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Digital agriculture in India: A review of ICT interventions for sustainable farming

¹Sumesh Sharma, ²Pratima Rana, ³Samriti and ⁴Subhash Sharma

¹Student, Department of Social Sciences, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

²Assistant Professor, Directorate of Extension Education, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

³Assistant Professor, Department of Social Sciences, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

⁴Associate Professor, Department of Social Sciences, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

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Corresponding Author: Sumesh Sharma

Abstract

The study explores the role of Information and Communication Technologies (ICTs) in enhancing agricultural extension services in India. Agriculture remains the backbone of India's rural economy, and effective extension services are essential for improving farmers' productivity, skills, and knowledge. The paper traces the evolution of agricultural extension, starting from the Green Revolution and the establishment of institutions like ICAR, and examines the pivotal role of ICTs in modernizing farming practices. It highlights various ICT tools, such as smartphones, computers, radios, and the internet, which facilitate the exchange of agricultural information and innovations. The paper also discusses several government and private sector initiatives, including the Digital Agriculture Mission and Kisan Call Centres, which aim to empower farmers with real-time data and expert advice. Despite the progress, challenges such as limited digital literacy, infrastructure gaps, and content localization issues remain significant barriers. The paper further explores the future potential of emerging technologies like the Internet of Things (IoT), Artificial Intelligence (AI), and Drones in revolutionizing agricultural practices. It emphasizes the need for improved digital literacy, infrastructure development, and better integration of ICTs to ensure equitable access to agricultural knowledge, ultimately contributing to the sustainable development of India's agriculture sector.

Keywords: ICT, innovation and technological advancement

Introduction

India is purely a rural economy dominated by agriculture, which generates employment for 70 per cent of the country's workforce (Ministry of Statistics & Programme Implementation, 2023). Each nation established a formal agricultural development organization with the mission of advancing farming practices and extension services (Agyei and Stringer, 2021) ^[1]. Agriculture extension services are responsible for improving farmers' knowledge, abilities, skills and attitudes by adopting new technologies and sharing agricultural information that boosts farm productivity and promotes sustainable agriculture.

The extension originated in the mid-19th century, especially in European countries. France was the first country to establish state-funded extension services in 1879, but extension services had their origin after the establishment of the Hatch Act (1887), Morrill Act (1890) and Smith-Lever Act (1914) in the USA (Gwyn E. Jones and Chris Garforth, 1996) ^[7]. When there was the American agricultural revolution in rural America where 50 per cent of the population lived in rural areas and 30 per cent of the population relied on farming, this revolution was

responsible for increasing farm productivity and allowed farmers to produce more food. First-time extension services work began when the United States Development Agency (USDA) and Land Grant University collaborated for research and offered education in agriculture. The first test for United States Extension Services began during World War I when the country's wheat production was insufficient to meet wartime demands, and this was resolved when wheat production increased to 74 million acres in 1919, more than 20 million as of 1913. Also, during the Second World War, food production in the USA increased by 38 per cent till 1944 as compared to 1938 (United States Department of Agriculture, 2014) ^[15].

After the independence of India, when there was not enough food production from 1947 to 1965 Indian Government came up with some initiatives like the establishment of ICAR, DARE, and other organizations. To encourage farmers to produce more food, the Green Revolution was started in the 1960s in India, which acted as a driving force for Indian agriculture. After that, there was abundant production and supply of food between 1965 to 2000. During this period, many schemes, programs and initiatives

were started for the development of agriculture in India, such as the Community Development Programme (1952), National Extension Services (1953), Training and Visit Program (1974), High-yielding variety program, Drought Prone Area Programme, Integrated Rural Development Program, etc.

In the present context, the public and private sectors currently place the greatest emphasis on agricultural research, education, and extension to boost farmer productivity, knowledge and skills and promote sustainable agriculture in India. Agriculture extension services help researchers to address farmer's needs and create innovations by bridging the gap between them. Several organizations, including ICAR, KVK, SAUs, ATMA, NAMET, EEs, NGOs, NPOs, FPOs and various other private sectors are involved in the development of extension services in India. These organizations provide extension services to the agriculture sector to empower it by solving problems, increasing knowledge, skills, attitude and transfer of technology. Also, the main reason for the increased production of agricultural products is promoting technology in the agriculture sector which helps to increase the intelligence of farmers to operate farm activities such as extension of irrigation facilities, different types of land preparation machinery, use of high-quality seeds, different types of plant protection techniques, etc. The main reason behind the advancement of the agriculture sector in India was Information and Communication Technologies (ICTs) which came into use when Jute Corporation of India designed the Financial Accounting Information System in 1971 which covered seven states of India. Modern ICTs encompass hardware, software and networking technologies with the use of computers, radio, smartphones, etc. for exchanging information between farmers which leads to the dissemination of agriculture innovations, improvement in farmer's knowledge, skills and attitude which increases the participation of farmers in different trainings and helps the researcher to work on needs of the agriculture sector.

