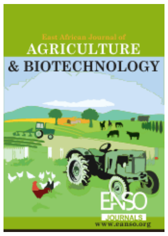

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Original Article

A Review of ICT Integration in Agricultural Extension Services. A Global Perspective

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ABSTRACT

The integration of Information and Communication Technologies (ICT) in agricultural extension services is transforming knowledge dissemination, addressing challenges of accessibility, efficiency, and inclusiveness. Traditional extension systems, constrained by resource limitations and outdated methods, struggle to meet modern agricultural demands. ICT tools such as mobile phones, internet-based platforms, Geographic Information Systems (GIS), drones, Artificial Intelligence (AI), and blockchain provide real-time, localised, and cost-effective solutions. This review examines the impact of ICT in enhancing agricultural extension services, highlighting initiatives like India's mKisan, Africa's e-Agriculture programs, and the global Digital Green initiative. These platforms have improved access to timely information on weather, pest management, and market trends, boosting productivity and resilience. However, several barriers hinder ICT adoption, including the digital divide, limited smartphone and internet access, unreliable electricity, and socioeconomic inequalities, particularly affecting women and marginalised groups. Low digital literacy, inadequate infrastructure, and weak policy support further constrain scalability. Addressing these challenges requires investments in rural connectivity, affordable technology, and capacity-building initiatives. Public-private partnerships, ICT funding, and participatory, farmer-centred approaches are crucial for long-term success. Future prospects include AI-driven predictive analytics, blockchain for transparent supply chains, and augmented/virtual reality for training.

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INTRODUCTION

Agricultural extension services have long served as a crucial link between agricultural research and practical implementation on farms, enhancing both productivity and farmer livelihoods (Jadhav et al., 2024). These services aim to educate farmers on innovative agricultural technologies, advanced farming techniques, and market opportunities. Historically led by public sector initiatives, extension systems have primarily relied on direct interactions, including field visits, demonstrations, and training programs. However, despite their importance, traditional agricultural extension systems encounter numerous challenges that limit their effectiveness.

Accessibility remains a significant challenge in agricultural extension services, with a single extension agent frequently tasked with supporting thousands of farmers, particularly in rural and remote regions (Byamukama et al., 2022). These systems are constrained by limited resources, including inadequate funding for infrastructure, training, and operational expenses (Travis et al., 2004). Outdated communication methods further compound the issue, as traditional approaches struggle to address the complex and rapidly changing demands of modern agriculture. Dependence on in-person meetings and printed materials is not only time-consuming and expensive but also ill-suited for addressing urgent issues such as pest infestations or climate variability, which demand prompt responses.

Low adoption rates of new technologies among farmers often stem from insufficient follow-up support and cultural resistance to change. Gender inequality exacerbates these issues, as women who make up nearly 43% of the agricultural workforce in developing nations frequently have less access to extension services than men (Benson and Ayiga 2022). These persistent challenges underscore the urgent need for innovative solutions, such as leveraging digital technologies, to enhance the efficiency, inclusivity, and adaptability of agricultural extension systems to better meet farmers' needs.

Importance of ICT in Extension Agricultural Systems

Information and Communication Technologies (ICT) have proven to be transformative in overcoming the limitations of conventional agricultural extension systems (Table 1). ICT encompasses a diverse range of digital tools and systems designed to create, process, store, and disseminate information. These include mobile phones, internet platforms, Geographic Information Systems (GIS), drones, and artificial intelligence (Bhat et al., 2024). These technologies are particularly impactful in agriculture, as they enable

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the swift dissemination of vital information to vast farmer populations, often in real-time.

Mobile-based platforms, for instance, offer advisory services through SMS notifications or mobile applications, providing updates on weather forecasts, pest control strategies, and market prices (Byamukama et al. 2023). India's mKisan initiative exemplifies this by reaching millions of farmers with tailored agricultural advice delivered via SMS in local languages (Turyasingura et al. 2023). Internet services and e-learning platforms have further simplified access to agricultural knowledge, allowing farmers to engage in virtual training sessions. Social media channels like WhatsApp and Facebook have also become valuable tools for farmer-to-farmer knowledge exchange and direct communication with extension agents.

Advanced technologies such as Artificial Intelligence (AI) and Big Data are paving the way for precision agriculture, offering predictive analytics for pest outbreaks, crop yields, and weather trends (Turyasingura et al. 2024). Meanwhile, drones and remote sensing technologies enable real-time field monitoring, helping farmers optimise resource use and boost productivity (Getahun et al., 2024). ICT's capacity to provide timely, affordable, and tailored solutions positions it as a pivotal innovation for modernising agricultural extension systems and addressing critical challenges such as climate change, market instability, and food insecurity.

Table 1: Impact of ICT on Revolutionising Agricultural Practices

Aspect of Agriculture	ICT Applications	Impact	Examples
Crop Management	Remote sensing, GIS, weather forecasting apps	Improved decision-making in sowing, irrigation, and pest Control	Smart Fertilizer Management Tools, Krishi Apps
Soil Management	Soil sensors, nutrient mapping, and fertility Analysis	Enhanced soil health monitoring, precision application of fertilisers	Soil Health Card Portal, Digital Soil Maps
Irrigation	IoT-based automated irrigation systems, mobile apps	Efficient water usage, reduced wastage, and optimised crop water Requirements	Drip-Irrigation Systems, mKRISHI Aqua
Market Access	e-NAM, digital marketing platforms, and mobile Applications	Improved access to the market information, price transparency, and reduced Exploitation	e-Choupal, AgriBazaar
Livestock Management	RFID, health tracking apps, and breeding data analytics	Enhanced productivity through health monitoring and better breeding practices	NDDB Dairy Dashboard, CattleTracs
Pest and Disease Control	AI-based pest identification tools, SMS-based Advisories	Reduced crop loss through timely detection and actionable guidance	Plantix App, Pest Prediction Models
Weather Forecasting	Weather apps, SMS alerts, and cloud Platforms	Minimising risks from extreme weather events and optimising field operations	AccuWeather for Farmers, Skymet Agriculture
Extension Services	Digital kiosks, m-learning platforms, video conferencing	Increased outreach and real-time knowledge Dissemination	Digital Green, eSagu

