

ARTIFICIAL INTELLIGENCE APPLICATIONS IN AGRICULTURE: TRANSFORMING FARMING FROM EXPERIENCE-BASED TO DATA-DRIVEN DECISION MAKING

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ABSTRACT

Agriculture is entering a technological era in which Artificial Intelligence (AI), Machine Learning (ML), IoT, remote sensing, drones, and robotics are transforming farm management. AI analyses data from weather stations, satellites, sensors, and crop records to support decisions on crop selection, irrigation, fertilization, pest management, disease detection, and yield forecasting. In India, these technologies offer opportunities for precision farming and climate-resilient agriculture. However, adoption requires reliable datasets, affordable technologies, connectivity, farmer training, data privacy, and locally validated models. AI should complement farmers' expertise through responsible, inclusive, and farmer-centred decision support.

KEYWORDS: Agricultural robotics, Artificial intelligence, Crop disease detection, Drones, IoT, Machine learning, Precision agriculture, Remote sensing, Smart farming, Yield prediction

INTRODUCTION

Agriculture is facing multiple challenges, including climate variability, declining natural resources, increasing production costs, labour shortages, emerging pests and diseases, and the growing demand for food. At the same time, farmers are expected to produce more food while using water, fertilizers, pesticides and energy more efficiently. These challenges have created a strong need for technologies capable of converting large amounts of agricultural data into practical decisions.

Artificial Intelligence provides an important opportunity in this context. AI refers to computer-based systems capable of learning from data, identifying patterns, making predictions and supporting decisions. In agriculture, AI can combine information from soil sensors, weather stations, satellite imagery, drones, machinery, market information and previous crop records. Recent reviews show that AI and deep learning

are increasingly being applied across crop monitoring, disease detection, yield prediction, resource management and livestock applications.

The concept is gradually shifting agriculture from reactive farming to predictive farming. Instead of waiting for a disease outbreak, water shortage or crop stress to become visible, AI systems can potentially identify risks at an early stage and recommend appropriate interventions.

MAJOR APPLICATIONS OF AI IN AGRICULTURE

1. *Crop and Yield Prediction:* One of the important applications of AI is predicting crop yield before harvesting. Machine learning models can analyse historical yield data together with rainfall, temperature, soil properties, satellite observations and crop-management information. Such predictions can assist farmers, government agencies, agricultural planners and agribusinesses in making decisions related to crop planning, storage and marketing. Recent research has specifically examined AI-based prediction of crop performance under drought and water-stress conditions, demonstrating the potential of models such as artificial neural networks and random forests for agricultural decision-making.
2. *Early Detection of Diseases and Pests:* Crop diseases can cause substantial yield and economic losses when they are not identified in time. AI-powered computer vision systems can analyse photographs captured by smartphones, drones or field cameras and identify visual symptoms of diseases. Deep learning models, particularly convolutional neural networks (CNNs), have become important tools for automated plant disease identification. Their advantages include rapid, non-destructive assessment and the possibility of real-time monitoring. The next generation of disease-monitoring systems is moving beyond simple image classification toward early warning systems that combine images, weather conditions, crop growth stages and environmental data.
3. *Precision Irrigation and Water Management:* Water is one of the most critical agricultural resources. AI can support irrigation scheduling by analysing soil moisture, weather forecasts, crop growth stage, evapotranspiration and historical irrigation records. Instead of applying the same amount of water throughout a field, AI-enabled systems can identify areas requiring more or less irrigation. Integration of AI with IoT sensors can enable automated irrigation systems that respond to changing field conditions. This approach can improve water-use efficiency and is particularly important in areas facing groundwater depletion, drought and irregular rainfall.
4. *Soil and Nutrient Management:* AI can also assist in assessing soil properties and recommending appropriate nutrient management. Soil test results, remote sensing data, crop history and weather information can be combined to estimate spatial variation in soil fertility. AI-based soil analysis has been investigated for improving data accuracy, reducing analytical costs and supporting large-scale agricultural decision-making. Such systems can contribute to site-specific nutrient management, where fertilizers are applied according to actual crop and soil requirements rather than using uniform application rates.
5. *Weed Detection and Smart Spraying:* Weeds compete with crops for water, nutrients, sunlight and space. Traditional weed management often involves blanket herbicide application, which can increase production costs and

environmental impacts. AI-powered cameras mounted on tractors, robots or drones can distinguish crops from weeds. The system can then guide mechanical removal or targeted spraying. This approach has the potential to reduce unnecessary pesticide application and improve input-use efficiency.

