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Artificial Intelligence for Agricultural Extension: Augmenting Human Wisdom with Artificial Intelligence

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Indian agriculture is undergoing a period of profound change, shaped by persistent challenges and emerging opportunities. As a cornerstone of the nation's economy, the sector continues to employ nearly half of the population while ensuring food security and contributing to economic resilience. Despite advancements in technology, policy initiatives, and expanded market access, agriculture in India still grapples with issues such as erratic weather conditions, dwindling natural resources, volatile supply chains, and the growing necessity for sustainable farming practices. However, the increased integration of digital technologies, modern agricultural tools, and enhanced government support is gradually steering the sector toward a more sustainable, resilient, and economically robust future.

This transformation is further propelled by the global need to boost food production due to a rapidly growing population. According to the 2022 World Population Data Sheet, the world's population reached 8 billion in late 2022 and is expected to rise to 8.5 billion by 2030, 9.7 billion by 2050, and 10.4 billion by 2100. This surge places tremendous pressure on agricultural systems worldwide, necessitating a 60-70 percent increase in food production by 2050 (Silva, 2018). To meet this challenge, agriculture must adopt more intelligent, data-driven methods. Technologies such as precision farming, satellite imaging, and AI-driven solutions are becoming increasingly vital. In this landscape, agricultural extension systems play a pivotal role in guiding and supporting farmers through the digital transition, ensuring that innovation reaches the grassroots and contributes effectively to food security and rural development. In developing and emerging economies, traditional agricultural extension systems play a vital role in guiding farmers, yet their reach remains limited compared to the vast number of smallholder farms—estimated at over 570 million and cultivated by more than a billion individuals, accounting for over 28% of the global workforce.

Crop productivity is often hampered by pests, diseases, and nutrient deficiencies, leading to potential yield losses of up to 30%, highlighting the urgent need for accessible agricultural technologies and timely, accurate information on modern farming practices, including the appropriate use of fertilizers and pesticides. However, challenges such as remote farm locations and a severe shortage of extension personnel—illustrated by a high farmer-to-extension worker ratio of 1:2000 in parts of India—make it difficult to provide adequate support, especially to women farmers, who have even less access. Although various ICT-based tools have been introduced, many fail to deliver real-time, context-specific solutions to farmers' problems during the growing season. Thus, regardless of advances in agricultural research and innovation, their impact will remain limited unless effectively delivered to the grassroots. This reinforces the critical role of agricultural extension systems in bridging this gap, and with artificial intelligence acting as a catalyst, these systems can be transformed to empower rural communities, enabling them to make informed decisions and pursue sustainable development independently.

Key concept of artificial intelligence

Artificial intelligence (AI) refers to the concept and creation of computer systems designed to carry out tasks that typically require human intelligence. These tasks include things like speech recognition, decision-making, and pattern identification. AI is a broad field that includes several technologies such as machine learning, deep learning, and natural language processing (NLP). While the term "AI" is widely used to describe many modern technologies, there is ongoing debate about whether these systems truly represent artificial intelligence. Some experts believe that what we currently call AI is, in fact, advanced machine learning—a stepping stone toward achieving general artificial intelligence (GAI), which would be capable of human-like reasoning and adaptability. Despite these philosophical differences, the term AI in common usage today generally refers to machine learning-driven tools and systems—like ChatGPT or computer vision applications—that perform tasks once thought to be uniquely human. These include writing content, driving vehicles, and interpreting complex data.

AI in agriculture refers to the use of artificial intelligence technologies—such as machine learning, computer vision, robotics, and data analytics—to optimize and automate various farming processes, improve crop yields, and enhance sustainable farming practices. AI helps farmers make smarter decisions by analyzing large amounts of data from soil sensors, drones, satellite images, and weather forecasts. It enables precision farming by predicting pest infestations, optimizing irrigation, monitoring crop health, and automating tasks like planting and harvesting. This leads to increased efficiency, reduced costs, and minimized environmental impact.

The use of Artificial Intelligence in agricultural extension to provide services and support to farming communities

Agricultural extension services play a crucial role in bridging the gap between scientific research and field-level agricultural practices. Traditionally, these services have relied heavily on human extension agents to disseminate information, conduct training, and provide support to farmers. However, the increasing complexity of modern agriculture, combined with a growing demand for timely and personalized information, has led to the exploration of advanced technologies. Among these, Artificial Intelligence (AI) has emerged as a transformative tool in enhancing the reach, efficiency, and effectiveness of agricultural extension services. Artificial Intelligence (AI) refers to the simulation of human intelligence processes by machines, particularly computer systems. In the context of agricultural extension, AI systems can analyse large volumes of data from multiple sources such as satellite imagery, climate data, soil sensors, and market trends to offer customized and data-driven advisory services to farmers. This reduces dependency on human intermediaries and ensures timely, location-specific, and scalable solutions.