Aspect of	ICT Applications	Impact	Examples
Financial Services	Mobile banking, digital wallets, and credit platforms	Improved access to credit and insurance services for smallholder farmers	Kisan Credit Card, M-PESA in Kenya
Supply Chain Management	Blockchain, ERP systems, and tracking Tools	Enhanced traceability, reduced food loss, and streamlined logistics	AgriChain, AgriDigital
Farmer Education	Online courses, SMS-based learning, and video tutorials	Enhanced skill development and knowledge transfer	ICAR’s e-Learning Portal, YouTube Agri-Ed Videos

Source: *Bhat et al., 2024; Getahun et al., 2024; Olumola, 2015*

Objectives and Scope of the Review Article

This review article primarily seeks to examine how ICT tools and technologies are being integrated into agricultural extension services to enhance their efficiency, accessibility, and overall impact. The objective is to analyse the role of ICT in transforming the dissemination of agricultural knowledge, focusing on mobile platforms, internet-based services, and emerging technologies such as Artificial Intelligence (AI) and drones. By exploring global case studies and successful initiatives, the review will highlight best practices and key lessons from the adoption of ICT in agricultural extension. For example, projects like Digital Green, which uses participatory videos to train farmers in developing countries, showcase ICT's potential in reaching underserved communities (Olumola, 2015).

The article will also address the challenges faced in ICT integration, such as the digital divide, which limits rural farmers' access to digital tools, especially for women and marginalised groups. It will discuss infrastructure challenges, including inadequate internet connectivity and the lack of electricity in remote areas. The review will propose practical solutions to overcome these barriers, such as investing in rural digital infrastructure, offering capacity-building programs for both farmers and extension agents, and creating policies that encourage gender-inclusive ICT adoption.

Additionally, the review will explore emerging ICT trends, such as using blockchain for improving supply chain transparency and employing augmented reality for virtual farmer training. Through these discussions, the article aims to provide a thorough understanding of ICT's transformative potential in agricultural extension services, contributing to sustainable agricultural development and advancing food security objectives.

METHODOLOGY

The methodology employed in this review focused on a systematic collection and analysis of data from diverse sources to explore the integration of Information and Communication Technologies (ICT) in agricultural extension services. The following steps were undertaken:

Literature Selection and Data Sources

Relevant literature was identified through a comprehensive search of peer-reviewed journal articles, conference proceedings, reports from international organisations, and case studies. Search engines and academic databases such as Google Scholar, PubMed, Scopus, and Web of Science were utilised. Search keywords included "ICT in agriculture," "digital agriculture," "agricultural extension services," "mobile technology in farming," and "precision agriculture."

Inclusion criteria for the literature were:

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- Publications within the last two decades to ensure relevance to modern ICT developments.
- Studies focusing on ICT applications in agricultural extension services across different geographical regions.
- Documents addressing both the benefits and challenges of ICT integration.

Exclusion criteria included sources with insufficient methodological details or those unrelated to agriculture or extension services.

Data Extraction

Information from selected sources was systematically extracted, focusing on:

- Types of ICT tools and their applications (e.g., mobile platforms, AI, drones).
- Case studies illustrating successful ICT implementations.
- Challenges hindering ICT adoption in rural farming communities.
- Proposed solutions and policy recommendations.

Thematic Analysis

A thematic approach was employed to organise data under predefined categories:

- Tools and technologies used in ICT-based agricultural extension.
- Benefits such as improved access to information, cost reduction, and enhanced productivity.
- Barriers including the digital divide, infrastructure challenges, and literacy gaps.
- Policy and strategic recommendations.

The thematic analysis allowed for the identification of patterns, trends, and gaps in ICT application within the sector.

Comparative Analysis

Regional comparisons were conducted to assess differences in ICT adoption and effectiveness across developed and developing countries. This step highlighted disparities in access, usage, and outcomes of ICT tools, providing insights into context-specific challenges and successes.

Synthesis and Integration

Extracted data were synthesised to provide a comprehensive understanding of the role of ICT in agricultural extension services. Findings from different sources were integrated to identify common themes and to develop evidence-based conclusions.

Validation of Findings

To ensure the reliability of conclusions, data were cross-referenced across multiple sources. This triangulation process minimised the risk of bias and enhanced the validity of the findings.

RESULTS AND DISCUSSION

Conceptualising Agricultural Extension Services

Goals and Functions of Extension Systems

Agricultural extension services act as a crucial link between scientific research and its practical application in farming, primarily aiming to improve productivity, sustainability, and the well-being of farming communities (Bhat et al., 2024). These systems strive to equip farmers with the necessary knowledge, skills, and technologies to overcome agricultural challenges, while also promoting broader goals like food security, poverty reduction, and environmental conservation. One of their key functions is technology transfer, which involves spreading innovations backed by research, such as enhanced seeds, fertilisers, and mechanisation methods to farmers.

