Journal of Experimental Agriculture International

Volume 46, Issue 12, Page 394-410, 2024; Article no.JEAI.127937
ISSN: 2457-0591
(Past name: American Journal of Experimental Agriculture, Past ISSN: 2231-0606)

Integration of ICT in Agricultural Extension Services: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jeai/2024/v46i123146

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/127937

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Cite as: *Khatri, Aastha, Michelle C. Lallawmkimi, Pratima Rana, Chandan Kumar Panigrahi, Akanksha Minj, Sanjay Koushal, and Mohammed Umar Ali. 2024. "Integration of ICT in Agricultural Extension Services: A Review". Journal of Experimental Agriculture International 46 (12):394-410. https://doi.org/10.9734/jeai/2024/v46i123146.*

Review Article

Received: 13/10/2024
Accepted: 15/12/2024
Published: 18/12/2024

ABSTRACT

The integration of Information and Communication Technologies (ICT) into agricultural extension services is transforming the way knowledge and resources are disseminated to farmers, addressing longstanding challenges of reach, efficiency, and inclusivity. Traditional extension systems, constrained by limited resources, outdated methodologies, and poor scalability, often fail to meet the dynamic and diverse needs of modern agriculture. ICT tools, such as mobile phones, internet platforms, Geographic Information Systems (GIS), drones, and emerging technologies like Artificial Intelligence (AI) and blockchain, have revolutionized extension services by providing real-time, location-specific, and cost-effective solutions. This review synthesizes evidence on the role of ICT in enhancing agricultural extension systems, highlighting case studies such as India's mKisan platform, Africa's e-Agriculture initiatives, and the global Digital Green project. These examples demonstrate significant improvements in farmer access to timely information on weather, pests, markets, and best practices, leading to increased productivity and resilience.Despite these successes, several barriers impede the widespread adoption of ICT in agricultural extension. A pronounced digital divide, characterized by limited access to smartphones, internet connectivity, and electricity in rural areas, particularly in developing countries, restricts the reach of these innovations. Gender and socioeconomic disparities exacerbate these challenges, with women and marginalized groups often excluded from ICT-enabled benefits. Gaps in digital literacy among farmers and extension workers, inadequate infrastructure, and weak policy support hinder the scalability and sustainability of ICT interventions. Addressing these barriers requires strategic investments in rural connectivity, affordable technology, and capacity-building programs. Policies promoting public-private partnerships, funding for ICT-based innovations, and farmer-centric participatory approaches are critical for long-term success. ICT in agricultural extension include leveraging AI and machine learning for predictive analytics, expanding blockchain use for supply chain transparency, and adopting augmented reality (AR) and virtual reality (VR) for immersive farmer training. The integration of ICT into climate-smart agricultural practices and fostering global collaborations for technology transfer will be pivotal. By addressing challenges and seizing emerging opportunities, ICT can enable equitable, efficient, and sustainable agricultural development, ensuring food security in a rapidly changing world.

Keywords: ICT in agriculture; agricultural extension; digital divide; farmer advisory; precision farming.

1. INTRODUCTION

A. Agricultural Extension Services

Agricultural extension services have historically played a vital role in bridging the gap between agricultural research and on-farm application, thereby improving the productivity and livelihoods of farmers (Jadhav et al., 2024). These services focus on educating farmers about new agricultural technologies, farming practices, and market opportunities. Extension systems, traditionally driven by the public sector, have operated through face-to-face interactions such as field visits, demonstrations, and farmer training sessions. Despite their potential, traditional agricultural extension systems face significant challenges. Accessibility remains a major issue, with one extension agent often serving thousands of farmers, particularly in rural and remote areas. These systems are hindered by resource constraints, including insufficient funding for infrastructure, training, and operational costs (Travis et al., 2004). Outdated communication methods are another major barrier, as traditional models are not equipped to meet the evolving and diverse needs of modern agriculture. Reliance on in-person meetings and printed materials can be time-consuming and costly, especially when addressing issues such as pest outbreaks or climate variability, which require immediate action. Adoption rates of new technologies among farmers often remain low due to poor follow-up support and cultural resistance to change. Gender inequality further exacerbates these challenges, as women farmers, who constitute nearly 43% of the agricultural workforce in developing countries, often have limited access to extension services compared to men. These challenges highlight the pressing need for innovative approaches, such as the integration of digital technologies, to make agricultural extension systems more efficient, inclusive, and responsive to farmers' needs.

