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Artificial Intelligence at the Farm Gate: Transforming Agricultural Extension for a Resilient Future

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Agricultural extension is entering a new era in which Artificial Intelligence (AI), machine learning, remote sensing, drones, Internet of Things (IoT), mobile applications and generative AI are increasingly influencing how agricultural knowledge reaches farmers. Conventional extension has traditionally depended on personal interaction among farmers, extension personnel, scientists and institutions. Digital extension subsequently expanded this system through mobile phones, websites, videos, social media and online advisory services. AI now offers the possibility of moving from generalized information delivery towards personalized, predictive and context-specific farm advisories. AI can support crop disease and pest identification, weather-risk prediction, crop monitoring, irrigation scheduling, nutrient management, yield estimation, market intelligence and decision support. Recent literature highlights the potential of AI to strengthen farmer advisory systems and knowledge delivery, while generative AI can make complex technologies more accessible through conversational interfaces). However, AI should not replace agricultural extension professionals. Its greatest value lies in a human–AI–farmer partnership, in which AI provides speed, data processing and prediction, while extension professionals contribute scientific validation, local knowledge, trust and social understanding. The future of agricultural extension therefore depends on responsible, inclusive and farmer-centric AI supported by local languages, reliable data, digital literacy and appropriate institutional mechanisms. Properly integrated, AI can transform extension from a reactive information-delivery service into a predictive, participatory and climate-resilient knowledge system.

Keywords: Artificial Intelligence, Agricultural Extension, Digital Agriculture, Farmer Advisory, Climate Resilience.

Introduction

Agricultural extension has always performed a central function in agriculture: connecting farmers with knowledge, technologies, institutions and services. Traditional extension relied heavily on personal visits, demonstrations, farmer meetings, training programmes and direct interaction with agricultural experts. However, agricultural decision-making has become increasingly complex. Farmers face climate variability, erratic rainfall, pest and disease outbreaks, water scarcity, soil degradation, changing market conditions and increasing input costs. These challenges require timely and location-specific information rather than generalized recommendations. The development of Information and Communication Technologies (ICTs) has already transformed agricultural extension. Mobile phones, websites, videos, social media and digital advisory services have expanded the reach of

agricultural knowledge. Research in southern India has demonstrated that mobile-based agricultural advisories can improve farmers' recall, knowledge and adoption of recommended practices (Singh et al., 2023). India's agricultural extension system is therefore moving from traditional interpersonal communication toward increasingly digital and data-supported advisory systems. Paliwal and Kumari (2024) highlight the increasing role of mobile-based ICTs and multimedia agricultural advisory services in transforming Indian agricultural extension. Artificial Intelligence represents the next major stage in this transformation. AI can process large volumes of data, identify patterns, generate predictions and support farm-level decision-making. Specifically identify AI's potential in farmer advisory systems, decision support and agricultural knowledge delivery. The question is therefore no longer whether AI will influence agricultural extension, but how AI can be integrated with agricultural science, extension expertise and farmer knowledge to create a more resilient agricultural system.

Evolution of Agricultural Extension:

Agricultural extension can broadly be viewed as evolving following three stages:
Traditional Extension → Digital Extension → AI-enabled Extension.

Traditional Extension

Farmer ↔ Extension Worker ↔ Scientist.

Digital Extension

Farmer ↔ Mobile/Internet/Apps/Videos ↔ Knowledge System.

AI-enabled Extension

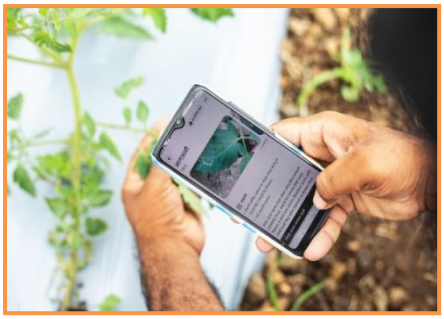
Farmer + Extension Professional ↔ AI + Data + Expert Knowledge ↔ Personalized Advisory**.**

Artificial Intelligence at the Farm Gate: From Information to Intelligence:

The most important contribution of AI to agricultural extension is its ability to convert complex information into usable farm-level intelligence. Imagine a farmer observing unusual spots on crop leaves. Instead of waiting for a field visit, the farmer could photograph the affected leaf with a smartphone. An AI-based image-recognition system could analyze the image and identify a probable disease or pest problem. AI-based crop monitoring and disease identification are rapidly developing areas of agricultural research. Barbedo (2025), in a comprehensive review of AI techniques for wheat crop monitoring and management, identifies machine learning and deep learning as promising technologies while also highlighting challenges related to data quality, model generalization and computational requirements.