Extension services also offer essential advisory support, providing timely solutions for issues such as pest infestations, water shortages, or soil

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degradation. Another critical aspect is capacity building, where extension agents conduct training sessions, workshops, and farmer field schools to empower farmers with technical and managerial skills for better resource management and informed decision-making (Simpson & Owens, 2002). Extension systems frequently promote collective action by encouraging social learning and knowledge sharing among farmers. This approach helps farmers work together to address common challenges like water management, market access, or adapting to climate change. In this way, extension systems play a comprehensive role in boosting the resilience of farming communities and fostering sustainable agricultural development.

Stakeholders in the Agricultural Extension Process

The agricultural extension process is a collaborative effort that involves a wide range of stakeholders working together to enhance the delivery and impact of extension services. Farmers, including smallholders, commercial producers, and farmer organisations, are the primary recipients of these services, relying on them for knowledge, training, and advisory support. Extension agents serve as vital intermediaries between researchers and farmers, facilitating the dissemination of innovations and offering tailored guidance (Chowdhury et al., 2014).

Research institutions, such as universities and agricultural research centres, play a crucial role by generating the scientific advancements and technologies that extension agents bring to farmers. Governments are key players in the process, providing the policy frameworks, funding, and institutional backing necessary for the operation of extension services, often through agriculture ministries. NGOs contribute by implementing innovative approaches and extending services to remote or underserved areas. Similarly, the private sector, including agribusinesses and technology firms, is increasingly involved in providing ICT-driven solutions for agricultural advisory services. International organisations, such as the Food and Agriculture Organization (FAO) and the World Bank, also play a significant role by offering funding, technical support, and capacity-building initiatives to strengthen extension systems (Rondot & Collion, 2001). Community-based organisations (CBOs), including farmer cooperatives and self-help groups, are integral to mobilising farmers and encouraging participatory approaches. This collaborative, multi-stakeholder framework ensures that agricultural extension systems remain adaptive, inclusive, and responsive to the diverse and changing needs of farmers.

ICT and Its Potential in Agriculture

Types of ICT Tools: Mobile Phones, Internet, GIS, Drones, etc.

Information and Communication Technologies (ICT) encompass a wide range of digital tools that have transformed agriculture by facilitating the swift exchange of information and resources. Among these tools, mobile phones are the most extensively used, especially in developing nations, where they provide farmers with real-time updates on weather, pest outbreaks, and market prices via SMS services and mobile apps. Programs like m-Kisan in India and E-soko in Africa illustrate how mobile technology bridges the gap between farmers and extension services (Naika et al., 2021).

Internet-based platforms, including farmer-focused websites and e-learning portals, offer comprehensive resources on best practices, crop management, and training, giving farmers the flexibility to access information when needed. Geographic Information Systems (GIS) and remote sensing technologies facilitate spatial analysis of soil health, crop conditions, and water resources, supporting precision agriculture through data-driven insights. Drones have gained traction for tasks such as crop monitoring, pest identification, and irrigation management, providing high-resolution imagery to enhance resource efficiency.

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Social media platforms like WhatsApp, Facebook, and YouTube have emerged as powerful tools for knowledge sharing among farmers, enabling informal yet impactful communication and peer learning. Additionally, cutting-edge technologies like Artificial Intelligence (AI) and blockchain are reshaping the agricultural landscape. AI-driven systems deliver predictive insights on weather trends, pest infestations, and crop productivity, while blockchain enhances transparency and traceability within agricultural supply chains (al Bakri et al., n.d.). Together, these ICT tools create a digital ecosystem that empowers farmers with critical information, fosters stakeholder collaboration, and promotes the adoption of innovative practices, contributing to the modernisation of agriculture.

Benefits of ICT in Disseminating Agricultural Knowledge

ICT has significantly enhanced agricultural extension services by addressing the limitations of traditional methods and making knowledge dissemination more efficient and accessible. One of its primary advantages is the ability to deliver real-time information, which is vital for managing urgent issues such as pest outbreaks or extreme weather conditions. For instance, mobile platforms offering weather updates and pest management advice have been instrumental in supporting farmers in regions highly susceptible to climate variability, such as sub-Saharan Africa and South Asia (Caine et al., 2015).

Another key benefit of ICT is improved accessibility, as it reaches farmers in remote and underserved areas where conventional extension services are often unavailable. Mobile phones, which are used by over 70% of rural households in sub-Saharan Africa, have been particularly effective in democratizing access to agricultural information. ICT-based solutions are also highly cost-effective, as services like SMS alerts, mobile apps, and online platforms reduce the expenses associated with physical visits and field demonstrations. This allows service providers to reach a larger audience at a much lower cost.

ICT tools are especially valuable for delivering localised and customised advice tailored to a farmer’s specific needs, including crop type, geographical location, and available resources. Applications like Plantix, powered by artificial intelligence, provide farmers with personalised solutions for pest and disease control by analysing photos they upload. ICT also fosters peer-to-peer learning and collaboration, with social media platforms and online forums enabling farmers to exchange experiences, address challenges, and adopt best practices, thereby promoting community-driven agricultural development.

Moreover, advanced ICT tools like drones, remote sensing, and IoT devices allow for continuous monitoring of farming activities, generating data that can be used to assess the effectiveness of extension services and refine their delivery (Bhat et al., 2024). By making extension systems more inclusive, adaptable, and responsive to the evolving needs of farmers, ICT contributes significantly to sustainable agricultural development and food security.

