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COVID-19 Post-Pandemic Agricultural Extension Services: A Strategic Analysis of Post-Pandemic Sustainability

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

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ABSTRACT

The COVID-19 pandemic profoundly disrupted agricultural extension systems worldwide, highlighting systemic vulnerabilities while accelerating digital transformation. This paper presents a comprehensive analysis of post-pandemic extension services, emphasizing sustainability, inclusivity, and resilience. It explores the breakdown of traditional service delivery due to lockdowns

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and movement restrictions and examines the rapid pivot toward digital platforms such as mobile apps, AI tools, and hybrid models that blend in-person and virtual engagement. The study identifies critical challenges, including digital inequality, labor shortages, trust deficits, infrastructural gaps, and market disconnection. Drawing from global case studies—India, Kenya, the Philippines, and the U.S.—the paper highlights best practices like public-private partnerships, community media, and localized content. A sustainability framework is proposed, encompassing farmer-centric approaches, digitally inclusive infrastructure, multi-stakeholder ecosystems, and crisis-ready systems. Policy recommendations focus on capacity development, monitoring and evaluation, and decentralized, culturally relevant service models. The findings underscore the need to reimagine agricultural extension as a dynamic, integrated, and digitally enabled system that centers farmer empowerment, equity, and adaptability in the face of future crises.

Keywords: Agricultural extension; COVID-19; digital advisory services; sustainability; public-private partnerships.

1. INTRODUCTION

The COVID-19 pandemic, which began as a global health crisis in 2019, and rapidly evolved in 2020 into a multifaceted challenge impacting economies, food systems, and rural livelihoods across the globe. Among the various sectors affected, agriculture—particularly the systems and services that support farmers—was significantly disrupted. One such critical support mechanism is agricultural extension services, which act as a bridge between research institutions and farmers by providing knowledge, technologies, and advisory support essential for sustainable agricultural practices. In the post-pandemic world, the sustainability and resilience of agricultural extension services have come under close scrutiny, both globally and in the Indian context.

Agricultural extension services have traditionally relied on face-to-face interactions, training programs, field demonstrations, and community-based dissemination methods. However, the COVID-19 pandemic necessitated a dramatic shift in these modalities due to restrictions on physical movement and social distancing protocols (FAO, 2021). The immediate halt in traditional extension activities highlighted the vulnerability of the system to external shocks and underscored the need for resilient, technology-driven, and inclusive approaches to ensure continuity and effectiveness of service delivery. Moreover, the pandemic exposed and often exacerbated existing gaps in access to extension services, particularly for smallholder farmers, women, and marginalized groups, further challenging the equity and sustainability of agricultural development (Swanson & Rajalahti, 2010).

Globally, the response to the disruption of extension services varied across countries depending on institutional capacities, infrastructure, and digital readiness. In developed economies, the rapid adoption of digital tools such as mobile apps, virtual advisory platforms, and AI-enabled decision support systems helped maintain a certain degree of service continuity. Countries like the United States, Canada, and Australia leveraged existing e-extension platforms and adapted quickly to remote service delivery (Siankwilimba et al., 2023). However, in many low- and middle-income countries, including those in Sub-Saharan Africa and South Asia, the digital divide posed significant challenges. Limited internet penetration, lack of digital literacy, and gendered access to mobile technology hindered the effectiveness of online extension interventions (Adjognon et al., 2020).

India, with its vast and diverse agricultural landscape, experienced both challenges and innovations during the pandemic. Agricultural extension in India is delivered through a pluralistic system involving public institutions such as the State Agricultural Universities (SAUs), Krishi Vigyan Kendras (KVKs), and the Department of Agriculture and Farmers Welfare (DAFW), alongside private sector and non-governmental actors. The pandemic disrupted on-ground activities like field visits and farmer training, particularly impacting the government-led initiatives (Zirmire et al., 2025). However, it also accelerated digital transformation in agricultural extension. Platforms like Kisan Call Centres, the Digital India campaign, and various mobile advisory services gained prominence, offering real-time solutions to farmers' problems through remote means (Zirmire et al., 2025).