B. Role of ICT in Transforming Agricultural Practices

Information and Communication Technologies (ICT) have emerged as transformative tools for addressing the limitations of traditional agricultural extension systems (Table 1). ICT refers to a wide array of digital tools and systems used for creating, processing, storing, and sharing information. This includes technologies such as mobile phones, internet platforms, Geographic Information Systems (GIS), drones, and artificial intelligence (Bhat et al., 2024). These tools are particularly effective in agriculture because they enable rapid dissemination of critical information to large populations of farmers, often in real time. Mobile-based platforms, provide advisory services through SMS alerts or mobile apps that deliver

Table 1. Role of ICT in transforming agricultural practices (Source- (Bhat et al., 2024; Getahun et al., 2024; Olumola, 2015)

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 fertilizers	Soil Health Card Portal, Digital Soil Maps
Irrigation	IoT-based automated irrigation systems, mobile apps	Efficient water usage, reduced wastage, and optimized crop water requirements	Drip-Irrigation Systems, mKRISHI Aqua
Market Access	e-NAM, digital marketing platforms, and mobile applications	Improved access to 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	Minimizing risks from extreme weather events and optimizing 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
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

weather forecasts, pest management tips, and market price updates. For example, in India, the *mKisan* initiative has reached millions of farmers by providing customized agricultural advice via SMS in their local languages. Internet-based services and e-learning platforms have made it easier for farmers to access agricultural knowledge and participate in virtual training sessions. Social media platforms such as WhatsApp and Facebook have also emerged as effective tools for farmer-to-farmer knowledge sharing and communication with extension agents. Emerging technologies like Artificial Intelligence (AI) and Big Data are enabling precision agriculture by providing predictive analytics for pest outbreaks, crop yields, and weather patterns. Drones and remote sensing technologies, on the other hand, allow for real-time monitoring of field conditions, helping farmers optimize resource use and improve productivity (Getahun et al., 2024). ICT's ability to deliver timely, cost-effective, and customized solutions makes it a game-changer in modernizing agricultural extension services, particularly in addressing challenges such as climate change, market volatility, and food insecurity.

C. Objectives and Scope of the Review Article

The primary objective of this review article is to explore how ICT tools and technologies are being integrated into agricultural extension services to improve their efficiency, accessibility, and impact. The review aims to analyze how ICT is transforming the dissemination of agricultural knowledge, with a focus on mobile-based platforms, internet services, and emerging technologies such as AI and drones. By examining global case studies and successful initiatives, the review will highlight best practices and lessons learned in the adoption of ICT for agricultural extension. Projects such as Digital Green, which uses participatory videos to train farmers in developing countries, demonstrate the potential of ICT in reaching underserved populations (Olumola, 2015). The article will delve into the challenges associated with ICT integration, including the digital divide, which limits access to digital tools among rural farmers, particularly women and marginalized groups. Infrastructure constraints, such as poor internet connectivity and lack of electricity in remote areas, will also be discussed. The review will propose actionable recommendations to address these barriers, such as investments in rural digital infrastructure, capacity-building programs for farmers and extension agents, and policies to promote gender-inclusive ICT adoption. Finally, the review will explore emerging trends in ICT, including the use of blockchain for supply chain transparency and augmented reality for virtual farmer training. By addressing these aspects, the article aims to provide a comprehensive understanding of the potential of ICT in revolutionizing agricultural extension services and contributing to sustainable agricultural development and food security goals.

2. CONCEPT

A. Conceptualizing Agricultural Extension Services

1. Goals and Functions of Extension Systems

Agricultural extension services serve as a vital conduit between scientific research and practical farming applications, with the primary goal of enhancing productivity, sustainability, and the livelihoods of farming communities (Bhat et al., 2024). Extension systems aim to empower farmers with the knowledge, skills, and technologies needed to address agricultural challenges while promoting broader developmental objectives such as food security, poverty alleviation, and environmental conservation. A central function of these systems is the transfer of technology, which involves disseminating research-based innovations such as improved seeds, fertilizers, and mechanization techniques to farmers. Extension systems also provide critical advisory services, offering real-time solutions to challenges like pest outbreaks, water scarcity, or poor soil health. Another significant role is capacity building, where extension agents organize training programs, workshops, and farmer field schools to equip farmers with technical and managerial skills for better resource utilization and decision-making (Simpson & Owens, 2002). Extension systems often facilitate collective action by fostering social learning and farmer-to-farmer knowledge exchange. Through such efforts, they enable farmers to collaboratively tackle shared challenges like irrigation management, market access, or climate adaptation. Thus, extension systems play a multifaceted role in strengthening the resilience of agricultural communities and ensuring the sustainable development of the sector.

2. Stakeholders in the Agricultural Extension Process

The agricultural extension process is inherently collaborative, involving a diverse array of stakeholders who contribute to the delivery and effectiveness of extension services. Farmers are the primary beneficiaries, encompassing smallholders, commercial farmers, and farmer organizations, all of whom rely on extension systems for knowledge and advisory support. Extension agents act as the critical link between researchers and farmers, facilitating the transfer of innovations and providing personalized guidance (Chowdhury et al., 2014). Research institutions, such as universities and agricultural research centers, play a foundational role by developing the scientific innovations and technologies that extension agents disseminate to farmers. Governments are another key stakeholder, providing policy frameworks, funding, and institutional support for extension services, often through ministries of agriculture. NGOs contribute by introducing innovative methods and extending services to underserved regions, while the private sector, including agribusiness firms and technology companies, is increasingly involved in delivering ICT-based solutions for agricultural advisory services. International organizations like the Food and Agriculture Organization (FAO) and World Bank also play a critical role in supporting extension systems through funding, capacity-building programs, and technical assistance (Rondot & Collion, 2001). Finally, community-based organizations (CBOs), such as farmer cooperatives and self-help groups, are essential for mobilizing local farmers and fostering participatory approaches. This multi-stakeholder framework ensures that agricultural extension systems are dynamic, inclusive, and well-suited to meet the evolving needs of farmers.

