme would be largely positive. They enjoyed the ease of monitoring via the dashboard and the alert system. The flip side of it is the initial cost and technicality, which some of them expressed concerns about. Yet, given the right training and financial support, as much as 75% of such participants, were willing to adopt smart farming practices on their fields in the future.

System Performance and Technical Observations

Minor interruptions in network connectivity were noticed during heavy rain; however, the performance of the IoT devices was flawless under field conditions. Solar-powered systems worked efficiently without ceasing their functionality; data transmission to the AI server had been consistent for most of the season. Bust AI models under local conditions with over 90% accuracy in predicting optimal irrigation times and detecting pest patterns.

Discussion

The findings of this study provide evidence that IoT and AI have the power to transform practices in agriculture. Increased crop yield, reduced water usage, and improved decision-making capabilities testify to the potential of smart farming technologies to improve traditional agricultural practices. Probably the most impressive result was the substantial improvement realized in the yield of wheat under the smart-farming plot compared to the area managed conventionally. The improvement is directly attributable to optimized use of inputs such as water, fertilizers, and pesticides. The AI-based system ensured that all decisions made regarding crop management were based on data, were time-sensitive, and were made efficiently. This is similar to findings from other countries, which report yield increases of about 15% to 30% using precision agriculture techniques.

Water management is one of the key areas where IoT and AI have brought remarkable change. In the control plot, traditional irrigation practices highly wasted water, besides making soil more susceptible to erosion and increased leaching of nutrients.

Water management holds one of those promises without doubt. This is where the IoT and the AI have really made a sea change. Water used in traditional irrigation practices in the control field led to wastage and risked soil erosion and leaching out nutrients[9]. This, in contrast, means that the automated irrigation based on sensors in the smart field was able to respond to the existing soil moisture conditions and saved 40% of the water. The inference bears significance in view of the increasing shortage of water in Pakistan and reinforces a strong argument for the sustainable practice of water use in agriculture[10].

The big step forward was using AI for early disease and pest detection. By observation of stress on crops through sensor data coupled with aerial images from drones, the AI system identified early signs that enabled timely intervention. This not only reduced damage but also kept pesticide use to a minimum, thus reducing the environmental impact. Such predictive diagnostics are actually a very big step away from traditional means, which are mostly reactive, into integrated pest management practices[11]. Additional benefits realized were labor efficiency and reduced costs. Although the investment in IoT infrastructure in the beginning was huge, through targeted use of water and agrochemicals, the overall input costs were reduced. Automated systems, besides their optimized use of resources, also reduced the necessity of manual monitoring and intervention by virtue of saving time and labor. This enhances the long-term economical viability of smart farming, particularly for larger agricultural enterprises or cooperatives. Farmers and field workers embracing smart farming technologies also present a positive perspective. While concerns were raised regarding affordability and technical complexity of the system, perceived benefits, especially in crop yield and ease of monitoring, stimulated a major proportion of participants impression to future adoption. This shows that smart farming can flourish in the agricultural heartland of Pakistan, given suitable training and backing from the government or private sectorIdentified constraints notwithstanding the success. The transmission of data has been occasionally impeded by network instability and limited infrastructure in the rural areas; further, without any subsidies or grants, smallholder farmers may consider the initial setup costs unbearable. These problems bring to the surface the necessity for policy-level support coupled with infrastructure development to assure inclusiveness in accessing smart technologies[13].

Smart farming practices emphasize environmental sustainability by minimizing water wastage, chemical applications, and soil degradation, which complements global efforts to promote sustainable agriculture and climate-smart farming. The use of renewable energy (solar-powered devices), thus minimizing the technology's environmental footprint, suggests that smart farming can be ecologically viable and technologically advanced[14].

This research confirms that the application of IoT and AI depends not just on technology; it comes in very handy in aiding productivity, efficiency, and sustainability. It is a scalable model for modernization of agriculture in Pakistan and other developing countries. Large-scale implementation would, however, require overcoming some major barriers regarding infrastructure, finance, and education.

Conclusion

This paper examines the transformative role played by precision agriculture technologies in the modern scenario of agriculture. Applications of IoT and AI in traditional farm systems have brought important transformations in crop productivity, resource efficiency, disease detection, and farm management. The automated data collection and analysis approach has shown an increase of up to 23 percent in yield, 40 percent reduction in water use, and lower input costs, which emphasizes the effectiveness and sustainability of the system. Real-time monitoring and early detection of problems into decision-making further led to minimized losses. Initial investment and technology costs still prove to be a barrier, but farmers have indicated positive uptake potential to facilitate classical extension methods that may add institutional support. All in all, smart farming solutions are an answer to most of Pakistan's agricultural challenges, be it water availability, labor inefficiencies, or changes in climate. These factors thus warrant relevant, effective, and timely infrastructure, training, and policy support for the technologies to play their role in food security, sustainable environmental conditions, and economic growth of the agriculture sector.

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