6. *Drones and Remote Sensing:* Drones and satellites generate valuable information about crop condition over large areas. AI algorithms can interpret these images to identify crop stress, nutrient deficiencies, water stress, pest infestation and changes in vegetation. The combination of remote sensing + AI + GIS is becoming an important component of modern precision agriculture. FAO has also highlighted the importance of integrating Earth Observation and AI for agricultural information and statistics.
7. *Agricultural Robots and Autonomous Machinery:* AI is increasingly being integrated into agricultural machinery. Autonomous tractors, robotic weeders, harvesting machines and intelligent spraying systems can perform repetitive operations with limited human intervention. Recent reporting from India has highlighted the use of AI-enabled autonomous tractors for operations such as planting, spraying and harvesting, illustrating the growing practical interest in agricultural automation. Robotics may become particularly valuable where agricultural labour is scarce or expensive.
8. *Livestock and Dairy Farming:* AI is not limited to crop production. In dairy and livestock systems, AI can support animal identification, behaviour monitoring, disease detection, heat detection, milk-yield prediction and feed management. Sensors and cameras can continuously monitor animals and alert farmers when abnormal behaviour or health indicators are detected. This can improve animal welfare and farm productivity.

AI AND CLIMATE-SMART AGRICULTURE

Climate change is making agricultural decision-making increasingly difficult because of unpredictable rainfall, heat waves, droughts, floods and changing pest populations. AI can analyse weather and crop data to identify potential climate-related risks. AI-based systems can support decisions such as when to sow, which crop or variety to select, when to irrigate and when to apply plant-protection measures. Consequently, AI can become an important component of climate-smart agriculture. However, AI predictions are only as reliable as the data used to develop them. Models trained in one geographical region may not perform equally well in another region because soil, climate, crop varieties and management practices differ.

CHALLENGES IN AI ADOPTION

Despite its considerable potential, several challenges must be addressed before AI can become widely accessible to farmers. First, agricultural data are often fragmented, incomplete or collected in different formats. Recent work focusing on India has highlighted challenges involving spatial and temporal integration of agricultural datasets and data governance. Second, many advanced AI systems require high-quality sensors, computing facilities and reliable internet connectivity. These requirements can make

adoption difficult for small and marginal farmers. Third, AI models need to be locally validated. A model developed using data from Europe or North America may not automatically provide reliable recommendations for Indian agricultural conditions. Other concerns include data ownership, privacy, cybersecurity, algorithmic bias, lack of technical skills and the difficulty of explaining complex AI recommendations to farmers. Low-cost Edge AI and TinyML technologies are emerging as promising solutions because some AI processing can be performed locally on low-power devices rather than relying completely on cloud connectivity.

THE FUTURE OF AI IN AGRICULTURE

The future is likely to involve greater integration of AI with IoT, drones, satellites, robotics, GIS, weather forecasting and agricultural machinery. Emerging technologies such as vision transformers, foundation models and multimodal AI are also being explored for agricultural applications. FAO's recent work on Digital Agriculture and AI emphasizes moving from problem identification and experimentation toward responsible deployment and scaling of digital agricultural innovations. For countries such as India, the greatest opportunity lies in developing affordable, multilingual, locally relevant and farmer-friendly AI solutions. Voice-based advisory systems could be particularly useful for farmers who have limited digital literacy. AI should complement agricultural extension workers and scientists rather than replace them.

CONCLUSION

Artificial Intelligence is emerging as a powerful technology for transforming agriculture into a more precise, efficient and climate-resilient sector. From crop disease detection and yield forecasting to irrigation management, smart spraying, soil analysis, livestock monitoring and autonomous machinery, AI can support farmers throughout the agricultural production cycle. Recent research indicates rapid progress in deep learning, computer vision, remote sensing, IoT integration and predictive agriculture. Nevertheless, technology alone cannot solve all agricultural problems. The success of AI will depend on the availability of reliable data, affordable equipment, rural connectivity, farmer training, transparent algorithms and strong institutional support. The most effective agricultural future will therefore be one in which AI intelligence and farmer experience work together. When developed responsibly and made accessible to small as well as large farmers, AI can contribute significantly to higher productivity, efficient resource use, reduced production risks and more sustainable food systems.

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How to cite:

Chinchorkar, S.S. (2026). Artificial intelligence applications in agriculture: transforming farming from experience-based to data-driven decision making. Leaves and Dew Publication, New Delhi 110059. *Agri Journal World* 6 (3): 51-55.

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