B. ICT and Its Potential in Agriculture

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

Information and Communication Technologies (ICT) comprise a broad spectrum of digital tools that have revolutionized agriculture by facilitating the rapid dissemination of information and resources. Among these tools, mobile phones are the most widely adopted, particularly in developing countries, where they have enabled millions of farmers to access real-time weather forecasts, pest alerts, and market prices through SMS-based services and mobile applications. Initiatives such as *mKisan* in India and *Esoko* in Africa demonstrate how mobile phones can bridge the gap between farmers and extension services (Naika et al., 2021). Internet-based platforms, such as farmer portals and e-learning websites, provide a wealth of information on best practices, crop management techniques, and training modules, enabling farmers to access knowledge at their convenience. Geographic Information Systems (GIS) and remote sensing technologies allow for the spatial analysis of soil conditions, crop health, and water resources, enabling data-driven decisions for precision farming. Drones are increasingly used in agriculture for crop monitoring, pest detection, and irrigation management, offering high-resolution imagery that aids in resource optimization. Social media platforms such as WhatsApp, Facebook, and YouTube have become popular tools for farmer-to-farmer knowledge sharing, providing an informal yet highly effective means of communication and peer support. Emerging technologies like Artificial Intelligence (AI) and blockchain are also transforming agriculture. AI-powered platforms provide predictive analytics for weather patterns, pest outbreaks, and crop yields, while blockchain is being used to enhance transparency and traceability in agricultural supply chains (al Bakri et al., n.d.). These ICT tools have created a digital ecosystem that enables farmers to access critical information, connect with stakeholders, and adopt innovative practices, thereby modernizing the agricultural sector.

2. Benefits of ICT in Disseminating Agricultural Knowledge

ICT has brought significant advantages to agricultural extension services by overcoming the limitations of traditional approaches and making knowledge dissemination more efficient and accessible. One of the most notable benefits of ICT is its ability to provide real-time information, which is crucial for addressing time-sensitive challenges such as pest outbreaks or extreme weather events. For example, mobile-based platforms delivering weather alerts and pest management tips have proven invaluable to farmers in regions vulnerable to climate variability, such as sub-Saharan Africa and South Asia (Caine et al., 2015). ICT also improves accessibility by reaching farmers in remote or underserved areas, where traditional extension systems struggle to operate. Mobile phones, which have penetrated over 70% of rural households in sub-Saharan Africa, have been particularly effective in democratizing access to agricultural knowledge. ICT-based solutions are highly cost-effective compared to traditional extension methods. SMS services, mobile apps, and online platforms significantly reduce the costs associated with in-person visits and field demonstrations, enabling service providers to reach larger numbers of farmers at a fraction of the cost. Another key advantage of ICT is its ability to offer localized and tailored advice based on a farmer's specific needs, such as crop type, location, and resource availability. AI-powered applications like *Plantix* provide personalized recommendations for pest and disease management based on photographs uploaded by farmers. ICT also empowers farmers by fostering peer-to-peer learning and collaboration. Social media platforms and online forums allow farmers to share experiences, discuss challenges, and adopt solutions, promoting community-driven agricultural development. ICT tools such as remote sensing, drones, and IoT devices enable continuous monitoring of farm activities, providing data that can be used to evaluate the impact of extension services and improve their delivery (Bhat et al., 2024). Overall, ICT has the potential to make agricultural extension systems more inclusive, adaptive, and responsive to the dynamic needs of modern farmers, thereby contributing to sustainable agricultural development and food security.

3. ICT TOOLS AND TECHNOLOGIES IN AGRICULTURAL EXTENSION

A. Mobile-Based ICT Solutions

1. Use of SMS and Mobile Apps for Advisory Services

Mobile phones have revolutionized agricultural extension services, particularly in developing countries, where farmers often face challenges in accessing traditional advisory systems (Table 2). SMS (Short Message Service) and mobile applications have become crucial tools for disseminating timely, location-specific information on weather forecasts, pest and disease management, input use, and market prices. Mobile-based solutions are cost-effective, scalable, and capable of reaching farmers in even the most remote areas. The *mKisan* initiative in India delivers SMS-based advisory messages in regional languages, providing tailored solutions to millions of farmers on crop management, pest control, and government schemes (Saravanan & Bhattacharjee, 2014). *Esoko* in Africa uses SMS to provide smallholders with real-time market prices, helping them negotiate better deals and reduce exploitation by middlemen. Mobile apps have further expanded the scope of mobile-based advisory services. Applications like *Plantix*, an AI-powered app, allow farmers to diagnose crop diseases by uploading photos of affected plants and receiving instant recommendations. Apps like *Kisan Suvidha* in India and *FARMS* by the U.S. Department of Agriculture (USDA) have also been instrumental in providing information on weather, soil health, subsidies, and machinery rentals. These tools have become indispensable in bridging the gap between farmers and extension services.