Why Information and Communication Technologies (ICTs)

Information and Communication technologies are important aspects of today's world as ICTs push globalization forward and increase digitalization in every sector or industry.

Sometimes ICT is also called Information Technology (IT), but there is a slight difference in both terms. Leavitt and Whisler (1958) ^[10] published their article in Harvard Business Review, where they stated that there is no single established name for the new technology, so they called it Information Technology (IT). IT is part of Information and Communication Technologies and comprises hardware, software, data storage, data governance, networking technologies, etc. whereas ICT includes a set of technological tools and resources that allow the user to create, store, share and exchange information that works together to facilitate the communication. In today's world ICT is responsible for the modernization of rural areas and improving the livelihood of rural communities. ICTs are responsible for exchanging information or knowledge with the target audience through networks, mobile devices, etc. Also, ICT is the acquisition, processing, storage and dissemination of information in the form of text, audio and picture by a microelectronic-based combination of computing and telecommunication (Karl, 1961) ^[9]. As the technological infrastructure of India has been developing for the last three decades the role of ICTs in the country's development increasing immensely.

Tools used in ICT-

Information and communication tools are categorized into two categories-

1. Traditional ICTs
2. Modern ICTs

Traditional ICTs

Very old ICTs are the technologies that were used before the introduction of modern ICT tools such as Books, posters, theatre, human interaction, radios, televisions, telephones, telegraphs, audio and films, etc. (Obayelu and Oyunlade, 2006) ^[13].

Modern ICTs

Modern ICT tools consist of computers, satellites, one-on-one connections, wireless phones (mobile), the internet, e-mail, the web, internet services, video conferences, global positioning systems (GPS), electronic cameras, databases, etc.

Different types of tools used in Extension Services	
ICT Tools	Purpose
Computer	Computers are used for the record-keeping of information related to production, transport, market, etc. It is also used for farmland assessment, automated farm equipment, farm software and access expert systems which increase the consistency and reliability of operation (Bajwa, 2020) ^[12] .
Telephones and Smartphones	Smartphones are the mass communication method that is used to share user-generated content such as audio, video, multimedia, etc. Smartphones and telephones are the best way to communicate information easily and effectively. Smartphones help the farmer to get real-time information regarding weather, market, transport and modern agriculture techniques and allow the farmers to share information and ask questions from extension agents.
Radio	Radio is the oldest and most popular information technology in the developing countries of the world due to its easy accessibility and affordability. Earlier it was a one-way communication tool but when new technologies are developed it becomes a good communication method for discussion, etc. In the agriculture sector farmers use radio to connect with specialists, policy makers, suppliers, weather-related information, etc. Generally, radio telecasts the program based on a demand-driven approach (Global Forum for Rural Advisory Services, GFRAS, 2024) ^[6] .
Internet	Internet is the technology that is used to improve the communication between research institutions, extension agents and farmers. The Internet is a key agent that helps a farmer to access and share information. Internet helps to expand knowledge resources, facilitate better information access, strengthen research-extension-client system linkage, ensure gender equity in the technology transfer process, etc.

Social media	Social media are digital communication comprising various tools that allow people to exchange information and interact with different people worldwide irrespective of the real-time location. Social media content contains text, video, calls, multimedia, etc. Some types of social media tools are YouTube, Facebook, WhatsApp, Instagram, telegram, etc. (Barau and Afrad, 2017) ^[3]
Video communication	Video communication is used to disseminate information to the farmers. In agriculture videos are generally used for raising awareness, farmer-to- farmer extension, training and agriculture information. Some of the video communication tools are Zoom meetings, Google Meet, etc.