ICT Tools and Technologies in Agricultural Extension

Mobile-Based ICT Solutions

1. Use of SMS and Mobile Apps for Advisory Services

Mobile phones have transformed agricultural extension services, especially in developing regions where traditional advisory systems often face significant limitations (Table 2). SMS (Short Message Service) and mobile applications are critical tools for delivering location-specific, timely information on weather forecasts, pest control, crop management, and market prices. These mobile-based solutions are not only cost-effective but also scalable, ensuring their accessibility to farmers in remote areas. For example, India’s m-Kisan initiative provides SMS-based advisory messages in

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local languages, offering customised guidance on crop care, pest management, and government schemes (Saravanan & Bhattacharjee, 2014). Similarly, E-soko in Africa empowers small-scale farmers with real-time market prices via SMS, enabling them to negotiate better deals and minimise exploitation by intermediaries.

Mobile apps extend these services by incorporating advanced features. For instance, Plantix, an AI-powered application, allows farmers to identify crop diseases by uploading images and receiving instant feedback. Other apps, like Kisan Suvidha in India and FARMS by the USDA, provide diverse resources, including weather forecasts, soil health insights, and access to machinery rentals. These tools effectively bridge the gap between traditional extension services and farmers, delivering practical and timely solutions.

Table 2: Mobile-based ICT Solutions in Agriculture

Aspect	**Mobile-Based ICT Solutions**	**Key Benefits**	**Examples**
Market Information	Market price apps, e-commerce platforms	Real-time access to price trends, enhanced bargaining power, and reduced Exploitation	Kisan Suvidha, eNAM Mobile App
Weather Updates	Weather forecast apps, SMS-based alerts	Minimised risks from weather uncertainties and optimised planning of agricultural Operations	Skymet Weather, IMD App
Advisory Services	Mobile advisory apps, SMS-based extension Services	Real-time expert advice on crop management, pest control, and fertilisers	mKRISHI, Digital Green
Pest and Disease Control	AI-integrated pest identification apps	Accurate diagnosis and timely intervention to reduce crop Losses	Plantix, Pestsense
Irrigation Management	IoT-enabled mobile apps for irrigation	Efficient water usage and scheduling of irrigation Operations	mKRISHI Aqua, Netafim Digital Farming
Soil Health Monitoring	Soil testing and mapping Apps	Enhanced understanding of Soil fertility and precision in fertilizer application	Soil Health Card App, FarmERP
Financial Inclusion	Mobile banking, loan, and insurance apps	Easy access to credit, insurance, and secure transactions for smallholder Farmers	PM Kisan App, Paytm for Agri
Livestock Management	Mobile apps for cattle health, breeding, and Tracking	Improved productivity, health management, and breeding Efficiency	NDDB Mobile App, Cattle Care App
Supply Chain Efficiency	Mobile-enabled tracking and logistics apps	Increased efficiency in logistics, traceability, and market linkages	AgriBazaar, DeHaat App
Skill Development	m-learning platforms, video tutorials, and WhatsApp groups	Access to training, educational materials, and peer-to-peer learning opportunities	ICAR e-Krishi Shiksha, YouTube Agri-Ed Videos

Source: *Saravanan & Bhattacharjee, 2014; KR et al., 2024*

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2. Success Stories from Developing and Developed Countries

Several case studies demonstrate the profound impact of mobile-based ICT solutions in agricultural extension. In Kenya, the iShamba platform delivers SMS and call-based agronomic advice, connecting farmers with input suppliers and reportedly increasing yields by 25% for over 200,000 farmers (KR et al., 2024). In Uganda, the CABI Pest Risk Information Service (PRISE) sends SMS alerts about pest outbreaks, reducing crop losses by up to 30%.

In developed nations, mobile-based solutions are equally impactful. For example, the USDA's Farm Service Agency (FSA) app provides U.S. farmers with real-time updates on disaster assistance programs, insurance options, and weather conditions. Similarly, AgriSync, a U.S.-based app, enables farmers to consult agronomists and extension agents through video calls, enhancing service delivery and decision-making efficiency (Chambyal, 2024). These examples highlight the global potential of mobile-based ICT tools in modernising agricultural extension services.

Internet-Based Platforms

1. E-Learning and Online Advisory Systems

The internet has transformed agricultural extension through e-learning platforms and online advisory systems, providing farmers with educational resources and expert advice on demand. For instance, e-Extension in the Philippines offers modules on topics like organic farming and pest management, while India's AgMOOCs, developed by IIT Kanpur, provides free courses on agronomy and climate-smart agriculture, enrolling thousands annually. Similarly, Kenya's Digital Green uses participatory videos to share best practices, achieving an 85% adoption rate of improved techniques (Mapiye et al., 2023). In the U.S., platforms like FarmLogs and Agriwebb offer farm analytics, enabling data-driven decision-making, with yield improvements of 20-30% among users.

2. Farmer Portals and Agricultural Websites

Farmer portals and agricultural websites function as centralised hubs of information, providing essential resources on crop production, livestock care, market trends, and government initiatives. For example, India's Farmer Connect Portal links farmers with input suppliers, buyers, and government advisory services, benefiting over 10 million users since its inception. Similarly, Australia's National Farmers' Portal equips users with tools for climate forecasting, water management, and pest monitoring, aiding farmers in adapting to climate variability.

Globally, platforms like FAO's e-Agriculture facilitate knowledge exchange and collaboration among agricultural stakeholders, promoting widespread access to valuable insights. By addressing information gaps, these platforms empower farmers to make well-informed decisions, improve productivity, and integrate more effectively into markets (Abdulquadri et al., 2024).