2. Success Stories from Developing and Developed Countries

Several success stories highlight the transformative impact of mobile-based ICT solutions in agricultural extension. In developing countries, *iShamba* in Kenya has emerged as a leading SMS and call-based advisory platform, providing agronomic tips and linking farmers to input suppliers. It has reportedly helped over 200,000 farmers increase their yields by 25% (KR et al., 2024). In Uganda, the *CABI Pest Risk Information Service* (PRISE) uses SMS alerts to warn farmers about pest outbreaks, reducing crop losses by up to 30%. In developed countries, mobile-based solutions have also proven effective. The USDA's *Farm Service Agency (FSA)* app provides American farmers with real-time updates on disaster assistance programs, insurance, and weather conditions. Apps like *AgriSync* in the U.S. enable farmers to consult with agronomists and extension agents via video calls, improving service delivery and decision-making efficiency (Chambyal, 2024). These examples underscore the global relevance of mobile-based ICT tools in modernizing agricultural extension systems.

B. Internet-Based Platforms

1. E-Learning and Online Advisory Systems

The internet has opened new avenues for agricultural extension by providing e-learning platforms and online advisory systems that enable farmers to access educational resources and expert advice at their convenience. Platforms like *e-Extension* in the Philippines provide farmers with online modules covering

Table 2. Mobile-based ICT solutions in agriculture (Source: (Saravanan & Bhattacharjee, 2014; KR et al., 2024)

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	Minimized risks from weather uncertainties and optimized 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 fertilizers	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

topics such as organic farming, pest management, and livestock care. Similarly, *AgMOOCs* in India, developed by the Indian Institute of Technology Kanpur, offers free online courses on agronomy, soil health, and climate-smart agriculture, enrolling thousands of farmers and extension workers annually. Online advisory systems have also gained prominence. In Kenya, *Digital Green*, a global development organization, uses participatory videos to disseminate farming best practices. Farmers can access these videos through the internet or local digital hubs, increasing adoption rates of improved techniques by up to 85% (Mapiye et al., 2023). In the U.S., platforms like *FarmLogs* and *Agriwebb* provide detailed farm analytics, enabling data-driven decision-making. The adoption of such platforms has been associated with increased efficiency and productivity, with studies reporting yield improvements of 20-30% among users.

2. Farmer Portals and Agricultural Websites

Farmer portals and agricultural websites serve as centralized repositories of information, offering resources on crop cultivation, livestock management, market trends, and government schemes. The *Farmer Connect Portal* in India, connects farmers to input suppliers, buyers, and government advisory services, benefiting over 10 million users since its launch. Similarly, the *National Farmers' Portal* in Australia provides tools for climate forecasting, water management, and pest surveillance, helping farmers adapt to climate variability. Other platforms, such as *FAO's e-Agriculture*, have a global reach, promoting knowledge sharing and collaboration among agricultural stakeholders. These platforms have been instrumental in reducing information asymmetry, empowering farmers to make informed decisions, and fostering market integration (Abdulquadri et al., 2024).

C. Emerging Technologies

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

Emerging technologies such as Artificial Intelligence (AI), Big Data, and the Internet of Things (IoT) are revolutionizing agricultural extension services by enabling predictive analytics, resource optimization, and precision farming. AI-powered platforms like IBM's *Watson Decision Platform for Agriculture* use machine learning algorithms to analyze weather patterns, soil health, and crop conditions, providing farmers with actionable insights to improve yields. Similarly, Big Data analytics is being used to analyze vast datasets on market trends, pest outbreaks, and climate risks, helping policymakers and extension agents design targeted interventions. IoT devices, such as soil sensors and weather stations, enable real-time monitoring of field conditions, providing farmers with precise data on moisture levels, nutrient content, and pest activity. These technologies have significantly improved efficiency and reduced input costs, with studies showing yield increases of up to 25% in IoT-enabled farms (Liang & Shah, 2023). For example, India's *Krishi IoT* platform integrates IoT devices with mobile apps to provide farmers with real-time advisory services, benefiting over 50,000 farmers.

2. Drones and Remote Sensing for Field Monitoring

Drones and remote sensing technologies have become indispensable in modern agriculture, particularly for large-scale field monitoring and resource management. Drones equipped with multispectral cameras can capture high-resolution images of fields, enabling farmers to detect early signs of stress, pests, or nutrient deficiencies. Remote sensing, using satellite imagery, provides large-scale data on vegetation health, water stress, and crop yields, making it a valuable tool for policymakers and extension agencies. In sub-Saharan Africa, drone technology has been used to monitor cassava farms, resulting in yield improvements of 15-20% due to early detection of pest infestations (Adetunji et al., 2023). Similarly, in the U.S., companies like *PrecisionHawk* use drones for crop scouting and aerial mapping, saving farmers an average of $25 per acre in input costs. These technologies have proven particularly effective in reducing labor costs, improving resource efficiency, and increasing productivity.