Status of ICT in India

ICT and digital sector have contributed 13 per cent to India's Gross Domestic Product. National Association of Software and Services Companies (NASSCOM) reports that India's technology sector surpassed \$245 billion in 2023 with an annual growth rate of 8.4 per cent. Bengaluru, Hyderabad, Chennai, New Delhi, Mumbai, Pune and Gurugram are India's ICT hubs. The Indian telecommunications sector has 1.2 billion wireless and fixed-line subscribers and comes in second number in terms of subscribers. India's mobile economy is increasing day by day because of the extensive use of mobile phones. Currently, 98 per cent of the population uses telephones. According to Deloitte, Currently, India has 770 million smartphones and it is expected that the number will increase

to 1 billion by 2026. India likely aims to grow the ICT sector to \$ 1 trillion by 2025 (International Trade Administration, 2023).

Information and Communication Technologies initiatives in agriculture

In India, spreading agriculture knowledge is very difficult especially in rural or poor communities because of illiteracy. With the help of different ICTs, you can provide online education, training, demonstration of innovations, government schemes, etc (Rawat et. al. 2019) ^[14].

Information and Communication Technologies (ICT) initiatives for agriculture in India-

Initiatives	Role
Jio-Agri	Jio-Agri was launched in February 2020 by the Jio Foundation offering two cutting-edge services to the farmers i.e. Automatic weather stations (Jio Krishi IoT) and evapotranspiration -based sensor-less (Jio Krishi Pro) smart agriculture solutions. - Jio Krishi IoT smart farm facility is also known as an automatic weather station comprised of two types of devices which is based on IoT technology- - Jio-Kawach- Jio Kawach has 8 sensors (Tipping bucket rain gauge, temperature and humidity sensor, Solar Panel, Leaf temperature and wetness sensor, Data logger, TDR soil moisture and conductivity sensor.) which provide the facility to monitor both soil and weather. - Jio-Netra- Jio-Netra has 3 sensors (Solar panel, Data logger, and TDR soil moisture and conductivity sensor) which provide the facility to monitor soil health. - Jio Krishi Pro is based on evapotranspiration technology which helps the farmer by providing smart precision advisory on irrigation, pest, disease, weather and nutrition inputs along with efficient farm management (Jio Foundation, 2020).
Digital Agriculture Mission (DAM) 2021-2025	DAM was launched in 2021 by the Ministry of Agriculture with a key initiative of developing Digital Public Infrastructure (DPI) and the Digital General Crop Estimation Survey (DGCES) with an approved outlay of 2817 crores in 2024. DAM is built on two pillars- - Agri- Stack (Kisan Ki Pehchan)- Agri Stack comprises three key components: the Farmer's Registry, Geo-referenced Village Maps, and the Crop Sown Registry. It aims to create a digital identity for farmers by linking their information to state land records, demographic details, family data, and other relevant information. Additionally, the system will record crop sowing data through digital surveys conducted each season. The primary goal of Agri Stack is to establish 11 crore digital farmer identities by 2026-27, with all districts participating in the Digital Crop Survey by the financial year 2025-26. - Krishi Decision Support System (K-DSS)- K-DSS integrates remote sensing data on crops, soil, weather and water resources into a comprehensive geospatial system. - Additionally, Soil profile mapping is also included in DAM to enable farmer-centric digital services which helps farmers to get timely and reliable information related to soil. (MoAFW, 2021)
Kissan Call Centre (KCC)	Kissan Call Centre was introduced by the Government of India on 21st January 2004 to deliver extension services to the farming community. The Kisan Call Centre utilizes telecom infrastructure which is used by the farmers to ask customized questions from experts in their local language and calls are attended in Instant Voice Response System (IVRS) mode using the toll-free number 1800-180-1551.(GoI, 2004)
Bhu-Parikshak	Bhu-Parikshak was launched by IIT Kanpur on 26th May 2022. It was the first device of its kind which is based on near-infrared spectroscopy technology and capable of detecting different soil health parameters like nitrogen, organic carbon, cation exchange, clay, potassium, phosphorus) through optical sensors in just 90 seconds through a mobile application. Also, it provides nutrient demand analysis and recommendations based on the soil test. (IIT Kanpur, 2022)
Agriculture Infrastructure Fund	The Agriculture Infrastructure Fund Portal was launched by the Government of India in 2020 with an announcement of Rs 1lakh crore AIF under the Atmanirbhar Bharat Package.