Despite these innovations, questions remain about the long-term sustainability of post-pandemic extension service provision. Sustainability, in this context, encompasses not only the ability to continue services without external shocks but also the adaptability of extension systems to meet evolving farmer needs, the inclusiveness of delivery mechanisms, and the environmental, social, and economic implications of disseminated practices. Building sustainable extension systems requires addressing structural issues such as inadequate funding, low extension agent-to-farmer ratios, and lack of integration among multiple service providers. Furthermore, a reimagining of extension delivery is essential—one that combines digital tools with traditional methods, builds local capacity, and fosters participatory, bottom-up approaches (Anderson & Feder, 2007).

In India, the way forward involves leveraging emerging technologies such as artificial intelligence, remote sensing, and machine learning for precision advisory services while simultaneously strengthening grassroots-level institutions. The role of Farmer Producer Organizations (FPOs), Self-Help Groups (SHGs), and community-based platforms has been highlighted as a means to localize extension services and enhance outreach (Venkattakumar et al., 2024). Moreover, the pandemic reinforced the importance of partnerships across public, private, and civil society sectors in ensuring the resilience of extension systems. Multi-stakeholder collaboration, supported by robust policy frameworks and financial investments, is imperative to institutionalize the learnings from the pandemic and build future-ready systems.

The global experience underscores that sustainability in agricultural extension post-COVID-19 is not just a matter of technology adoption, but also of systems thinking, inclusivity, and resilience. As climate change, market volatility, and health risks continue to pose interconnected threats to food security, agricultural extension must evolve into a more dynamic, integrated, and farmer-centric system. In India, this evolution must be rooted in context-specific solutions that consider linguistic diversity, regional agro-ecologies, and socio-economic realities. This review provides a comprehensive analysis of post-COVID agricultural extension systems, focusing on sustainability in service delivery. It evaluates how extension mechanisms adapted during the crisis, identifies the persistent challenges, and outlines pathways for building resilient and sustainable agricultural advisory systems for the future.

2. BACKGROUND OF AGRICULTURAL EXTENSION SERVICES

Agricultural extension services have long played a pivotal role in fostering rural development, improving farm productivity, and ensuring food security. These services are especially crucial in developing countries where a significant proportion of the population is dependent on agriculture for their livelihood. In many such regions, rural populations rely heavily on agriculture not only for subsistence but also as the primary source of income, employment, and economic activity. Agricultural extension — the system of providing farmers with access to timely information, improved technologies, training, and support services — serves as a bridge between research institutions and farming communities (Anderson & Feder, 2007). Historically, extension services have been largely public-sector driven, based on a top-down, supply-led approach wherein government-employed agents disseminate standardized recommendations to farmers. These traditional systems, while instrumental in the Green Revolution and other large-scale agricultural transformations, have come under criticism for being insufficiently responsive to the diverse, localized needs of smallholder farmers, especially in marginalized or remote areas (Baffoe-Bonnie et al., 2021). Moreover, the capacity of extension systems in many developing nations has been constrained by inadequate staffing, funding shortages, logistical barriers, and outdated infrastructure.

Over the past few decades, the model of agricultural extension has evolved toward more participatory, demand-driven approaches, emphasizing farmer empowerment, inclusivity, and innovation. In many developing countries, agricultural value chains — the series of activities involved in producing, processing, marketing, and distributing agricultural products — have become increasingly central to rural development strategies. This trend has given rise to a broader, more integrated view of extension that goes beyond farm-level productivity to include market access, climate resilience, gender equality, and sustainable resource management (Mbo'o-Tchouawou & Colverson, 2014). As agricultural value chains become more complex, so too do the expectations and roles of extension services. However, the advent of the COVID-19 pandemic

brought a massive disruption to agricultural extension systems worldwide. The crisis, which affected nearly every aspect of economic and social life, had a particularly severe impact on rural populations and smallholder agriculture. In response to the spread of the virus, governments implemented stringent containment measures such as lockdowns, quarantines, travel restrictions, and social distancing guidelines. These actions, while necessary for public health, had profound implications for the delivery of agricultural extension services.