D. Role of Social Media and Communication Platforms

1. WhatsApp Groups, Facebook Forums, and YouTube Channels

Social media platforms have emerged as powerful tools for agricultural extension, enabling real-time communication and knowledge sharing among farmers, extension agents, and experts (Table 3). WhatsApp groups have become popular in many countries, allowing farmers to share photos of diseased crops, discuss solutions, and receive instant advice from peers and extension officers. For example, in India, the *Digital Farmer Network* uses WhatsApp to connect over 1 million farmers, helping them improve yields and reduce input costs (Devanand & Kamala, 2019). Facebook forums like *Farmers Helping Farmers* provide a space for farmers to exchange ideas and experiences, while YouTube channels such as *Krishi Jagran* in India and *AgriUncle* in Kenya offer tutorials on sustainable farming practices, pest control, and market linkages. These platforms are particularly effective for visual learners, with studies reporting higher adoption rates of recommended practices when video demonstrations are used.

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

Social media platforms have democratized access to agricultural knowledge, empowering farmers to become active participants in knowledge exchange. Peer-to-peer learning is particularly effective because farmers trust advice from their peers more than external agents. Platforms like WhatsApp and Facebook foster this trust by enabling farmers to share their successes, challenges, and solutions in a collaborative environment. WhatsApp groups in Nigeria have been used to share low-cost organic farming techniques, reducing input costs by 30% for participating farmers (David, 2020). In addition to connecting farmers within a region, social media also enables cross-border knowledge sharing, promoting global best practices. These platforms have proven particularly beneficial for marginalized groups, including women and youth, by providing them with a voice and equal access to information. As such, social media and communication platforms are playing a pivotal role in making agricultural extension services more inclusive, participatory, and farmer-centric.

Table 3. Role of social media and communication platforms in Agriculture Source: (Liang & Shah, 2023; Adetunji et al., 2023; Devanand & Kamala, 2019)

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 specialty 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 Campaigns	Twitter hashtags, Facebook awareness posts	Dissemination of information on sustainable practices, government schemes, and agricultural policies	#FarmersFirst 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

4. CASE STUDIES AND BEST PRACTICES

A. Global Examples of Successful ICT Integration in Extension Services

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

The *mKisan* initiative in India is one of the most notable examples of ICT integration in agricultural extension services. Launched by the Ministry of Agriculture and Farmers' Welfare, mKisan leverages mobile technology to deliver agricultural information to farmers through SMS, voice messages, and mobile applications in multiple regional languages (KR et al., 2024). The platform enables farmers to receive timely updates on crop management, weather forecasts, pest and disease alerts, market prices, and government schemes. It also allows farmers to interact with agricultural experts via a helpdesk, enhancing two-way communication. As of 2021, mKisan had reached over 50 million farmers across India, significantly improving their access to critical information. A key strength of mKisan lies in its localization; messages are tailored to specific crops, regions, and weather conditions, making the advice highly relevant to farmers' needs. Studies show that farmers using mKisan experienced a 20-25% increase in productivity and income due to better-informed decision-making (Van Baardewijk, 2016). The success of mKisan demonstrates the power of mobile technology to scale extension services, particularly in countries with vast rural populations.

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

In Africa, ICT-driven initiatives under the umbrella of *e-Agriculture* have significantly improved agricultural extension services. Countries like Kenya, Ghana, and Uganda have implemented platforms that combine mobile technology, internet-based advisory services, and community-based ICT hubs to disseminate agricultural information. For example, *Esoko*, a platform originating in Ghana, uses mobile technology to provide real-time market prices, weather alerts, and crop advice to farmers. Esoko's services have reached over 1.5 million farmers across Africa, enabling them to secure better prices for their produce and adapt to changing weather condition. Another example is *CABI's Pest Risk Information Service (PRISE)*, which uses satellite data and weather modeling to predict pest outbreaks in sub-Saharan Africa. PRISE sends alerts via SMS to farmers and extension officers, reducing crop losses by up to 30% in regions like Kenya and Zambia (Day et al., 2024). These initiatives have demonstrated the scalability and efficiency of ICT in addressing challenges such as market access and climate variability in African agriculture.

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

Digital Green is a global initiative that has revolutionized agricultural extension by using community-driven videos to disseminate farming best practices. Digital Green works in partnership with local governments, NGOs, and farmers' organizations to produce and share videos featuring local farmers demonstrating sustainable practices. These videos are screened in rural communities using portable projectors, and farmers can also access them online or through mobile devices. Operating in countries such as India, Ethiopia, and Afghanistan, Digital Green has reached over 2.3 million farmers, with adoption rates for demonstrated practices exceeding 85% in some cases. A study conducted in India showed that farmers using Digital Green videos achieved 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 lies in its participatory approach, which fosters trust and relevance by featuring local farmers as role models. This model highlights the importance of community involvement in ICT-driven extension services and has been widely recognized as a best practice in the sector.