Portal	The main aim of the AIF portal is to improve post-harvesting infrastructure such as supply chain services, e-marketing platforms, warehouses, pack houses, cold chain, logistic facilities, etc. by giving loans up to two crores in collaboration with 24 commercial banks, forty cooperative banks, NABARD, etc. The fund benefits farmers, Farmer's groups (FPOs, SHGs, etc.), Agri entrepreneurs, large businessmen (FMCG players, exporters, equipment manufacturers, etc), and State agencies (APMCs, CSWC, etc). (GoI, 2020)
Kissan e- Mitra Chatbot	Kisan e-Mitra is an artificial intelligence-based chatbot which is developed by the government of India in collaboration with ITCMAARS and Microsoft in 2023. Kisan e-Mitra helps the farmers by solving their queries through technological intervention which offers real-time assistance and enhances overall user experience. This app was initially launched in five languages i.e. Hindi, English, Odiya, Tamil and Bangla so that barriers based on language can be overcome. (MoAFW, 2023)
Krishi Nivesh Portal	Krishi Nivesh Portal was launched in 2024 by the Ministry of Agriculture and Farmers Welfare with a vision of modernizing agriculture through technological advancement and innovation practices. The main aim of the portal is to revolutionize the agricultural investment ecosystem in India. It provides information about the wide range of government schemes and incentives that give the best opportunities for farmers, domestic and international investors to contribute to India's agricultural growth. Also, it provides special provisions and training programs to empower women in agriculture. (MoAFW, 2024)
Digital green	Digital Green is a global development organization that was introduced in 2008 to help small-scale farmers.(Digital Green, 2008) Digital green makes farmers, government agencies and private sector organizations their partners to create sustainable solutions for the problems of the farming community by making participatory videos and mediated instructions. At present Digital Green works in five countries.
National Pest Surveillance System (NPSS)	NPSS is a mobile application and web portal that uses Artificial intelligence and machine learning which was initiated by the Ministry of Agriculture and Farmers Welfare of India in 2024. This system provides GIS-based pest information and collaborates with experts and various organizations to provide farmers information regarding pest identification, pest management advice, and timely advisories and stores data digitally to track pest trends on selected crops such as rice, cotton, maize, mango and chilies (MoAFW, 2024).
ITCMAARS	ITC launched its market-related ITCMAARS app in seven states with more than 200 Farmer Producer Organizations in 2022. Initially in this app, four value chains are covered i.e. wheat, paddy, soya and chili and it aims to increase it to 20 value chains with 4000 FPOs. It is based on Artificial intelligence which provides driven personalized and hyperlocal crop advisories to farmers, access to quality inputs and market linkages (ITC, 2022).
Kisan Sarathi	Kisan Sarathi is an Information and Communication Technology (ICT)-enabled interface introduced by the Indian Council of Agricultural Research (ICAR) on its 93rd Foundation Day in 2021. The platform, available in 13 regional languages, has been conceptualized to strengthen agricultural extension by integrating local needs with a national perspective. It offers seamless, multimedia, and multi-directional connectivity, thereby enabling farmers to access updated agricultural technologies, expert knowledge, and advisory services from a wide pool of subject matter specialists. Presently, the portal has registered nearly 2.4 crore farmers and 746 institutions, covering around 3 lakh villages across India. In Himachal Pradesh alone, about 1.8 lakh farmers are actively registered on the platform, highlighting its significant outreach and utility (ICAR, 2021).
Plantix	Plantix is a mobile-based application developed by PEAT GmbH, Germany, and introduced in India in 2015. It uses artificial intelligence (AI) and image recognition to diagnose crop diseases, pests, and nutrient deficiencies from photographs uploaded by farmers. The app provides instant treatment recommendations, preventive measures, and advisory support, along with access to a digital community of experts and farmers. With over 20 million downloads globally and availability in multiple Indian languages, Plantix is widely adopted across states such as Andhra Pradesh, Maharashtra, and Madhya Pradesh, supporting major crops like rice, wheat, cotton, and vegetables (PEAT, 2015).
Kisan Suvidha App	Kisan Suvidha App was launched by the Ministry of Agriculture and Farmers' Welfare, Government of India, in 2016 as part of the Digital India initiative. It is a multilingual mobile application designed to provide farmers with timely information on weather forecasts, market prices, input dealers, seed and fertilizer availability, pesticide use, and crop insurance. The app also offers advisories on integrated pest management, as well as information on soil health cards and government schemes. By consolidating multiple services into a single platform, Kisan Suvidha aims to strengthen decision-making and reduce information gaps among farmers across the country. The app has achieved over 1.06 million downloads since its launch (MoAFW, 2016).
Kisan Rath App	Kisan Rath App was introduced by the Ministry of Agriculture and Farmers' Welfare in collaboration with the National Informatics Centre (NIC) in April 2020 to facilitate agri-logistics, especially during the COVID-19 pandemic (Ministry of Agriculture & Farmers' Welfare, 2020). The app connects farmers and traders with transporters by providing a national-level marketplace for hiring vehicles and tractors to move produce from farms to mandis and warehouses. It integrates details of over 5 lakh trucks and 20,000 tractors, enabling seamless movement of perishable and non-perishable commodities(Drishti IAS, 2020) ^[16] . Within the first week of launch, over 150,000 farmers and traders had downloaded the app, and as of April 24, 2020, there were 80,474 farmers and 70,581 traders registered. By reducing intermediaries in transportation, Kisan Rath has improved market access, reduced post-harvest losses, and ensured better price realization for farmers.
Krishi Nivesh Portal	Krishi Nivesh Portal was launched by the Ministry of Agriculture and Farmers' Welfare, Government of India, in 2022 to promote investments and business opportunities in the agriculture sector. It acts as a one-stop platform connecting agribusiness companies, investors, startups, and farmers with government schemes, policies, and incentives. The portal provides information on sector-specific opportunities, project profiles, and guidelines for availing institutional support. By facilitating transparency and ease of doing business, Krishi Nivesh Portal aims to attract private investment, strengthen agri-infrastructure, and generate rural employment. (Ministry of Agriculture & Farmers Welfare, 2025, https://www.gktoday.in/question/which-ministry-launched-the-krishi-nivesh-portal)

