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ARTIFICIAL INTELLIGENCE IN INDIAN AGRICULTURE FOR A SUSTAINABLE FUTURE

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ABSTRACT

Indian agriculture remains a cornerstone of the national economy, contributing nearly 16 per cent to the Gross Domestic Product and providing livelihood support to about half of the country's workforce. However, the sector continues to face persistent structural challenges such as declining soil fertility, land degradation, groundwater depletion, low crop productivity, and increasing vulnerability to climate change. In this context, Artificial Intelligence (AI) has emerged as a transformative technology capable of addressing these challenges through precision agriculture, real-time soil and crop health monitoring, accurate weather forecasting, pest and disease detection, and efficient supply chain management. This study examines the role and impact of AI-driven technologies in promoting sustainable agriculture in India using secondary data from government reports, institutional studies, and published research. The findings reveal that AI-based interventions have resulted in yield improvements of 10–30 per cent, reductions in water and fertilizer use by 25–30 per cent, a decline in pest-related crop losses by 30–40 per cent, and significant improvements in market efficiency and post-harvest management. Case evidence from initiatives led by NITI Aayog, IBM, and ICRISAT highlights the potential of AI to enhance farmers' decision-making, climate resilience, and income levels. Despite these benefits, challenges such as high technology costs, limited digital literacy, inadequate rural connectivity, and data privacy concerns continue to restrict widespread adoption, particularly among small and marginal farmers. The study concludes that with appropriate policy support, digital infrastructure, and capacity-building initiatives, Artificial Intelligence can play a crucial role in achieving sustainable agricultural development, improving farmers' incomes, and ensuring long-term food security in India.

Keywords: Artificial Intelligence, Indian Agriculture, Agronomy, Precision Farming, Sustainability, Climate Resilience, Digital Agriculture

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INTRODUCTION

Agronomy is the branch of agricultural science dedicated to examining crops and the soils they inhabit to enhance agricultural productivity sustainably and with ecological responsibility. It integrates principles from biology, chemistry, ecology, soil science, and climate science to develop effective crop management strategies. Soil fertility management, crop rotation, irrigation strategies, weed and pest management, nutrient supervision, and conservation practices are merely some of the numerous tasks included in the expansive field of agronomy. Agronomists help farmers optimize resource utilization, enhance crop production, maintain soil quality, and adjust to changing climate factors by comprehending the interactions between plants, soil, water, and the environment. To aid in evidence-based decision-making, contemporary agronomy more frequently incorporates technological advancements such as data analytics, remote sensing, and precision agriculture. Taking everything into account, agronomy is crucial for securing food.

Agriculture in India represents 16% of the national GDP and employs nearly half of the country's workforce, but it continues to face ongoing structural challenges such as land degradation, reduced soil fertility, groundwater depletion, and low crop productivity. The escalating unpredictability of climate conditions intensifies these vulnerabilities, highlighting the essential demand for sustainable and technology-based solutions. Artificial Intelligence (AI) has emerged as a game-changing force that can address these issues through precision agriculture, real-time monitoring of soil and crop health, accurate weather forecasting, identification of pests and diseases, and improvement of supply chain effectiveness. AI-driven solutions—such as Plantix, IBM–NITI Aayog's predictive tools, and ICRISAT's digital agriculture initiatives—have demonstrated significant improvements, exhibiting yield boosts of 10–30%, reduced resource waste, enhanced climate resilience, and better market access. However, challenges such as high technology costs, insufficient digital skills, connectivity problems, and data privacy concerns continue to hinder widespread adoption, especially among small farmers. The integration of AI in Indian agriculture presents considerable opportunities to enhance productivity, sustainability, and profitability, supporting national objectives like Doubling Farmers' Income and guaranteeing long-term food security

OBJECTIVES OF THE STUDY

1. To analyze the present condition and structural issues of Indian agriculture.
2. To evaluate the function and impact of Artificial Intelligence (AI) technologies.
3. Assess the effects of AI-driven interventions on agricultural output resource utilization.
4. To analyze the obstacles to AI implementation in Indian agriculture.
5. To evaluate AI's ability to assist national agricultural objectives.
6. To suggest approaches for expanding AI-based agricultural solutions.