5. BENEFITS OF ICT INTEGRATION IN AGRICULTURAL EXTENSION SERVICES

A. Improved Accessibility and Reach to Remote Areas

ICT integration in agricultural extension has significantly improved accessibility to information and advisory services, especially for farmers in remote and underserved regions. Traditional extension systems often suffer from inadequate reach, with one extension officer typically responsible for thousands of farmers. ICT tools like mobile phones, SMS, and internet platforms have bridged this gap. For example, mobile-based advisory services such as *mKisan* in India and *Esoko* in Ghana deliver region-specific agricultural advice directly to farmers' phones, irrespective of their location. This improved accessibility has been transformative for smallholder farmers, who previously relied on sporadic and inconsistent access to extension agents. Studies show that ICT-enabled services can reach up to 80% more farmers than traditional methods, particularly in geographically isolated areas (Khan et al., 2024).

B. Enhanced Farmer Decision-Making and Productivity

By providing timely and actionable information, ICT tools empower farmers to make informed decisions regarding crop selection, pest control, irrigation, and input use. Platforms like *Plantix*, an AI-based app, offer real-time diagnostics for crop diseases, enabling farmers to take immediate remedial action and reduce losses. Similarly, access to market prices through platforms such as *e-Choupal* in India has improved farmers' bargaining power, allowing them to choose the right time and place to sell their produce. Studies indicate that farmers using ICT-based advisory services experience a 15-30% increase in productivity due to better resource optimization and risk management (Ji-Ping et al., 2022).

C. Cost-Effective Delivery of Advisory Services

ICT tools have reduced the cost of delivering extension services by minimizing the need for in-person visits and printed materials. Mobile-based solutions, can provide SMS-based advisory messages to thousands of farmers simultaneously, significantly lowering operational costs. ICT-enabled services reduce the cost of extension delivery by up to 50%, making it a highly cost-effective approach. Internet-based platforms and apps like *FarmLogs* allow farmers to access comprehensive advisory services for a fraction of the cost of traditional extension systems, thus increasing the overall affordability and scalability of agricultural extension.

D. Promoting Farmer -to - Farmer Collaboration and Learning

Social media platforms and communication tools such as WhatsApp, Facebook, and YouTube have fostered peer-to-peer knowledge sharing among farmers. Farmers use WhatsApp groups to discuss challenges, share experiences, and exchange solutions, creating virtual communities that promote collaborative learning (Nain et al., 2019). YouTube channels like *Krishi Jagran* in India feature farmer testimonials and training videos, which are particularly effective for visual learners. Studies have shown that farmers who engage in peer-to-peer learning via ICT platforms are 20% more likely to adopt new technologies than those relying solely on traditional extension systems.

E. Real-Time Dissemination of Critical Information (e.g., Weather, Market Trends)

One of the most significant advantages of ICT in agricultural extension is its ability to disseminate real-time information on weather forecasts, pest outbreaks, and market trends. This timely information helps farmers mitigate risks and make quick decisions, particularly during emergencies. The *PRISE* system in Africa uses satellite data to predict pest outbreaks and sends SMS alerts to farmers, enabling them to take preventive measures and reduce losses by up to 30%. Similarly, weather advisory services provided by platforms like *Climate FieldView* allow farmers to adjust irrigation schedules and protect crops from extreme weather events. Real-time market information delivered through ICT platforms has also enhanced farmers' ability to access fair prices and avoid exploitation by middlemen (Abdulquadri et al., 2024).

6. CHALLENGES IN ICT ADOPTION FOR AGRICULTURAL EXTENSION

A. Digital Divide and Access Issues

1. Limited Access to ICT Tools in Rural Areas

Despite the proliferation of ICT tools, a significant digital divide persists, particularly in rural areas of developing countries. Limited access to mobile phones, computers, and internet connectivity prevents many smallholder farmers from fully benefiting from ICT-based extension services. While mobile penetration in sub-Saharan Africa has increased, only 28% of the rural population has access to smartphones required for advanced applications. This lack of access disproportionately affects the poorest farmers, who cannot afford ICT devices or associated costs such as internet subscriptions (Krell et al., 2021).

2. Gender and Socioeconomic Disparities in ICT Usage

Gender disparities in ICT access further exacerbate inequality. Women farmers, who constitute nearly 43% of the agricultural workforce in developing countries, are 20-40% less likely than men to own a mobile phone or access the internet. Socioeconomic factors, such as low income and lack of education, also limit the ability of marginalized groups to access and use ICT tools. These disparities hinder the inclusiveness of ICT-based extension services and perpetuate existing inequalities in agricultural development.