Future trends of ICT in agriculture

Internet of Things (IoT)

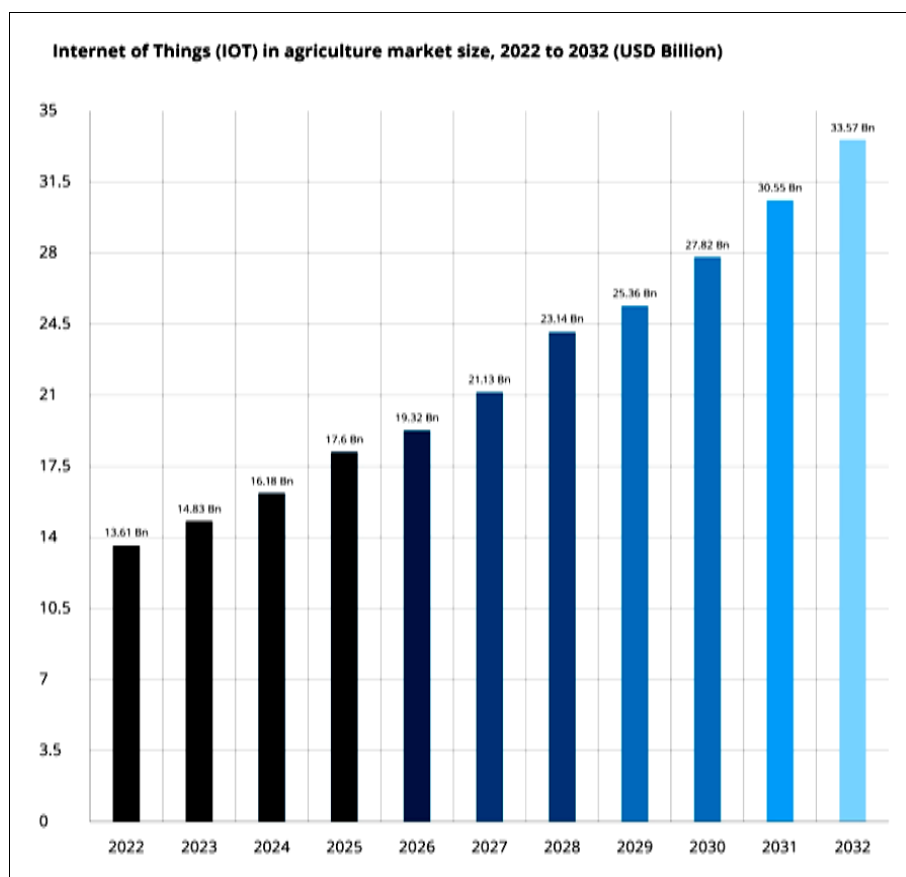
The Internet of Things (IoT) refers to a network of interconnected physical devices equipped with sensors, processors, and actuators that facilitate the collection, exchange, and analysis of data through the Internet as a shared platform (Miraz *et al.*, 2015) ^[12]. This technology enables real-time communication and interoperability among devices, thereby enhancing automation, efficiency, and precision across diverse sectors including smart cities, healthcare, logistics, and agriculture (Ray, 2017; Tzounis *et al.*, 2017) ^[29, 30].