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HYPOTHESES

1. Precision farming powered by AI lowers water and fertilizer consumption while boosting yield.
2. AI-powered pest and disease identification decreases crop losses by a minimum of 30%.
3. Weather forecasting powered by AI greatly improves the precision of farmers' decision-making.
4. Supply chain and price forecasting tools driven by AI enhance market efficiency and decrease post-harvest waste.
5. The uptake of AI in farming is hindered by significant technology expenses, insufficient digital skills, connectivity issues, and worries over data privacy.
6. Successful government programs (Digital India, AgriStack, Aspirational Districts) can boost.
7. AI integration and lead to better results for smallholder farmers.

RESEARCH METHODOLOGY

The present study adopts a descriptive and analytical research design to examine the role and impact of Artificial Intelligence (AI) in Indian agriculture for sustainable development. The study is based primarily on secondary data collected from credible sources such as government reports (NITI Aayog, ICAR), institutional publications (ICRISAT, IBM), scholarly journals, policy documents, and digital agriculture databases. The analysis employs descriptive statistics, comparative analysis, and content analysis to evaluate the effects of AI-driven interventions on agricultural productivity, resource utilization, climate resilience, pest and disease management, and supply chain efficiency. Hypotheses are examined through with-and-without AI comparisons**,** trend analysis, and interpretation of case studies and empirical evidence reported by national and international institutions. Tables and indicators related to yield, water use, fertilizer application, pest loss reduction, weather forecasting accuracy, and market efficiency are used to support the analysis. The methodology enables a comprehensive assessment of AI’s contribution to Indian agriculture while identifying structural challenges and policy implications for scaling AI-based solutions, particularly for small and marginal farmers.

DATA ANALYSIS AND INTERPRETATION

The analysis of data and interpretation as follow as:

Importance of AI in Agronomy

AI is transforming Indian agriculture by boosting productivity, lowering costs, and tackling issues such as erratic weather, pests, and ineffective supply chains.

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Factor	Influence of AI
Yield Optimization	AI enhances crop yields by 15-20% via precision agriculture.
Weather forecasting	AI-powered weather forecasting prediction models enhance accuracy by 85%.
Pest and disease control using	AI detection can lower crop losses by 30-40%.
Soil Health monitoring	AI-driven soil analysis for Soil Health monitoring enables farmers to reduce fertilizer usage by 25%.
Supply Chain efficiency	AI in Supply Chain efficiency can lower post-harvest losses by 20-25%.

Source: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)-2025

AI Applications in Agronomy

Precision Farming Using AI

Sensors powered by AI and Internet of Things (IoT) technologies track soil moisture, temperature, and the health of crops. Example: Agricultural technology firm Crop In offers real-time crop observation through AI, aiding more than 7 million farmers.

Table 2: Precision Farming Using AI

Parameter	Conventional Farming	AI-Enhanced Farming
Water Consumption	High (Unproductive)	30% Decrease
Pesticide Usage	Excessive	Reduced by 25%
Crop Yield	Moderate	15-20% Growth

NITI Aayog & IBM. (2025)

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AI for Predicting Weather

- AI models examine satellite images and historical data to forecast rainfall, droughts, and storms.
- Instance: IBM's Watson Decision Platform offers AI-powered weather predictions to farmers in India, enhancing precision by 85%.

Table 3: Advantages of AI-Based Weather Forecasting

Weather Event	Conventional Accuracy	AI-Enhanced Accuracy
Precipitation Forecast	60%	85%
Drought Prediction	50%	80%
Cyclone Alerts	70%	90%

Source: ICRISAT (2025)

AI in Pest and Disease Identification

- Applications utilizing AI examine plant images to identify diseases and pests at an early stage.
- ICRISAT's Kalagadi AI application has decreased pest-induced losses by 30% for farmers.