Emerging Technologies

1. Use of AI, Big Data, and IoT in Agriculture

Emerging technologies like AI**,** Big Data, and IoT enhance agricultural extension through predictive analytics, resource optimisation, and precision farming. Platforms like IBM's Watson Decision Platform analyse weather and soil data to offer actionable insights, while Big Data analytics aid policymakers in designing targeted interventions. IoT devices such as soil sensors and weather stations enable real-time monitoring of field conditions, boosting yield by up to 25%. For example, India's Krishi IoT integrates IoT devices with mobile apps, benefiting over 50,000 farmers (Liang & Shah, 2023).

2. Drones and Remote Sensing for Field Monitoring

Drones and remote sensing are essential for large-scale monitoring and resource management. Drones with multispectral cameras detect stress, pests, and

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nutrient deficiencies, while satellite imagery assesses vegetation health and crop yields. In sub-Saharan Africa, drones monitoring cassava farms have improved yields by 15-20% (Adetunji et al., 2023). U.S.-based Precision Hawk uses drones for aerial mapping, reducing input costs by $25 per acre. These tools enhance resource efficiency, lower labour costs, and boost productivity.

Role of Social Media and Communication Platforms

1. WhatsApp Groups, Facebook Forums, and YouTube Channels

Social media platforms enable real-time communication and knowledge sharing. WhatsApp groups like India's Digital Farmer Network connect over 1 million farmers for peer-to-peer advice. Facebook forums such as Farmers Helping Farmers and YouTube channels like Krishi Jagran provide tutorials on sustainable farming and market linkages. Visual content is particularly impactful, with higher adoption rates reported for video demonstrations (Devanand & Kamala, 2019).

2. Enhancing Peer-to-Peer Knowledge Sharing Among Farmers

Social media fosters collaborative learning, empowering farmers to share experiences and solutions. In Nigeria, WhatsApp groups promote organic farming, reducing input costs by 30% (David, 2020). These platforms also enable cross-border knowledge sharing and empower marginalised groups, such as women and youth, by providing them with equal access to information. Social media has thus made agricultural extension more inclusive, participatory, and farmer-centric.

Table 3: Role of Social Media and Communication Platforms in Agriculture

Aspect	Social Media/Platform	Key Benefits	Examples
Knowledge Sharing	Facebook groups, YouTube channels, WhatsApp	Enhanced exchange of farming practices, techniques, and innovations among farmers	"ICAR Agri Talk" on Facebook, YouTube Agri-Channels
Community Building	WhatsApp, Telegram, and Facebook groups	Strengthened farmer networks for collaborative problem-solving and information dissemination	Farmer WhatsApp Networks, Kisan Mitra Groups
Marketing and Branding	Instagram, Twitter, and Facebook Pages	Direct connection with consumers, promotion of organic and speciality products	Local Farm Pages on Instagram, Agri-Influencers
Advisory Services	Video conferencing apps, Telegram groups	Real-time expert consultations and updates on pest management, weather, and market trends	Digital Green Advisory on Telegram
Skill Development	YouTube tutorials, Facebook live sessions	Access to skill-building videos and interactive live training sessions	ICAR YouTube Tutorials, Online Agri-Webinars
Awareness	Twitter hashtags,	Dissemination of	#FarmersFirst

Aspect	Social Media/Platform	Key Benefits	Examples
Campaigns	Facebook awareness posts	information on sustainable practices, government schemes, and agricultural policies	Campaign, FAO's Facebook Page
Crisis Management	WhatsApp and Twitter for disaster alerts	Rapid dissemination of disaster alerts, weather warnings, and contingency measures	Cyclone Alerts via WhatsApp Groups
Crowdsourcing Solutions	Discussion forums, Q&A platforms (Quora)	Collective problem-solving and real-time answers to agricultural challenges	AgriStack Forums, Quora Agri-Community
Supply Chain Integration	LinkedIn, Facebook, and Instagram	Creating professional networks and improving B2B and B2C connectivity in agri-businesses	LinkedIn Agri-Groups, Facebook Marketplaces
Advocacy and Policy Dialogue	Twitter, LinkedIn, and Facebook campaigns	Amplifying farmer voices, policy advocacy, and engaging stakeholders for agricultural reforms	Twitter Trends like #AgriReform

Source: *Liang & Shah, 2023; Adetunji et al., 2023; Devanand & Kamala, 2019*

Case Studies and Best Practices

Global Successes in ICT Integration for Agricultural Extension

1. mKisan (India): Mobile-Driven Agricultural Advisory Services

The mKisan initiative in India, launched by the Ministry of Agriculture and Farmers' Welfare, stands out as a prime example of integrating ICT into agricultural extension. This platform uses mobile technologies such as SMS, voice messages, and apps in multiple regional languages to deliver essential agricultural information to farmers (KR et al., 2024). It provides updates on crop management, weather forecasts, pest and disease alerts, market prices, and government schemes. Farmers can also engage with agricultural experts through a help-desk, fostering two-way communication. By 2021, mKisan had reached over 50 million farmers, enhancing their access to critical information. The platform's strength lies in its ability to tailor messages based on specific crops, regions, and weather conditions. Studies show that farmers who used mKisan saw a 20-25% increase in productivity and income due to improved decision-making (Van Baardewijk, 2016). mKisan highlights how mobile technology can scale extension services, especially in rural populations.

2. E-Agriculture (Africa): ICT-Based Extension Initiatives

In Africa, ICT-driven platforms within the e-Agriculture framework have greatly enhanced agricultural extension services. Countries like Kenya, Ghana, and Uganda have integrated mobile technology, internet-based advisory services, and community ICT hubs to deliver agricultural information. For example, E-soko, a Ghana-based platform, uses mobile technology to provide

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farmers with real-time updates on market prices, weather forecasts, and crop management tips. Over 1.5 million farmers across Africa have benefited from E-soko, helping them secure better prices and adapt to changing climates. Another initiative, CABI's Pest Risk Information Service (PRISE), uses satellite data and weather models to forecast pest outbreaks and sends SMS alerts to farmers, reducing crop losses by up to 30% in regions like Kenya and Zambia (Day et al., 2024). These initiatives demonstrate the effective scalability of ICT solutions for addressing challenges such as market access and climate change in African agriculture.