Within the agricultural domain, IoT is revolutionizing farming practices by enabling data-driven decision-making and optimizing resource utilization. Key applications include automated irrigation systems that regulate water supply based on soil moisture; sensor-based soil and nutrient monitoring systems that provide real-time fertility status; and agricultural drones used for crop health assessment, spraying, and field mapping (Wolfert *et al.*, 2017) ^[32]. Furthermore, robotics and automation are being

employed for precision seeding, weeding, and harvesting, while smart greenhouse systems regulate climatic parameters such as temperature, humidity, and light to ensure optimal plant growth (Gebbers & Adamchuk, 2010) ^[26]. In livestock farming, IoT is applied through GPS-enabled tracking collars, wearable health monitoring sensors, and automated feeding systems (Kumar *et al.*, 2019) ^[28]. Data analytics integrated with IoT devices also support predictive modeling for pest and disease outbreaks, yield forecasting, and climate risk assessment, thereby reducing uncertainties in agricultural operations (Kamilaris *et al.*, 2017) ^[27].

The increasing adoption of IoT in agriculture is narrowing the gap between conventional farming practices and digital agriculture, thereby fostering sustainable food production, reducing resource wastage, and enhancing farmer income (United Nations, 2021).

The IoT market size in agriculture was \$13.61 billion in 2022 and it is expected that the market size of IoT can reach up to \$33.57 billion by 2032, with a CAGR of 9.5%.



Source- Mordor Intelligence

Artificial Intelligence (AI)

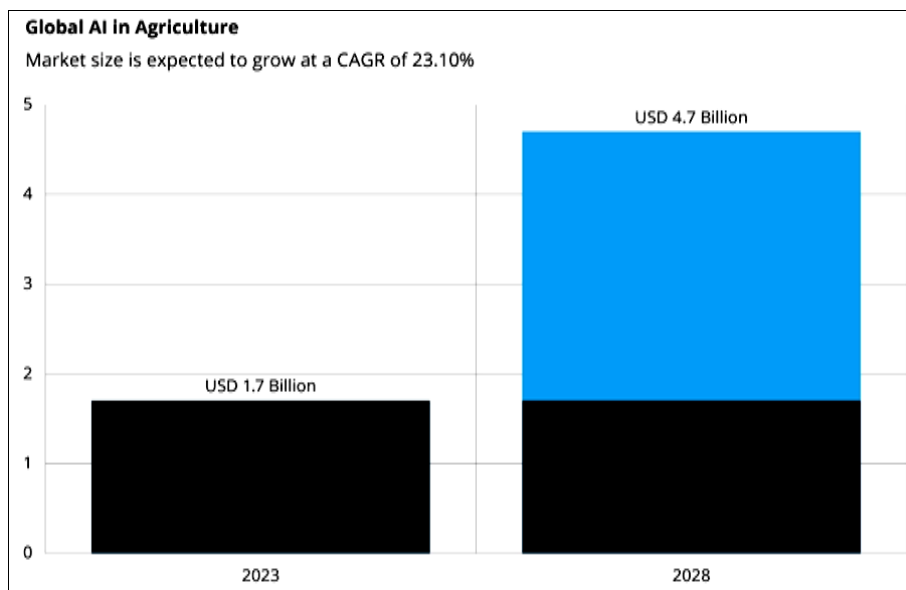
Artificial Intelligence (AI) refers to advanced computer systems that replicate human intelligence by learning from data, recognizing patterns, solving problems, reasoning, and understanding language (Russell & Norvig, 2021) ^[36]. AI technologies are enabled through methods such as machine learning, computer vision, robotics, and natural language processing (Goodfellow *et al.*, 2016) ^[33]. Common examples include digital voice assistants like Google Assistant, autonomous vehicles such as Tesla, and image recognition

platforms (GeeksforGeeks, 2024) ^[5].