AI in Soil Health Assessment

- AI-driven soil testing kits evaluate pH levels, moisture, and nutrients, offering suggestions.
- Example: Fasal AI company assists farmers improving fertilizer application, cutting waste by 25%.

Table 3: AI Influence on Soil Wellness Management

Factor	Without AI	With AI
Fertilizer Usage	Elevated (Overuse)	25% Decrease
Crop Yield	Moderate	10-15% Increased
Water Retention	Low	30% Improved

Source: ICRISAT (2025)

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AI in Market Price Forecasting & Supply Chain

- AI examines market trends and forecasts crop prices, assisting farmers in selling at the optimal moment.
- AI-driven supply chain models decrease post-harvest losses by 20%.
- NITI Aayog's AI-driven pricing prediction tool assists farmers in obtaining equitable prices.

Table 4: Obstacles to AI Adoption in Indian Agriculture

Challenge	Effect	Potential Resolution
Expensive AI Technology	Small-scale farmers lack the resources for AI-driven tools	Government funding and affordable AI options
Insufficient Digital Skills	Farmers find it difficult to use AI-driven applications	Programs for training under Digital India
Internet Access Limited in Rural Areas	Tools Powered by AI Depend on Internet Connectivity	Growth of 5G and rural connectivity
Data Privacy Issues	AI tools gather farmers private information	Enhanced data protection regulations for farming

Source: Indian Council of Agricultural Research (ICAR)-2025

Prospects of AI in Agriculture in India

i. By 2025, AI in Indian agriculture is anticipated to boost productivity by 20%.
ii. The Indian government's AgriStack project will establish a nationwide AI-based agricultural database.
iii. Automation powered by AI (such as robotic farming) will further cut labor expenses and enhance productivity.

Role of ICRISAT Hyderabad for Sustainable Practices in Agriculture

The Cluster employs various cutting-edge tools and technologies to foster agricultural change and enable farming communities. We leverage digital solutions to boost productivity, improve resource management, and promote sustainable practices in agriculture. Utilize mobile apps and ICT platforms to provide timely and context-relevant information to farmers. These applications offer access to weather predictions, market values, crop management techniques, and diagnostics for

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pests and diseases. Through the use of mobile technologies, we empower farmers to make knowledgeable choices, boost productivity, and refine their overall farm management.

Reports from ICRISAT Hyderabad underscore the game-changing impact of AI in Indian farming, emphasizing the Plantix App for identifying pests and diseases, AI-based climate advice (iSAT) for small-scale farmers, and utilizing AI/IoT for instantaneous crop health assessments, which enhance yields by 10-30% and minimize losses, offering substantial advantages for millions of farmers, particularly in climate-sensitive semi-arid areas, through data-driven, localized recommendations and customized assistance. However, obstacles such as farmer trust and communication issues remain, as outlined in their digital agricultural strategies and collaborations with governmental organizations and technology companies.

Main Focus Areas of ICRISAT's AI Programs in India:

1. Digital Diagnosis (Plantix Application):

Utilizes AI to examine images of crop problems (insects, illnesses, nutrient shortages) in regional languages. Benefited more than 30 million farmers, providing immediate solutions and decreasing crop loss by 20-40%.

2. Agriculture Built for Climate Resilience:

iSAT (Intelligent Systems Advisory Tool): A platform utilizing AI/ML for tailored, highly localized weather and agricultural recommendations, aiding Monsoon Mission III. Assists smallholders in handling climate threats and strengthening resilience via practical insights.

3. Smart Agriculture & Internet of Things:

Integrates AI with IoT sensors (soil moisture, temperature, nutrients) for forecasting crop health. Facilitates prompt actions in irrigation, fertilization, and pest management, enhancing production.

4. Empowerment and Training of Farmers:

Remote training and digital tools (e.g., Plantix app) have greatly enhanced productivity for large groups of farmers. Concentrate on gender-sensitive guidance to support women farmers.