In-person training sessions, farmer field schools, demonstration plots, and routine field visits — the backbone of traditional extension — were halted or significantly reduced due to restrictions on gatherings and movement. This led to an abrupt suspension of many public and private extension activities, cutting off millions of farmers from critical technical support, market information, and policy updates during a time of heightened uncertainty and volatility in food systems (CSTD & FAO, 2024). Additionally, supply chain disruptions, labor shortages, and price volatility further compounded the challenges faced by rural producers. The pandemic exposed the lack of preparedness and resilience within many national extension systems. Many extension workers lacked digital tools and training to pivot to remote modes of communication, and institutional frameworks were often ill-equipped to support digital transition. This left many service providers unable to maintain regular contact with the farming communities they serve. In some instances, spontaneous community-based responses or individual initiatives emerged to fill gaps in service delivery, but these were often informal, inconsistent, and limited in scale and scope. The vulnerabilities exposed by COVID-19 have highlighted the urgent need for reimagining and restructuring extension services to withstand future disruptions. The sustainability of traditional, infrastructure-heavy extension systems is now in question, as the conditions of mobility, physical distancing, and rapid digitalization become the norm in the post-pandemic world. In particular, the rigid, centralized structures of many public extension systems have proven ill-suited to the current environment, where flexibility, innovation, and rapid information dissemination are essential.

To maintain continuity of services, it is essential to adopt alternative, innovative models that leverage digital tools, decentralized networks, and public-private partnerships. Remote advisory services via mobile phones, SMS, radio, video conferencing, and dedicated agricultural apps have become vital lifelines for farmers during the pandemic. For instance, platforms like eNAM (Electronic National Agriculture Market) and Kisan Suvidha in India, or iShamba in Kenya, have enabled farmers to receive timely information on prices, weather, pest outbreaks, and input availability (Zirmire et al., 2025). However, transitioning to digital extension is not without challenges. Large segments of the rural population, particularly women, indigenous groups, and those in remote areas, face barriers such as lack of digital literacy, poor connectivity, and limited access to smartphones or internet services. This digital divide threatens to widen inequalities in agricultural knowledge and innovation adoption if not addressed through inclusive policies and targeted investments. In light of these challenges, it is evident that the future of extension services must be resilient, inclusive, and technologically adaptive. Governments and development organizations must not only enhance their capacity to manage digital tools but also reorient extension strategies around participatory, farmer-led models. This involves empowering local actors, investing in digital infrastructure, ensuring gender equity, and creating feedback mechanisms to continually adapt services to changing needs.

The background of agricultural extension services in developing countries reflects both enduring challenges and emerging opportunities. The COVID-19 pandemic served as a catalyst for innovation but also exposed the fragility of traditional systems. Building sustainable extension systems for the future requires a paradigm shift — one that integrates technology, fosters inclusivity, and prepares for uncertainty. Only then can extension services truly support the resilience and prosperity of farming communities in an increasingly complex world.

3. PRE-COVID EXTENSION MODELS: AN OVERVIEW

Prior to the COVID-19 pandemic, agricultural extension services across the globe largely adhered to a traditional, top-down model characterized by a unidirectional flow of information from experts to farmers. Rooted in post-Green Revolution paradigms, these extension systems emphasized the transfer of technology (ToT) approach, wherein state agencies or publicly funded institutions identified problems, developed solutions, and

disseminated them to farmers through extension personnel (Anderson & Feder, 2007). The model presumed uniformity in farmer needs and often overlooked the local context, indigenous knowledge, and participatory approaches essential for sustainable agricultural development. Globally, public-sector agencies were the primary drivers of agricultural extension. However, over the decades, as the limitations of this centralized approach became evident, non-governmental organizations (NGOs), farmer-based organizations (FBOs), private agribusinesses, and international development bodies began participating more actively. These actors brought innovation and responsiveness to localized needs but often operated in silos, leading to fragmentation and duplication of efforts (Davis, 2008). This multi-stakeholder environment highlighted the need for a more integrated and pluralistic extension system.

A key criticism of pre-COVID extension models was their limited capacity to cater to the diverse needs of smallholder farmers, especially in developing countries. The extension worker-to-farmer ratio remained inadequate, with one agent often responsible for thousands of farmers, resulting in poor coverage and impact (Swanson & Rajalahti, 2010). Moreover, these systems were often underfunded, suffered from weak institutional coordination, and lacked performance-based accountability. Gender disparities, youth engagement, and the inclusion of marginalized communities also remained significant challenges, further limiting the effectiveness of traditional models. In India, agricultural extension evolved through various reforms, from the Training and Visit (T&V) system in the 1970s to more decentralized models like the Agricultural Technology Management Agency (ATMA), introduced in the early 2000s. ATMA aimed to create district-level platforms integrating research, extension, and farmer organizations, with the objective of fostering demand-driven and participatory approaches (Glendenning et al., 2010). While conceptually sound, ATMA's operational effectiveness was hampered by bureaucratic inefficiencies, irregular funding, limited autonomy, and insufficient capacity-building initiatives. Furthermore, the reliance on physical means of communication—such as field visits, group training sessions, on-farm demonstrations, and farmer field schools—was central to pre-pandemic extension systems. These methods, although effective in knowledge transfer, were labor-intensive and costly to scale. They were also inherently vulnerable to external shocks such as pandemics, natural disasters, and political disruptions. The COVID-19 crisis highlighted this vulnerability as extension services, particularly those dependent on in-person contact, experienced major disruptions in outreach and implementation (FAO, 2021).