3. Digital Green (Global): Community Video Sharing through ICT

Digital Green has revolutionised agricultural extension by using community-driven videos to spread farming best practices. In collaboration with local governments, NGOs, and farmers' organisations, Digital Green produces videos where local farmers showcase sustainable farming practices. These videos are screened in rural communities using portable projectors, and they are also accessible online or via mobile devices. Operating in countries such as India, Ethiopia, and Afghanistan, Digital Green has reached over 2.3 million farmers. Adoption rates for the practices demonstrated in these videos exceed 85% in some regions. A study in India found that farmers who used Digital Green videos had a 24% higher adoption rate of new technologies compared to those who received traditional extension services (Gandhi et al., 2007). The success of Digital Green underscores the significance of community involvement in ICT-based extension services, which has become a widely recognised best practice.

Advantages of ICT in Agricultural Extension

Enhanced Accessibility for Remote Farmers

The incorporation of ICT into agricultural extension has made it easier for farmers in remote and underserved regions to access critical information and advisory services. Traditional extension systems, where one agent serves a large number of farmers, often struggle with inadequate reach. Tools like mobile phones, SMS, and internet platforms bridge this gap. Mobile-based advisory services, such as m-Kisan in India and E-soko in Ghana, provide region-specific advice directly to farmers, regardless of their location. This has transformed access to services for smallholder farmers, who previously had limited interactions with extension officers. Research indicates that ICT services can reach up to 80% more farmers than traditional methods, especially in geographically isolated regions (Khan et al., 2024). CT devices, especially radios and phones, have increasingly become cheaper in the 21st century, given governments' investments in rural development and enhancement of satellite, internet, and frequency modulation (FM) waves and rural electrification, which makes personal ownership very easy (Byamukama et al., 2022).

Improving Decision-Making and Agricultural Productivity

By delivering timely and relevant information, ICT tools empower farmers to make better decisions regarding crop selection, pest management, irrigation, and input usage. Apps like Plantix, an AI-powered tool, offer real-time disease diagnostics, enabling farmers to take quick actions to prevent crop losses. Similarly, platforms like e-Choupal in India provide market price data, helping farmers negotiate better prices and decide when and where to sell their produce. Studies show that farmers who use ICT-based advisory services see a 15-30% increase in productivity due to improved resource management and risk mitigation (Ji-Ping et al., 2022).

Cost-Effective Extension Delivery

ICT tools have significantly lowered the costs associated with agricultural extension, reducing the need for in-person visits and printed materials.

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Solutions like SMS-based advisory services can reach thousands of farmers simultaneously, making the delivery of information much more affordable. ICT-driven platforms like FarmLogs also allow farmers to access advisory services at a fraction of the cost of traditional extension methods, which boosts the scalability and cost-effectiveness of these services.

Encouraging Peer-to-Peer Collaboration and Learning

Platforms such as WhatsApp, Facebook, and YouTube have become powerful tools for fostering knowledge exchange among farmers. Through WhatsApp groups, farmers can share experiences, discuss issues, and offer solutions, thus creating virtual communities that support collaborative learning (Nain et al., 2019). YouTube channels like Krishi Jagran in India showcase farmer testimonials and training videos, which are particularly helpful for visual learners. Khatri et al. (2024) have shown that farmers engaged in peer-to-peer learning through ICT platforms are 20% more likely to adopt new technologies compared to those relying solely on traditional methods.

Real-Time Access to Critical Information

A key benefit of ICT in agricultural extension is its ability to deliver real-time information, such as weather forecasts, pest outbreaks, and market trends. This enables farmers to make quick decisions in response to immediate challenges. The PRISE system in Africa, for instance, uses satellite data to predict pest outbreaks and sends SMS alerts to farmers, helping them reduce crop losses by up to 30%. Additionally, platforms like Climate FieldView provide weather-related advice, enabling farmers to adjust irrigation schedules and protect crops from extreme weather events. Real-time market information, also available through ICT platforms, allows farmers to secure fair prices and avoid exploitation by middlemen (Abdulquadri et al., 2024).

Challenges in ICT Adoption for Agricultural Extension

The Digital Divide and Access Challenges

1. Limited Access to ICT Resources in Rural Areas

Despite the widespread adoption of ICT tools, a significant digital divide remains, especially in rural areas of developing nations. Many smallholder farmers face challenges in accessing smartphones, computers, and reliable internet connections, preventing them from fully benefiting from ICT-based extension services. While mobile phone usage in sub-Saharan Africa has increased, only 28% of the rural population has access to smartphones capable of running advanced agricultural apps. This lack of access disproportionately affects poorer farmers who are unable to afford the necessary devices or the associated costs, such as internet subscriptions (Krell et al., 2021).

2. Gender and Socioeconomic Gaps in ICT Utilisation

Gender disparities in ICT access contribute to broader inequalities. Women, who make up nearly 43% of the agricultural workforce in developing nations, are 20-40% less likely than men to own mobile phones or have internet access (Rahman et al. 2023). Socioeconomic factors, such as low income and limited education, further restrict marginalised groups' ability to engage with and utilise ICT tools. These gaps hinder the inclusivity of ICT-based agricultural extension services, perpetuating existing disparities in agricultural development.