In agriculture, AI has emerged as a powerful tool to modernize farming practices and improve efficiency. It enables precision farming through predictive analytics for optimal input use, AI-based disease and pest detection using image recognition, and automated harvesting systems that reduce dependence on manual labor (Kamilaris & Prenafeta-Boldú, 2018) ^[34]. AI-driven drones and field sensors further support crop health monitoring, yield forecasting, and soil analysis (Liakos *et al.*, 2018) ^[35]. Moreover, AI facilitates

sustainable farming by promoting climate-smart decisions, resource optimization, and eco-friendly practices (Sharma *et al.*, 2020) ^[37]. These advancements not only enhance productivity but also strengthen food security and farmer incomes.

The market size of AI in agriculture reached US\$ 1.8 Billion in 2023. AI industry expected that the AI market will grow with a CAGR of 21.1 per cent between 2023-2032 and reach up to US\$ 10.1 billion.

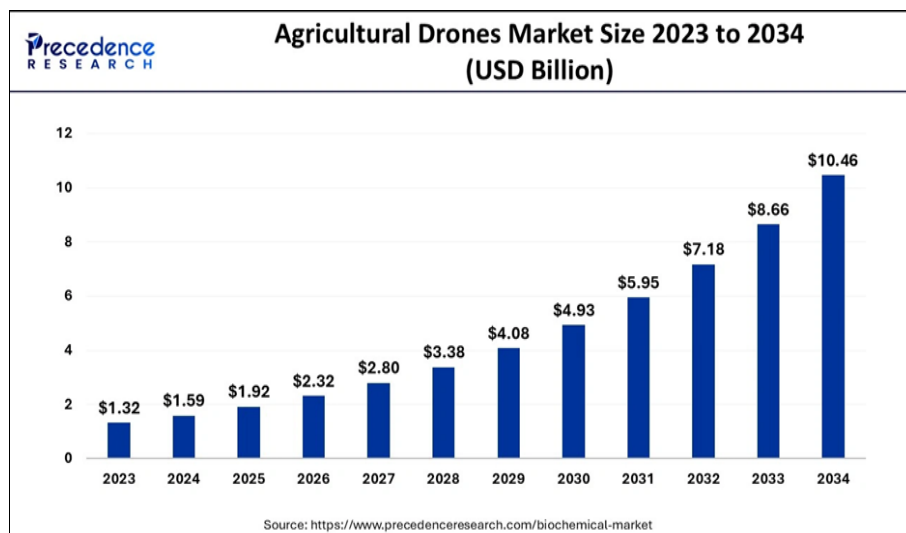


Source: Global Agriculture Market Report, 2024

Drone and Unmanned Aerial Vehicle Technology

Drones are also called unmanned aerial vehicles. Drones are flying robots that can be controlled through a remote or fly autonomously through controlled software with sensors and a Global Positioning System. In the agriculture sector drones are used for Crop spraying, crop monitoring, irrigation, seed pod planting, crop health assessment,

weather monitoring, etc. Some drones that are used in agriculture such as multi-rotor drones (China), DJI Agras MG-1 (Liquid pesticides, fertilizers and herbicides), etc. The drone market in agriculture was \$1.1 billion in 2022 and this industry is growing at a CAGR of 20.7 per cent and reaching \$7.19 billion.



Advanced Analytics

Advanced Analytics is a collection of data analytics techniques such as machine learning and modelling used by different organizations to improve their decision-making. This technique is used for both predictive and prescriptive analysis i.e. predict future outcomes and future course of action. Some of the techniques used in advanced analytics are predictive modeling, data mining, sentiment analysis, cluster analysis, cohort analysis, data visualization, etc.

Advanced analytics helps in different ways in the agriculture sector such as enhanced decision-making, precision farming integration, improved supply chain efficiency, yield prediction, field analytics, etc.

A report of Data bridge market research, Data analytics in the agriculture market size was US\$ 1.24 billion in 2022 and expected to grow at a CAGR of 15.60 per cent between 2023-2030 which increases the market size to US\$3.95 billion.

Opportunities for Information and Communication Technologies in Agriculture Extension Services

Human Resource Development: It is essential to create awareness among extension personnel and farmers regarding ICTs. It is only possible when human resource development is aligned with ICTs by equipping the necessary skills in extension workers such as capacity development through training, knowledge transfer, promoting decision-making, enhancing communication and collaboration, improving access to resources, promoting innovative ICT solutions, etc.