In addition to institutional limitations, the traditional extension models often failed to adapt to rapidly evolving agricultural landscapes characterized by climate change, market volatility, and technological advancements. Farmers increasingly required real-time market information, climate-resilient practices, and digital advisory services—demands that conventional systems struggled to meet due to outdated infrastructure and resistance to innovation (Rivera & Sulaiman, 2009). Despite these limitations, pre-COVID extension systems laid foundational structures for agricultural development and food security. The presence of established networks, experienced personnel, and historical data provided a base upon which post-pandemic transformations could build. The pandemic ultimately served as a catalyst for rethinking and restructuring agricultural extension systems, pushing stakeholders to embrace more flexible, inclusive, and technology-enabled models. While pre-COVID extension services played a crucial role in disseminating agricultural innovations, their top-down nature, limited inclusivity, and reliance on physical interactions rendered them insufficient in addressing contemporary and localized challenges. The disruption caused by the pandemic underscored the urgency of reforming these systems toward more resilient, participatory, and digitally integrated approaches.

4. IMPACT OF COVID-19 ON AGRICULTURAL EXTENSION SYSTEMS

The COVID-19 pandemic drastically altered the landscape of agricultural extension systems worldwide. With global lockdowns, travel restrictions, and social distancing mandates, traditional extension models that relied heavily on face-to-face interactions were severely disrupted. Governments, NGOs, and private extension providers were forced to innovate rapidly and adopt new approaches, particularly through digital means, to maintain support for farmers. This transition highlighted both the vulnerabilities of pre-pandemic systems and the potential of digital tools to redefine extension services.

4.1 Disruptions in Service Delivery

One of the most immediate and profound impacts of COVID-19 on agricultural extension systems was the disruption of physical service delivery mechanisms. Nationwide lockdowns and regional containment zones meant that field visits, group meetings, farmer field schools, training programs, and live demonstrations were abruptly halted (FAO, 2021). These disruptions posed significant challenges for smallholder farmers, especially during critical agricultural seasons when timely information and input support are essential. Extension personnel encountered numerous logistical hurdles. The unavailability of public transportation and movement restrictions impeded their ability to travel to rural areas. Many extension agents were repurposed for public health and pandemic relief duties, further straining the already inadequate workforce (Baffoe-Bonnie et al., 2021). Health concerns and fears of virus transmission discouraged both agents and farmers from in-person engagements, effectively paralyzing outreach efforts. Additionally, the pandemic exposed weaknesses in communication channels. Extension systems that lacked robust contingency plans or diversified communication modes struggled to maintain consistent farmer engagement. The unavailability of physical resources like inputs, diagnostic kits, and training materials further undermined the efficacy of advisory services. These interruptions were particularly damaging in low- and middle-income countries where agricultural extension remains the primary knowledge conduit for millions of resource-poor farmers.

4.2 Digital Acceleration

In response to these disruptions, the agricultural extension sector witnessed an unprecedented pivot to digital technologies. The crisis accelerated the adoption of tools like WhatsApp, Zoom, Facebook Live, and YouTube for disseminating advisories, conducting virtual training sessions, and maintaining communication with farmer groups (Zirmire et al., 2025). In India, government initiatives like Kisan Suvidha, mKisan SMS Portal, and eNAM became crucial for sharing market updates, weather forecasts, and crop management tips (Arulmanikandan et al., 2024). These platforms offered real-time and location-specific advisories to farmers, bridging part of the service delivery gap caused by physical restrictions. Private sector actors and agri-tech startups also entered the fray, offering AI-powered chatbots, remote sensing-based advisories, and e-commerce solutions for agri-inputs. NGOs leveraged Interactive Voice Response Systems (IVRS) and community radio to reach illiterate and semi-literate farmers. These innovations not only ensured continuity in extension but also demonstrated the potential scalability of digital advisory systems. Despite these advances, the digital transition also highlighted persistent inequities in access and capacity. Rural India, like many developing regions, suffers from a pronounced digital divide. Internet penetration, although improving, remains uneven across geographies and socio-economic strata. Many farmers, especially women, older individuals, and those in tribal or remote areas, lack access to smartphones, reliable internet, or the digital literacy needed to utilize these services effectively (Zirmire et al., 2025). Language barriers and the lack of localized content further limited the utility of many digital solutions.