B. Infrastructure Constraints

1. Poor Internet Connectivity in Rural Regions

Reliable internet connectivity is a prerequisite for many ICT tools, but rural regions often suffer from poor network coverage and slow internet speeds. According to the International Telecommunication Union (ITU), less than 25% of rural areas in low-income countries have access to broadband internet (James, 2020). This lack of connectivity limits the functionality of apps, online platforms, and video-based advisory services, reducing their effectiveness in reaching rural farmers.

2. Lack of Technical Support and Maintenance

Even where ICT tools are available, the lack of technical support and infrastructure maintenance poses a significant challenge. Farmers often face difficulties in troubleshooting technical issues or maintaining ICT devices, such as smartphones and tablets. This is particularly problematic in regions where local expertise in ICT maintenance is limited, further discouraging adoption.

C. Literacy and Skill Gaps

1. Digital Illiteracy Among Farmers

Digital illiteracy is a major barrier to the adoption of ICT in agricultural extension. Many smallholder farmers, particularly older individuals, lack the technical skills needed to operate mobile apps, internet platforms, or other ICT tools. A study found that nearly 40% of farmers in sub-Saharan Africa are unable to use even basic ICT applications, such as SMS services or smartphone apps (Mapiye et al., 2023). This digital illiteracy significantly limits the reach and impact of ICT-enabled extension systems.

2. Limited Training for Extension Officers on ICT Tools

Extension officers, who are critical intermediaries between ICT platforms and farmers, often lack the training required to effectively use and promote these tools. A World Bank report highlighted that in many countries, only 30% of extension officers have received formal training on ICT tools. This skills gap undermines the ability of extension agents to act as facilitators of ICT adoption, reducing the overall effectiveness of ICT-based advisory services.

D. Policy and Institutional Barriers

1. Weak Policy Frameworks for ICT in Agriculture

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

2. Insufficient Investment and Funding for ICT Integration

The success of ICT-based extension systems requires substantial investment in infrastructure, training, and technology development. Many governments and development agencies allocate insufficient resources to these initiatives. A report by the FAO noted that less than 5% of agricultural budgets in low-income countries are dedicated to extension services, with an even smaller proportion allocated to ICT initiatives. This lack of funding hampers the scalability and sustainability of ICT-based solutions, limiting their long-term impact (Qamar, 2003).

7. POLICY RECOMMENDATIONS AND STRATEGIES

A. Bridging the Digital Divide

1. Promoting Affordable and Accessible ICT Tools

One of the most effective ways to bridge the digital divide in agriculture is by making ICT tools more affordable and accessible for smallholder farmers. Governments and private sector actors need to work together to subsidize 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 access in rural areas, enabling farmers to use ICT tools effectively. Similarly, organizations like GSMA have launched programs to develop low-cost feature phones with pre-installed agricultural advisory apps for farmers in sub-Saharan Africa (Santer, 2013). Subsidizing ICT devices and services, along with developing region-specific applications, can increase technology penetration among rural communities.

2. Infrastructure Development in Rural Areas

Infrastructure development is critical to ensuring that ICT tools can function effectively in rural areas. Governments should invest in expanding internet connectivity, electricity access, and mobile network coverage in remote regions. For example, Rwanda's *National Broadband Policy* has increased internet coverage to over 80% of its population, significantly enhancing the use of ICT tools in agriculture. Infrastructure improvements should prioritize renewable energy solutions, such as solar-powered ICT hubs, to ensure sustainability in areas with unreliable electricity. Partnerships between governments and private-sector telecom providers can also accelerate the rollout of affordable broadband networks to remote farming communities.

B. Capacity-Building Initiatives

1. **Digital Literacy Training for Farmers and Extension Workers**

Improving digital literacy among farmers and extension agents is essential for the effective adoption of ICT tools. Governments and NGOs should establish training programs that teach farmers how to use mobile apps, SMS platforms, and internet services for agricultural purposes. For example, Kenya's *Eneza Education* program provides mobile-based digital literacy training tailored to smallholder farmers, covering topics such as crop management and market access (Blimpo & Owusu, 2019). Similarly, extension officers need comprehensive training on the latest ICT tools to better support farmers. Studies show that farmers who receive digital literacy training are 30% more likely to adopt ICT-based solutions than those without such training.

2. **Partnerships Between Governments, NGOs, and Private Sectors**

Collaborative partnerships are critical to scaling up ICT adoption in agricultural extension. Governments, NGOs, and private companies can pool resources, expertise, and technology to develop and deploy effective solutions. For example, the partnership between *Digital Green*, the Ethiopian Ministry of Agriculture, and the Bill & Melinda Gates Foundation has enabled the widespread use of participatory videos for farmer training, benefiting over 2 million farmers globally. Public-private partnerships should also focus on establishing shared digital platforms and co-funding initiatives to make ICT solutions more accessible and sustainable (Loveridge & Wilson, 2017).