5. Collaborations & Expansion:

Works with government entities (SERP, Monsoon Mission), technology firms (Microsoft), and various organizations to expand solutions.

6. Impacts & Advantages Reported:

Enhanced Efficiency: Yield improvements ranging from 10-30% noted in trial initiatives.

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Economic Benefits: Digital soil mapping and precise nutrient recommendations aided over 5 million farmers, generating US$ 453 million in economic value.

Resilience: Improved climate risk management for over 10 million smallholder farmers.

7. Obstacles and Future Pathways:

Addressing farmers' trust concerns and overcoming literacy and language obstacles. Transitioning from disjointed solutions to cohesive, scalable platforms. Creating AI for various crops and agricultural systems throughout the Global South. Essentially, ICRISAT leads in incorporating AI/ML to develop intelligent, localized agricultural solutions that greatly enhance resilience and profitability for smallholder farmers in India facing climate challenges, as highlighted in their press releases and digital agricultural brochures.

8. Data analysis and Artificial Intelligence (AI):

Data analysis and AI are essential in digital farming. We utilize sophisticated analytical methods to handle and examine extensive amounts of agricultural data, encompassing weather information, soil details, and crop performance statistics. Utilizing machine learning algorithms and predictive modeling, we derive valuable insights that guide decision-making, enhance yield forecasts, and optimize resource distribution.

9. Precision Agriculture Technologies:

Precision agriculture technologies play a crucial role in improving farm management techniques and maximizing resource utilization. We employ technologies like GPS, drones, and sensors to gather accurate information on soil conditions, crop health, and nutrient levels. This information is subsequently combined with digital maps to generate comprehensive farm profiles. Through the use of precision agriculture methods, farmers can accurately apply resources, reduce waste, and enhance productivity.

10. Blockchain and Traceability Solutions:

We examine the application of blockchain technology and traceability solutions to improve transparency, trust, and efficiency within agricultural value chains. Through the use of traceability systems, we allow farmers to monitor their crops from the farm to the market, guaranteeing food safety and quality. Blockchain technology ensures secure transactions, minimizes intermediaries, and encourages fair and transparent trading methods.

11. Internet of Things (IoT) and Sensor Networks:

The Internet of Things (IoT) along with sensor networks is crucial for gathering real-time information regarding soil moisture, temperature, humidity, and the growth of crops. These

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technologies allow farmers to track field conditions from a distance and make decisions based on data. Through the incorporation of IoT devices and sensor networks, we offer farmers practical insights for effective irrigation, crop protection, and resource management.

12. Digital Platforms for Market Access:

We utilize digital platforms and e-commerce tools to link farmers with markets, purchasers, and participants in the value chain. These platforms assist in direct marketing, allow for price discovery, and offer market information to farmers. By utilizing digital market access tools, smallholder farmers can break through conventional market obstacles and broaden their business prospects.

13. Cloud Computing and Data Storage:

The infrastructure for cloud computing and data storage is crucial for managing and processing significant amounts of agricultural data. We leverage cloud-based systems to securely store, manage, and share agricultural data. Cloud computing facilitates scalable and economical data processing, allowing us to examine large datasets and produce actionable insights.

HYPOTHESIS-WISE ANALYSIS

Hypothesis 1

"Precision farming powered by AI lowers water and fertilizer consumption while boosting yield."

The hypothesis is strongly supported by the evidence presented in the study. AI-driven precision farming technologies such as IoT-enabled soil sensors, satellite imagery, and machine-learning-based decision systems have significantly optimized resource use. As shown in Table No. 2, AI-enhanced farming practices resulted in a 30% reduction in water consumption, a 25% decline in pesticide usage, and a 15–20% increase in crop yields compared to conventional farming methods. Furthermore, AI-based soil health monitoring reduced fertilizer overuse by approximately 25%, improving both productivity and environmental sustainability. These outcomes validate that AI precision farming effectively enhances yields while conserving critical inputs like water and fertilizers.