This divide meant that while some farmers benefitted from the digital surge, a significant portion was left behind, exacerbating pre-existing inequalities in information access. The rapid digitalization of extension services, while necessary during the pandemic, thus underscored the need for inclusive digital strategies that cater to diverse farmer profiles and infrastructure realities. COVID-19 served as a stress test for agricultural extension systems, revealing their strengths, limitations, and adaptability. While the pandemic severely disrupted traditional service delivery models, it also catalyzed innovation and fast-tracked digital transformation. Moving forward, hybrid extension models that combine in-person and digital strategies may offer a more resilient and inclusive approach. Investments in digital infrastructure, capacity building, and localized content will be essential to ensure that the benefits of this digital acceleration are equitably distributed among all farming communities.

4.3 Labor Shortages

The COVID-19 pandemic significantly disrupted labor availability in agriculture, with cascading effects on the delivery and effectiveness of agricultural extension systems. Lockdowns, travel restrictions, and quarantines led to widespread labor shortages, not only among farm workers but also within extension services themselves. This disruption hampered seasonal agricultural activities, delayed knowledge

transfer, and undermined the continuity of advisory support to millions of farmers, especially in developing countries. Labor shortages in agriculture during the pandemic were primarily driven by restricted human mobility, both internationally and within countries. Many regions, particularly those reliant on migrant or seasonal labor, experienced acute workforce shortages during critical farming periods such as planting and harvesting (Cortignani et al., 2020). For instance, in India, the abrupt nationwide lockdown in March 2020 resulted in the mass exodus of migrant workers from urban to rural areas, leaving a vacuum in commercial agriculture and extension activities in peri-urban zones (Zirmire et al., 2025). Consequently, the lack of skilled labor affected productivity, led to post-harvest losses, and disrupted the scheduling of extension interventions such as field trials, demonstrations, and data collection.

This workforce crisis also directly affected extension personnel. Many extension agents were reallocated to emergency response duties such as health awareness campaigns and food distribution, limiting their availability for regular agricultural support roles (Baffoe-Bonnie et al., 2021). In some cases, health-related concerns, personal safety fears, and lack of protective gear further reduced extension workers' willingness or ability to conduct in-person visits. The dependency on face-to-face communication made the situation more difficult, especially in areas with limited digital infrastructure. As a result, the quality and frequency of farmer support diminished just when it was most needed for navigating market disruptions, input shortages, and disease outbreaks. Additionally, the shortage of extension labor affected the functioning of farmer producer organizations (FPOs), self-help groups, and agri-cooperatives, which often rely on facilitators or rural youth trained in basic extension functions. With restrictions in place, these groups faced challenges in organizing collective activities, engaging with stakeholders, and accessing timely information. The absence of ground-level support reduced farmers' ability to adapt to changing conditions and exacerbated the digital divide, as many were unable to use mobile advisory platforms without guidance (FAO & ITU, 2023).

Furthermore, the extension system's ability to respond to the labor crisis was limited by structural weaknesses, such as staffing deficits, poor working conditions, and underfunded rural services. In many countries, extension systems were already operating below capacity, with high agent-to-farmer ratios. The added stress of COVID-19 exposed the fragility of these systems and highlighted the need for a more flexible, decentralized, and technology-enabled workforce capable of operating under crisis conditions. The labor shortages triggered by COVID-19 significantly undermined the effectiveness of agricultural extension systems by reducing both farm-level and institutional capacity. Moving forward, policy responses must focus on building resilient, multi-skilled extension workforces, expanding rural labor pools through training programs, and investing in remote service delivery mechanisms that are less reliant on physical presence.