AI-based Crop Disease/Pest Identification





AI-based crop disease and pest identification through smartphones image analysis the AI-enabled extension can potentially support to Crop disease and pest identification , Crop-stage monitoring weather-based advisories , soil and nutrient management , irrigation scheduling , yield prediction, market intelligence , early-warning systems government scheme information, farm management decision support. The significance of AI is therefore not merely that it provides information. Its real value is its capacity to convert information into decision support.

Artificial Intelligence, Drones and Remote Sensing for Precision Extension:

Agricultural extension has traditionally depended on field observations. AI combined with remote sensing and drones can provide a much wider view of crop conditions. Satellite imagery and drone-based sensors can provide information on crop vigour, vegetation stress, water availability and spatial variation within a field. AI algorithms can process these data and identify areas requiring attention.

Gupta and Pal (2025) highlight applications of AI in precision agriculture including crop monitoring, pest management, resource optimization, predictive analytics, irrigation and farm automation. Saha et al. (2025) similarly describe precision agriculture as a data-driven approach that uses sensing technologies, machine learning and remote sensing to improve crop management and yield prediction.

Drone + Remote Sensing + AI

AI-enabled drone and remote-sensing technologies for crop monitoring and precision agriculture.

The process can be represented as: Satellite/Drone → Image → AI Analysis → Crop Stress Detection → Expert Validation → Farmer

Advisory. This can help extension professionals identify priority farms and priority problems, making extension services more targeted.

Artificial Intelligence for Climate-Smart and Resilient Agriculture:

Climate variability is making agricultural decisions increasingly uncertain. An AI-enabled advisory system can potentially integrate weather forecasts, historical climate information, crop stage, soil conditions and farm location to support climate-sensitive decisions. For example, if rainfall is expected, the system could advise farmers to postpone irrigation. If weather conditions become favorable for a disease outbreak, farmers could receive an early warning. If extreme heat is expected, appropriate protective measures could be recommended. Saha et al. (2025) emphasize that precision agriculture combines data-driven technologies with field-level management to improve productivity while reducing costs and environmental impacts.

Artificial Intelligence at the Farm Gate: Integrating Multiple Data Sources

AI becomes particularly powerful when information from multiple sources is integrated.

Weather Data+Soil Data+Crop Data+Pest & Disease Data+Satellite/Drone Data+Market Information+Farmer Query.

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Artificial Intelligence & Data Analytics

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Personalized Farmer Advisory

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Farmer Decision → Farm Action → Feedback → Improved Advisory

This creates a continuous learning cycle in agricultural extension.

The Extension Professional in the Artificial Intelligence (AI) Era

A common concern is whether AI will replace agricultural extension workers. A more realistic scenario is that AI will change the role of extension professionals.

The extension professional of the future may become:

- AI-assisted agricultural advisor, Digital technology facilitator
- Knowledge validator, Farmer trainer
- Local-context interpreter
- Data-informed decision facilitator
- Link between scientific and indigenous knowledge
- Facilitator of farmer feedback

Future Agricultural Extension Model

AI- Data processing-Prediction-Diagnosis-Early warning-Personalization

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EXTENSION PROFESSIONAL- Validation-Interpretation-Training-Trust-Local adaptation

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FARMER

Experience-Local knowledge-Decision-making-Feedback-Farm action

Future Outlook

The agricultural extension system of the future may work through the following cycle:

Farmer Question

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Voice / Image / Text Input

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Artificial Intelligence (AI) + Agricultural Knowledge Base

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Weather + Soil + Crop + Satellite + Market Data

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Artificial Intelligence (AI) -generated Contextual Advisory

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Extension Expert Validation

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Farmer Action

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Feedback and Farm Data

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Continuous Learning

This model can transform extension from a periodic service into a continuous decision-support system. The objective should not be to create technology-heavy agriculture merely for technological advancement. The objective should be to make scientific knowledge accessible, timely, understandable, affordable and actionable.

Summary and Conclusion

Artificial Intelligence (AI) is transforming agricultural extension by making advisory services faster, more accurate, personalized, and accessible. It supports disease and pest diagnosis, crop monitoring, weather forecasting, irrigation and nutrient management, yield prediction, and market intelligence. When combined with technologies such as remote sensing, drones, Internet of Things (IoT), mobile applications, and generative AI, it strengthens decision-making for farmers. However, successful AI adoption depends on reliable data, digital infrastructure, local validation, digital literacy, and institutional support. Extension professionals remain essential for interpreting Artificial Intelligence (AI recommendations, building farmer trust, providing training, and adapting technologies to local conditions. Therefore, the future of agricultural extension should be based on the collaboration of

Artificial Intelligence (AI**, extension professionals, and farmers,** rather than AI replacing human expertise. By integrating Artificial Intelligence (AI) with scientific knowledge and farmers' practical experience, agricultural extension can become more efficient, climate-resilient, and sustainable, ultimately improving productivity, resource-use efficiency, and the livelihoods of farming communities.

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