Hypothesis 2

"AI-powered pest and disease identification decreases crop losses by a minimum of 30%."

The findings from AI-enabled applications such as Plantix and ICRISAT's Kalagadi AI platform clearly support this hypothesis. These tools use deep learning and image recognition to identify pest infestations, nutrient deficiencies, and plant diseases at early stages. Empirical data indicate

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that AI-based pest and disease detection has reduced crop losses by 30–40%, particularly in climate-sensitive and rainfed regions. The ability to deliver instant recommendations in local languages further strengthens adoption and effectiveness among smallholder farmers.

Hypothesis 3

"Weather forecasting powered by AI greatly improves the precision of farmers' decision-making."

AI-driven weather forecasting models have substantially enhanced predictive accuracy, as evidenced in Table No. 3. AI-enhanced systems improved precipitation forecasting accuracy from 60% to 85%, drought prediction from 50% to 80%, and cyclone alerts from 70% to 90%. Platforms developed by IBM, NITI Aayog, and ICRISAT integrate satellite data, historical climate records, and real-time meteorological inputs, enabling farmers to make informed decisions regarding sowing, irrigation, and crop protection. This improved accuracy directly strengthens farmers' adaptive capacity to climate variability.

Hypothesis 4

"Supply chain and price forecasting tools driven by AI enhance market efficiency and decrease post-harvest waste."

The study findings strongly validate this hypothesis. AI-powered market intelligence and price forecasting tools help farmers identify optimal selling periods, reduce information asymmetry, and improve bargaining power. Evidence suggests that AI-driven supply chain models have reduced post-harvest losses by 20–25% by optimizing storage, logistics, and market linkages. Initiatives like AgriStack and AI-based pricing tools promoted by NITI Aayog further enhance transparency and efficiency across agricultural value chains.

Hypothesis 5

"The uptake of AI in farming is hindered by significant technology expenses, insufficient digital skills, connectivity issues, and worries over data privacy."

This hypothesis is strongly corroborated by the study. Table No. 4 highlights key barriers such as the high cost of AI technologies, limited digital literacy among farmers, inadequate rural internet connectivity, and data privacy concerns. These challenges disproportionately affect small and marginal farmers, limiting large-scale AI adoption despite proven benefits. The findings indicate that technological capability alone is insufficient without institutional support, affordable solutions, and regulatory safeguards.

Hypothesis 6

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"Successful government programs (Digital India, AgriStack, Aspirational Districts) can boost AI integration and lead to better results for smallholder farmers."

The hypothesis is validated by multiple government-led initiatives documented in the study. Programs such as Digital India have improved rural connectivity and digital literacy, while AgriStack aims to create a unified AI-enabled agricultural database. The Aspirational Districts Programme, in collaboration with IBM and NITI Aayog, has successfully implemented AI-based advisory systems in 10 districts, delivering real-time crop and weather guidance. These interventions have improved productivity, resilience, and access to markets for smallholder farmers.

All the formulated hypotheses are empirically supported by secondary data, case studies, and institutional evidence from NITI Aayog, ICRISAT, ICAR, and IBM. The hypothesis-wise analysis confirms that Artificial Intelligence is a powerful enabler of sustainable, efficient, and resilient agriculture in India, provided that structural and institutional barriers are adequately addressed.

FINDINGS OF THE STUDY

1. Agriculture Remains Central to India's Economy

Despite structural transformation in the Indian economy, agriculture and allied sectors continue to play a vital role by contributing nearly 16% to the national GDP and providing employment to about 49% of the workforce, underscoring its importance for food security and rural livelihoods.

2. Persistent Structural Challenges in Indian Agriculture

The study reveals that Indian agriculture continues to suffer from soil degradation, declining soil fertility, groundwater depletion, low crop productivity, and inefficient resource use. These challenges are further aggravated by climate variability and dependence on rainfall, particularly in rainfed regions.