Infrastructure Challenges

1. Inadequate Internet Access in Rural Areas

Access to reliable internet is essential for many ICT tools, but rural areas often experience poor network coverage and slow internet speeds. The International Telecommunication Union (ITU) reports that fewer than 25% of rural regions in low-

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income countries have broadband access (James, 2020). This lack of connectivity limits the functionality of mobile apps, online platforms, and video-based advisory services, reducing their impact on rural farmers.

2. Absence of Technical Support and Maintenance

Even in areas where ICT tools are accessible, the lack of technical support and infrastructure maintenance poses a significant barrier. Farmers often struggle with troubleshooting technical problems or maintaining devices like smartphones and tablets. In regions where local ICT expertise is scarce, these challenges discourage the adoption of technology.

Gaps in Literacy and Skills

1. Digital Illiteracy among Farmers

Digital illiteracy remains a significant barrier to the adoption of ICT in agricultural extension. Many farmers, particularly older individuals, lack the necessary skills to operate mobile apps, internet platforms, and other digital tools. A study found that nearly 40% of farmers in sub-Saharan Africa struggle to use basic ICT services, such as SMS or smartphone applications (Mapiye et al., 2023). This lack of digital skills severely limits the reach and impact of ICT-based extension services.

2. Insufficient ICT Training for Extension Officers

Extension officers play a crucial role in bridging the gap between ICT platforms and farmers, but many lack the necessary training to effectively use and promote these tools. Nyarko and Kozári (2021) found that only 30% of extension officers in several countries have received formal ICT training. This skills gap undermines their ability to facilitate the adoption of ICT tools, thus reducing the overall effectiveness of these services.

Policy and Institutional Barriers

1. Weak ICT Integration Policies in Agriculture

In many countries, the integration of ICT into agricultural extension services is hindered by weak policy frameworks. Governments often lack clear, comprehensive strategies for promoting ICT adoption in agriculture, leading to fragmented efforts and limited coordination (Hanna, 2003). Regulatory barriers, such as high taxes on ICT devices and restrictive internet policies, further limit the accessibility and affordability of digital tools for farmers.

2. Lack of Funding and Investment for ICT Integration

Effective ICT-based extension systems require significant investment in infrastructure, technology, and capacity building. However, many governments and development organisations allocate inadequate resources to these initiatives. According to the FAO, less than 5% of agricultural budgets in low-income countries are dedicated to extension services, with an even smaller share allocated to ICT-related programs. This insufficient funding hampers the scalability and long-term sustainability of ICT solutions in agriculture (Qamar, 2003).

Policy Recommendations and Strategies

Bridging the Digital Divide

1. Promoting Accessible and Affordable ICT Tools

One of the most effective ways to bridge the digital divide in agriculture is to make ICT tools affordable and accessible to smallholder farmers. Governments and private sectors must collaborate to subsidise the costs of mobile phones, smartphones, and internet services for farmers in underserved regions. Initiatives like India's PM-WANI scheme (Prime Minister Wi-Fi Access Network Interface) aim to provide free or low-cost internet in rural areas, helping farmers utilise ICT tools effectively. Similarly, organisations like

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GSMA have developed low-cost feature phones with pre-installed agricultural apps for farmers in sub-Saharan Africa (Santer, 2013). Offering subsidies for ICT devices and services, along with creating region-specific applications, can enhance technology access among rural communities.

2. Improving Rural Infrastructure

Infrastructure development is critical for enabling ICT tools to function effectively in rural areas. Governments should invest in expanding internet connectivity, electricity access, and mobile network coverage in remote regions. For instance, Rwanda's National Broadband Policy has increased internet coverage to over 80% of its population (Oughton et al. 2022), thereby improving ICT adoption in agriculture. Infrastructure projects should prioritise renewable energy solutions, such as solar-powered ICT hubs, to address challenges in areas with unreliable electricity. Partnerships between governments and telecom companies can also help expand affordable broadband networks to rural farming communities.

Capacity-Building Programs

1. Enhancing Digital Literacy among Farmers and Extension Workers

Increasing digital literacy is essential for the successful adoption of ICT tools. Governments and NGOs should implement training programs that teach farmers how to use mobile apps, SMS services, and internet-based platforms for agricultural purposes. For example, Kenya's Eneza Education program offers mobile-based digital literacy training that covers topics like crop management and market access (Blimpo & Owusu, 2019). Additionally, extension officers require comprehensive ICT training to better assist farmers in using these tools. Liu et al. (2025) indicate that farmers who receive digital literacy training are 30% more likely to adopt ICT solutions than those who do not.

2. Fostering Partnerships Between Governments, NGOs, and the Private Sector

Collaboration among governments, NGOs, and private companies is crucial for scaling up ICT adoption in agricultural extension. By pooling resources, expertise, and technology, these groups can create and deploy effective ICT solutions. For instance, the partnership between Digital Green, Ethiopia's Ministry of Agriculture, and the Bill & Melinda Gates Foundation has enabled the use of participatory videos for farmer training, benefiting over 2 million farmers worldwide. Public-private partnerships should focus on developing shared digital platforms and co-funding initiatives to increase the accessibility and sustainability of ICT-based agricultural solutions (Loveridge & Wilson, 2017).

Strengthening Policy Frameworks

1. Advocating for ICT-Friendly Agricultural Policies

Governments must create policies that prioritise ICT integration into agricultural extension. These policies should address issues such as data privacy, affordable ICT access, and open innovation. For example, India's National e-Governance Plan in Agriculture (NeGPA) aims to develop ICT-based solutions to enhance agricultural productivity, improve market linkages, and expand extension services. ICT-friendly policies should also promote interoperability among various platforms and encourage the use of open-source technologies to reduce costs and prevent fragmentation.