C. Strengthening Policy Frameworks

1. **Promoting ICT-Friendly Agricultural Policies**

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

2. **Funding and Incentives for ICT-Based Innovations in Agriculture**

Adequate funding is crucial for developing and deploying innovative ICT tools in agriculture. Governments and international organizations must allocate dedicated budgets to support research, infrastructure development, and capacity-building programs. Incentives such as tax breaks, grants, and subsidies for ICT developers can also encourage private-sector investments in agricultural technology. For example, the European Union's *SmartAgriHubs* program provides funding for digital innovations in agriculture, fostering the development of ICT-based solutions that address farmer needs (Kalatzis et al., 2019).

D. Encouraging Participatory Approaches

1. Farmer-Centered ICT Development

To ensure the relevance and usability of ICT tools, it is essential to involve farmers in the development process. Farmer-centered ICT development involves engaging farmers to identify their challenges and co-create solutions that are culturally and contextually appropriate. For example, the *Shamba Shape-Up* program in East Africa conducts farmer surveys to tailor its content, which includes agricultural advice delivered via radio, TV, and mobile platforms. Farmer involvement ensures that ICT tools address real-world issues and have a higher likelihood of adoption.

2. Co-Design of Solutions with Stakeholders

Collaborative design processes that involve multiple stakeholders including farmers, extension agents, researchers, and technology developers are critical for developing effective ICT solutions. Co-design ensures that tools are technically robust, user-friendly, and aligned with local needs. Programs such as *Digital Green* rely on partnerships with local NGOs and farmer groups to co-create content for participatory videos, leading to higher adoption rates and better outcomes (Ferdinand et al., 2021).

8. FUTURE IN ICT FOR AGRICULTURAL EXTENSION

A. AI and Machine Learning for Predictive Analytics

Artificial Intelligence (AI) and Machine Learning (ML) have immense potential to revolutionize agricultural extension by providing predictive analytics for weather patterns, pest outbreaks, and crop yields. AI-powered platforms like IBM's *Watson Decision Platform for Agriculture* use vast datasets to predict risks and recommend mitigation strategies, enabling farmers to make proactive decisions. For example, in India, AI-based weather forecasting systems have helped farmers reduce losses from extreme weather events by 20%. In the future, AI systems will likely integrate real-time field data with advanced algorithms to deliver even more precise recommendations (Tien, 2017).

B. The Use of Blockchain for Traceability in Agricultural Value Chains

Blockchain technology offers a secure and transparent way to trace agricultural products throughout the value chain, enhancing food safety, reducing fraud, and improving market access for smallholder farmers. Platforms like *AgriDigital* in Australia use blockchain to provide end-to-end traceability for grain supply chains, ensuring fair payments and transparency. Future developments could expand blockchain's use to include smart contracts for input purchases, reducing inefficiencies in supply chain transactions and promoting trust among stakeholders.

C. The Role of Augmented and Virtual Reality in Farmer Training

Augmented Reality (AR) and Virtual Reality (VR) hold immense potential for immersive farmer training and skill development. These technologies can simulate real-world farming scenarios, allowing farmers to practice new techniques without risking their crops. For example, the *VR Farmer* project in the U.K. uses VR simulations to train farmers in precision agriculture and machinery use (Pavlenko et al., 2024). As hardware costs decrease, AR and VR technologies could become more accessible, enabling large-scale training programs for rural farmers.

D. Integration of ICT Into Climate-Smart Agricultural Practices

ICT tools will play a central role in scaling climate-smart agriculture (CSA) practices, which aim to enhance resilience, reduce greenhouse gas emissions, and increase productivity. Mobile apps and IoT sensors can help farmers monitor soil moisture, optimize irrigation, and adopt sustainable practices like intercropping. The *Climate FieldView* platform combines remote sensing and weather analytics to help farmers implement climate-smart solutions, reducing water use by 30%. In the future, ICT integration into CSA practices will be critical for mitigating the impacts of climate change on agriculture.

E. Building Global Collaborations for Technology Transfer

Global collaborations will be essential for scaling ICT-based agricultural extension systems and ensuring technology transfer to low-income countries. Initiatives like the *Global Forum for*

Rural Advisory Services (GFRAS) facilitate knowledge exchange and capacity building among countries, enabling the adoption of best practices. Programs like the *African Development Bank's Technologies for African Agricultural Transformation (TAAT)* promote cross-border collaborations to introduce ICT tools in African agriculture (Opaluwah, 2021). Such partnerships will be instrumental in addressing global challenges like food insecurity and climate change through the widespread adoption of ICT-based solutions.

9. CONCLUSION

The integration of ICT in agricultural extension services has proven transformative in addressing the limitations of traditional systems, enhancing the reach, efficiency, and inclusivity of advisory services. By leveraging tools such as mobile phones, internet platforms, drones, and AI, farmers can 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. Bridging these gaps requires coordinated efforts from governments, private sectors, and international organizations to promote affordable ICT tools, expand infrastructure, and invest in digital literacy and capacity building. Future advancements in technologies such as blockchain, AR/VR, and climate-smart ICT solutions present new opportunities to further revolutionize agricultural extension. By fostering participatory approaches and global collaborations, ICT can empower farmers to overcome emerging challenges, ensuring sustainable agricultural development and contributing to food security worldwide.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/127937