Applications of AI in Agricultural Extension

Artificial Intelligence (AI) is significantly transforming agricultural extension services by revolutionizing how information is shared, enhancing decision-making capabilities, and promoting the adoption of advanced farming practices. The following are some crucial aspects of AI's contribution to agricultural extension, along with a few additional insights:

1. AI-Powered Advisory Systems

AI-based advisory systems are transforming how farmers access real-time, personalized, and data-driven agricultural guidance. These systems bridge the gap between traditional extension services and modern digital solutions, ensuring farmers receive accurate, timely, and actionable advice. With help of Artificial Intelligence AI analyzes soil type, weather, crop variety, and pest/disease history to provide customized advice for each farm. Example: An AI tool recommends optimal sowing dates based on rainfall predictions and soil moisture levels. Instant & 24/7 Access to Expert Knowledge is possible through various services viz Chatbots (e.g., WhatsApp, SMS, voice-based AI) which answer farmer queries in local languages, reducing dependency on human extension agents. For Example, ANGRAU has developed

India's first SAU Chatbot-ANGRAU Chatbot a WhatsApp based Chatbot and was designed in Telugu to serve as a virtual one-stop solution for Andhra Pradesh farmers. The Chatbot was released on 2nd December, 2023 (+91 9494921873)

2. Precision Agriculture & Decision Support

AI technologies like drones, IoT sensors, and satellite imagery are used to monitor soil conditions and crop health in real time. This data helps farmers apply the right amount of water, fertilizers, and pesticides exactly where needed, reducing waste and improving yields. Additionally, AI-powered predictive analytics can forecast potential threats such as disease outbreaks, pest infestations, and expected crop yields. By analyzing patterns from historical and real-time data, these tools enable farmers to take early action, minimize losses, and make smarter planning decisions. Few of examples include- Krishi 24/7 by Wadhvani AI in Maharashtra and other cotton-growing areas, Microsoft & ICRISAT Collaboration- AI-powered sowing app provides optimal sowing dates and fertilizer recommendations. Crop In Technology Offers AI-driven farm management and monitoring solutions, Gramophone App Provides real-time, AI-based agronomic advice and input recommendations which is being used by Lakhs of farmers in Madhya Pradesh, Rajasthan, and other regions. Fasal Precision agriculture platform offering AI-based irrigation and disease alerts which is being by farmers of Maharashtra, Karnataka, Andhra Pradesh.

3. Automated Pest & Disease Detection

In India, AI-powered image recognition and early warning systems are helping farmers quickly detect and manage crop issues such as pests, diseases, and nutrient deficiencies. Here's a brief explanation along with real examples. There are two concepts how this automated pest and disease detection works viz., A. Image Recognition via Smartphone Apps: Farmers take a photo of the affected crop using a mobile app. The AI analyzes the image to identify the specific disease, pest, or deficiency. The app then recommends the appropriate treatment or management practice. B. AI-Based Early Warning Systems: These systems use weather data, satellite images, and historical records. They predict upcoming risks like pest outbreaks or disease spread. Farmers are alerted in advance to take preventive measures.

a) Plantix App

Function: Uses AI to identify plant diseases, pest damage, and nutrient deficiencies. Farmers upload crop images via the app, and it instantly provides diagnosis and treatment. Available in several Indian languages like Hindi, Telugu, and Marathi.

b) National Pest Surveillance & Pest Identification System (AI-Based Initiative in India): A Collaborative Initiative by Directorate of Plant Protection, Quarantine & Storage And ICAR-National Research Centre for Integrated Pest Management National Pest Surveillance System (NPSS), an Artificial Intelligence (AI)-based platform aimed at connecting farmers with agricultural scientists and experts to enhance pest control measures. The system utilises Artificial Intelligence (AI) to analyse real-time data on pest infestations, allowing for timely interventions. Farmers can easily communicate with experts by uploading images of affected crops or pests via their mobile phones, facilitating rapid diagnosis and treatment recommendations. By providing accurate pest management advice, NPSS aims to decrease the overuse of pesticides, thereby promoting sustainable agricultural practices. NPSS collaborates with state agricultural departments, Krishi Vigyan Kendras (KVKs), and local field officers to monitor pest activities. Farmers receive on-ground support for pest management strategies.

4. Smart Irrigation & Resource Management

Artificial Intelligence (AI) is revolutionizing smart irrigation and resource management in agriculture by enabling data-driven, precise water delivery systems. Through the integration of IoT sensors, satellite imagery, and weather forecasting models, AI analyses real-time soil moisture levels, crop water requirements, and environmental conditions to optimize irrigation schedules automatically. These intelligent systems can reduce water usage by 30-50% while improving crop yields by ensuring plants receive the exact amount of water they need at the

right time. AI-powered solutions like automated drip irrigation controllers and drone-based field monitoring help farmers make informed decisions, prevent both water wastage and crop stress, and adapt to changing climate patterns. Advanced systems even incorporate machine learning to predict future water needs based on historical data and weather trends. By combining precision agriculture technologies with AI analytics, farmers can achieve sustainable water management, lower operational costs, and enhance productivity while conserving precious water resources - a critical advantage in regions facing water scarcity. The continuous evolution of AI in irrigation promises smarter, more efficient farming practices that balance agricultural demands with environmental conservation.