3. Artificial Intelligence is Emerging as a Transformative Technology

AI has emerged as a powerful tool in addressing agricultural inefficiencies. AI-driven applications in agronomy, including precision farming, real-time monitoring, and predictive analytics, have significantly enhanced farm-level decision-making and productivity.

4. Improved Resource Efficiency Through Precision Agriculture

AI-enabled precision farming practices have resulted in 30% reduction in water usage, 25% reduction in pesticide and fertilizer application, and a 15–20% increase in crop yields, demonstrating improved sustainability and cost efficiency.

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5. Enhanced Soil Health Monitoring and Management

AI-based soil health assessment tools reduce the need for laboratory testing and enable timely interventions. The study finds that AI-driven soil analysis helps farmers lower fertilizer overuse by around 25% while improving soil moisture retention and crop productivity.

6. Effective Pest and Disease Detection

AI-powered image recognition tools such as Plantix and ICRISAT applications have significantly reduced crop losses caused by pests and diseases by 30–40%, improving farm income and yield stability.

7. High Accuracy in Weather Forecasting and Climate Adaptation

AI-driven weather forecasting models have improved prediction accuracy to 85–90%, enabling farmers to make informed decisions regarding sowing, irrigation, and crop protection, thereby enhancing resilience to climate variability.

8. Improved Supply Chain Efficiency and Market Access

AI-based price forecasting and supply chain management systems have reduced post-harvest losses by 20–25% and improved market efficiency by supporting better storage, logistics, and price discovery mechanisms.

9. Significant Impact of ICRISAT's AI Initiatives

ICRISAT's digital agriculture programs, including Plantix, iSAT, and IoT-based crop monitoring systems, have benefited millions of farmers, leading to 10–30% yield improvements, enhanced climate resilience, and substantial economic gains.

10. Adoption Barriers Persist Among Small and Marginal Farmers

The study identifies high technology costs, limited digital literacy, inadequate rural internet connectivity, and data privacy concerns as major obstacles restricting the widespread adoption of AI in agriculture.

11. Government Initiatives Support AI Integration

National initiatives such as Digital India, AgriStack, and the Aspirational Districts Programme play a crucial role in facilitating AI adoption by improving digital infrastructure, promoting capacity building, and encouraging data-driven agricultural practices.

12. AI Aligns with National Agricultural Objectives

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The study finds that AI-based interventions strongly support national goals such as Doubling Farmers' Income, sustainable resource management, and long-term food security, provided institutional and infrastructural challenges are adequately addressed.

CONCLUSION

The study concludes that Artificial Intelligence has emerged as a transformative and strategic tool for achieving sustainable agricultural development in India. Despite agriculture's continued importance to the national economy and employment, the sector remains constrained by structural challenges such as declining soil fertility, inefficient water use, low productivity, climate vulnerability, and weak supply chains. The findings clearly indicate that AI-driven interventions—particularly in precision farming, soil health monitoring, pest and disease detection, weather forecasting, and market intelligence—have significantly enhanced agricultural productivity, resource efficiency, and climate resilience. Evidence from institutional initiatives led by NITI Aayog, IBM, and ICRISAT demonstrates yield improvements ranging from 10–30%, reductions in water and input usage by 25–30%, lower post-harvest losses, and improved decision-making accuracy among farmers. However, the study also highlights critical barriers to large-scale adoption, including high technology costs, limited digital literacy, inadequate rural connectivity, and concerns over data privacy, which disproportionately affect small and marginal farmers. Government initiatives such as Digital India, AgriStack, and the Aspirational Districts Programme play a crucial role in addressing these constraints by strengthening digital infrastructure, capacity building, and institutional support. Overall, the integration of Artificial Intelligence in Indian agriculture holds immense potential to enhance farmers' income, promote sustainable resource management, and ensure long-term food security, provided that supportive policies, inclusive access, and farmer-centric digital solutions are effectively implemented.

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