2. Supporting ICT Innovations in Agriculture Through Funding and Incentives

Adequate funding is essential for advancing ICT-based innovations in agriculture. Governments and international organisations should allocate dedicated budgets for research, infrastructure, and capacity-building programs. Offering incentives like tax breaks, grants, and subsidies for ICT developers can stimulate private-sector investment in agricultural technology. For example, the European Union's SmartAgriHubs program provides funding for digital innovations in

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agriculture, supporting the development of ICT solutions tailored to farmers' needs (Kalatzis et al., 2019).

Encouraging Participatory Approaches

1. Farmer-Centred ICT Design

For ICT tools to be effective and relevant, it is crucial to involve farmers in the development process. Farmer-centred ICT design engages farmers in identifying their challenges and co-developing solutions that are culturally and contextually suitable. For instance, the Shamba Shape-Up program in East Africa conducts surveys to customise its content, which includes agricultural advice delivered via radio, TV, and mobile platforms. Farmer involvement ensures that ICT solutions address real-world problems, increasing their chances of widespread adoption.

2. Collaborative Design of Solutions with Stakeholders

Engaging multiple stakeholders, including farmers, extension agents, researchers, and technology developers, is key to creating effective ICT solutions. Co-design ensures that the tools are technically sound, user-friendly, and aligned with local needs. Programs like Digital Green work in collaboration with local NGOs and farmer groups to create participatory videos, which have led to higher adoption rates and improved outcomes (Ferdinand et al., 2021).

The Future of ICT in Agricultural Extension

AI and Machine Learning for Predictive Insights

Artificial Intelligence (AI) and Machine Learning (ML) are poised to transform agricultural extension by offering predictive analytics for weather patterns, pest outbreaks, and crop yields. AI-driven platforms like IBM's Watson Decision Platform for Agriculture utilise large datasets to forecast risks and propose mitigation strategies, enabling farmers to make proactive decisions. In India, AI-powered weather systems have helped reduce losses from extreme weather by 20%. Moving forward, AI will integrate real-time field data and sophisticated algorithms to offer even more precise recommendations (Tien, 2017).

Blockchain for Transparency in Agricultural Supply Chains

Blockchain technology offers a secure and transparent method for monitoring agricultural products throughout the value chain. This enhances food safety, reduces fraud, and improves smallholder farmers' access to markets. For instance, AgriDigital, a platform based in Australia, uses blockchain to enable traceability within grain supply chains, ensuring transparent transactions and fair payments. Looking ahead, blockchain could be used to implement smart contracts for purchasing agricultural inputs, improving supply chain efficiency and building trust between stakeholders (Lucena et al., 2018).

The Potential of Augmented and Virtual Reality for Farmer Training

Augmented Reality (AR) and Virtual Reality (VR) have great potential to offer immersive training experiences for farmers. These technologies can simulate real farming scenarios, allowing farmers to practice new techniques without risking actual crops. For example, the VR Farmer project in the U.K. uses VR simulations to teach precision agriculture and machinery skills (Pavlenko et al., 2024). As hardware costs continue to fall, AR and VR could become more accessible, enabling large-scale training programs for rural farmers.

Incorporating ICT in Climate-Smart Agricultural Practices

ICT tools will play a key role in scaling climate-smart agricultural (CSA) practices that focus on enhancing resilience, reducing emissions, and increasing productivity. Mobile apps and IoT sensors will help farmers monitor soil moisture, optimise irrigation, and adopt sustainable practices like intercropping. Platforms like Climate FieldView combine remote sensing and weather analytics to assist farmers in implementing climate-

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smart solutions, reducing water use by 30%. In the future, ICT integration in CSA practices will be vital for mitigating the effects of climate change on agriculture.

Facilitating Global Partnerships for Technology Transfer

Global collaborations will be crucial for expanding ICT-based agricultural extension systems and ensuring the transfer of technology to low-income countries. Initiatives like the Global Forum for Rural Advisory Services (GFRAS) facilitate knowledge exchange and capacity building, enabling the adoption of best practices. Programs such as the African Development Bank's Technologies for African Agricultural Transformation (TAAT) encourage cross-border cooperation to introduce ICT tools to African agriculture (Opaluwah, 2021). Such collaborations will be instrumental in tackling global issues like food insecurity and climate change by promoting the widespread use of ICT solutions.

CONCLUSION

The integration of ICT into agricultural extension services has significantly enhanced the reach, efficiency, and inclusivity of advisory services, addressing the limitations of traditional systems. Tools such as mobile phones, internet platforms, drones, and AI allow farmers to access real-time information, improve decision-making, and boost productivity. Challenges such as the digital divide, infrastructure gaps, low digital literacy, and weak policy frameworks hinder widespread adoption. Overcoming these barriers requires collaborative efforts from governments, private sectors, and international organisations to promote affordable ICT solutions, expand infrastructure, and invest in digital literacy programs. Future technological advances, including blockchain, AR/VR, and climate-smart ICT tools, present new opportunities to further enhance agricultural extension services. By supporting participatory approaches and fostering global collaborations, ICT can empower farmers to tackle emerging challenges, ensuring sustainable agricultural development and contributing to global food security.

Disclaimer (Artificial Intelligence)

The authors declare that no generative AI technologies, such as Large Language Models (ChatGPT, COPILOT, etc.) or text-to-image generators, were used during the writing or editing of this manuscript.

Competing Interests

The authors have declared that no competing interests exist.

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