Integration of ICTs with the public-private extension system: The public-private extension system is the collaboration between government agencies and the private sector to improve extension services, provide information to the farmers and rural community. Collaboration of these different entities with ICTs helps to promote different changes in the agriculture sector such as improved service delivery by fastening response time and automating routine tasks, promoting data-driven decision-making, expanding outreach, cost-effective extension services, improving market linkages and value chain development.

Mobile-based Extension Services: Mobile-based extension services help to develop agriculture-based applications, SMS-based platforms, interactive voice responses, etc. This will allow the remote area farmers and farming community to easily access information regarding pest management, market prices, market linkages and crop rotation without internet on their mobile phones.

ICT-Enabled Farmer Field Schools: Farmer field schools allow the farmer to learn, experiment with farming practices in real conditions and make decisions based on their findings, integrating this with ICT tools can provide knowledge to the farmers through digital learning material, use virtual field visits and demonstrate best agricultural practices.

ICT-Driven digital training platforms: ICT-Driven digital learning platforms allow the training institutions to organize webinars, video tutorials and e-learning for the farmers so that farmers can learn about new technologies, sustainable farming practices, advanced techniques and develop knowledge management systems for farmers.

ICT for access to financial services and credit: Different financial institutions engaged in agricultural extension services can create mobile banking by integrating ICTs to provide farmers with affordable credit, subsidies, insurance and a digital payment system for farmers.

Challenges for ICT in agriculture extension services

Limited Digital Literacy: Digital literacy is important for the development of ICT in the agriculture sector because the effective use of ICTs is fully dependent on the individual's ability to understand and utilize these technologies. In rural and remote areas rate of digital literacy is not good because of some factors such as the digital divide, inability to use digital platforms, social and economic isolation, fear of adopting technology, cultural barriers and inadequate use of

available resources.

Limited Infrastructure: Infrastructure acts as a driving force for the adoption of ICTs. In India, ICT infrastructure is good in cities but in rural and remote areas it is inadequate in many ways such as unreliable internet services, high cost of connectivity, unstable electricity, lack of local expertise and mismatch of technology with local infrastructure. Geographical and topographical barriers.

Difficulty in Localization: Content needs to be aggregated from different sources but it needs local content for rapid adaptation. Localization of content is still not practiced and most of the farmers are illiterate in India because these farmers do not see the content that is not available in the local language. Localization of content is difficult because of several reasons such as complexity of translation, cultural sensitivity, network infrastructure, costs of localization, low adoption of ICT in poor regions, technical literacy, etc.

Conclusion

This study provides an all-inclusive aspect of how Information and Communication Technologies (ICTs) have significantly transformed the agricultural extension services in India, helping bridge the gap between farmers, researchers, and policy-makers. The integration of ICT tools such as computers, smartphones, radios, and the internet has revolutionized the way agricultural knowledge and innovations are disseminated, ultimately enhancing farm productivity, sustainability, and farmer empowerment. Various government initiatives, such as the Digital Agriculture Mission and Kisan Call Centres, alongside private sector contributions, have facilitated access to vital agricultural information and services. Despite these advancements, challenges persist, including limited digital literacy, inadequate infrastructure in rural areas, and the difficulty of localizing content to meet diverse needs. Addressing these barriers is crucial to maximizing the potential of ICTs in agricultural extension and ensuring that farmers, particularly in remote areas, fully benefit from technological advancements. The future of ICT in agriculture looks promising with emerging technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and drones, all of which offer significant opportunities to further modernize farming practices, improve decision-making, and enhance crop management. Moving forward, it is essential to focus on enhancing human resource development, improving ICT infrastructure, and promoting the digital literacy of farmers. The successful integration of ICTs into India's agricultural extension system will not only bolster the productivity and knowledge of farmers but also contribute to the sustainable development of agriculture, ensuring food security and improved livelihoods for rural communities.

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Author information

Authors and Affiliations

Sharma Sumesh

Department of Social Sciences, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, H.P., India.

Rana Pratima

Directorate of Extension Education, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, H.P., India.

Samriti

Department of Social Sciences, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, H.P., India.

Contributions

All the work of this review article combinely performed by all authors

Corresponding author

Correspondence to Sharma Sumesh

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