5. Market Linkages & Price Prediction

Artificial Intelligence (AI) is transforming agricultural market linkages and price prediction in India by empowering farmers with real-time, data-driven insights to maximize profits. AI-powered platforms analyze vast datasets including historical price trends, weather patterns, transportation costs, and demand-supply dynamics across India's APMC markets to generate accurate price forecasts. These systems help farmers determine the optimal time and location to sell their produce, often through simple SMS or voice alerts in regional languages. Startups like Ninjacart and Crofarm leverage AI to directly connect farmers with retailers and processors, eliminating exploitative middlemen. The government's eNAM platform incorporates AI to provide pan-India price transparency, while private apps like AgriApp use machine learning to predict price fluctuations for specific commodities. AI-driven market intelligence not only prevents distress sales but also enables better crop planning by showing which crops will fetch higher prices in coming seasons. By democratizing access to market information, these technologies are helping India's smallholder farmers increase their income by 15-30% while reducing post-harvest losses through smarter selling decisions.

6. Training & Knowledge Dissemination

AI is transforming agricultural training through personalized, accessible digital solutions. Chatbots like Digital Green's deliver voice-based farming advice in local languages via WhatsApp, while VR systems like AgriVR simulate field conditions for practical training. Image recognition apps (PlantVillage Nuru) diagnose crop diseases through smartphone photos, serving as mobile extension tools. Predictive systems (Microsoft's Sowing App) send optimized planting alerts via SMS by analyzing weather patterns. These AI solutions overcome literacy barriers, provide real-time guidance, and adapt to regional needs, accelerating the adoption of modern farming techniques. China's Alibaba Cloud and India's KisanMitr demonstrate how AI-powered video tutorials and advisory services can scale expert knowledge to millions of farmers efficiently.

7. Livestock Monitoring & Management

AI is revolutionizing livestock management in India through smart monitoring solutions. Wearable devices like Stellapps' 'MoofIT' collars track cattle health metrics (rumination, activity) and milk quality in real-time, alerting farmers to illnesses early. Startups such as Animal use facial recognition technology to maintain digital health records and pedigree tracking for cattle. ICAR's Pashu Poshan app employs AI to optimize feed formulations based on animal breed and productivity data. These technologies help Indian dairy farmers improve breeding decisions, detect diseases promptly (like mastitis), and enhance milk yields while reducing operational costs. The NDDB's 'Information Network for Animal Productivity and Health' (INAPH) platform integrates such AI tools for nationwide livestock monitoring.

Key Challenges in Utilizing AI for Agricultural Extension in India

India faces multiple challenges in leveraging AI for agricultural extension, including low digital literacy among farmers, high costs of AI solutions, and poor rural connectivity, limiting access to real-time advisories. Language barriers and lack of localized content reduce AI tool adoption, while insufficient farm-level data affects predictive accuracy. Resistance to tech-driven farming and trust deficits in digital solutions further slow adoption. Additionally, last-mile implementation gaps, maintenance issues, and data privacy concerns hinder scalability. Without affordable infrastructure, training programs, and

inclusive AI models tailored for smallholders, the potential of AI in agri-extension remains underutilized despite promising innovations.

Suggestions to overcome key challenges

To overcome challenges in AI-driven agricultural extension, India must prioritize affordable, inclusive, and farmer-centric solutions. Subsidized AI tools (drones, sensors) and low-bandwidth platforms (SMS/IVR in regional languages) can enhance accessibility. Strengthening rural digital infrastructure (BharatNet, 5G coverage) is critical for real-time data flow. Public-private partnerships should curate hyperlocal datasets to improve AI accuracy while ensuring data privacy via blockchain or anonymization. Farmer training programs (through KVKs/FPOs) must demystify AI, and offline-capable apps can bypass connectivity gaps. Government schemes (e.g., Digital Agriculture Mission) should incentivize agri-startups to develop low-cost, vernacular AI solutions with last-mile support. A national AI-in-agri policy could standardize implementation, ensuring scalability without excluding smallholders.

Conclusion

Artificial Intelligence holds transformative potential for revolutionizing agricultural extension services in India by bridging critical gaps in knowledge dissemination, resource optimization, and market access. The integration of AI-powered advisories, precision farming tools, and real-time monitoring systems can empower farmers—especially smallholders—to make data-driven decisions, enhance productivity, and adopt sustainable practices. However, realizing this potential requires addressing key challenges such as digital literacy gaps, infrastructure limitations, and affordability concerns through collaborative efforts between policymakers, researchers, and the private sector. By prioritizing inclusive design (vernacular tools, offline access), targeted investments (subsidies, rural connectivity), and farmer-centric training, India can harness AI to build a resilient agricultural ecosystem. The success of early initiatives like ANGRAU's chatbot, NPSS, and eNAM demonstrates that scalable solutions are within reach. With strategic implementation, AI can democratize agricultural expertise, ensuring equitable growth and food security for India's farming communities in the decades ahead.