4.4 Market Access Challenges

The COVID-19 pandemic created severe disruptions in agricultural markets globally, significantly impacting the ability of smallholder farmers to sell their produce and access critical inputs. These disruptions also affected agricultural extension systems, whose role in facilitating market linkages, price information, and post-harvest support became more complex and constrained. The combination of lockdowns, supply chain breakdowns, and transportation restrictions created a crisis of market access that extended beyond production to encompass distribution, marketing, and consumption (Epse Taku-Forchu, 2019). During the early stages of the pandemic, mobility restrictions and closure of local markets led to a breakdown in the traditional supply-demand channels. Farmers in remote areas, particularly those dependent on physical wholesale markets or periodic rural bazaars, found it nearly impossible to sell their perishable produce. In India, for example, the shutdown of mandis (agricultural markets) during lockdowns resulted in significant losses for fruit, vegetable, and flower growers (Zirmire et al., 2025). Without timely market access, produce was left to rot, prices plummeted, and incomes sharply declined.

This market disconnection also reduced the effectiveness of extension services, which often include facilitating value chain coordination, organizing collective marketing, or advising farmers on crop choices based on market trends. The absence of such feedback loops led to uncoordinated production, mismatch in supply and demand, and increased vulnerability for farmers reliant on cash crops or export

commodities. Additionally, farmers faced difficulties in accessing inputs such as seeds, fertilizers, and agrochemicals, which are typically sourced from agri-retailers or cooperatives that were shut or operating at limited capacity. Extension agents, who often act as intermediaries or advisors in these supply chains, were unable to assist farmers in identifying alternative sources or logistical support, further limiting productivity and exacerbating uncertainty (Davis et al., 2021). Although some digital platforms attempted to bridge the gap through e-commerce, online trading, or digital advisory tools (e.g., eNAM in India or AgriMarket apps), these innovations had limited reach in rural areas due to poor internet connectivity and digital literacy, particularly among women and marginalized groups (FAO, 2021). Thus, the digital divide also became a market divide. The COVID-19 pandemic exposed the fragility of market systems and the dependency of agricultural extension on physical market linkages. Strengthening market resilience through digital platforms, decentralized storage, localized procurement, and extension-led market literacy will be critical to future-proof food systems and protect farmer livelihoods.

5. POST-PANDEMIC EXTENSION LANDSCAPE

The COVID-19 pandemic has served as a critical inflection point in the evolution of agricultural extension services worldwide. The restrictions on movement, closure of physical extension outlets, and the need for continued farmer support during the crisis catalyzed a transformation in the way extension services are delivered. The post-pandemic extension landscape is increasingly characterized by adaptive, resilient, and technologically enabled systems that combine digital innovation with human-centered support. Key themes that define this new landscape include the emergence of hybrid extension models, the strengthening of public-private partnerships (PPPs), and the incorporation of advanced technologies like artificial intelligence (AI) and information and communication technologies (ICTs) into service delivery.

5.1 Emergence of Hybrid Models

In the wake of the pandemic, agricultural extension systems across the globe have shifted towards hybrid models that blend digital tools with traditional, face-to-face interactions. These models aim to address the weaknesses of both purely physical and entirely digital approaches, providing flexibility, scalability, and greater inclusivity. While digital platforms offer efficiency, cost-effectiveness, and the ability to reach large numbers of farmers, in-person interactions remain crucial for trust-building, contextual understanding, and support for digitally marginalized groups (Baffoe-Bonnie et al., 2021).

In India, for example, post-pandemic extension initiatives often involve the use of mobile apps, SMS services, and social media platforms for sharing technical advisories, combined with localized farmer meetings or on-site visits where safe and necessary (Ojha & Mishra, 2021). Farmer Producer Organizations (FPOs), Krishi Vigyan Kendras (KVKs), and ATMA functionaries have increasingly employed this dual strategy to maintain engagement with farming communities (Kedia et al., 2020). This model has shown promise not only in delivering timely information but also in facilitating feedback, monitoring adoption, and enhancing learning outcomes. The hybrid model also allows for differentiated engagement strategies, such as tailoring communication based on farmer literacy levels, crop types, or regional needs. For instance, digital content can be complemented by community radio broadcasts, field demonstrations, or peer-to-peer learning through lead farmers, thereby ensuring inclusiveness and cultural relevance (Swanson & Rajalahti, 2010; Ojha, 2023). However, implementing such models at scale requires investments in capacity building, digital infrastructure, and institutional coordination.

5.2 Public-Private Partnerships (PPP)

Public-private partnerships have gained new momentum in the post-COVID extension framework. The pandemic highlighted the limitations of public extension systems in reaching dispersed and diverse farming populations, particularly during crises. To bridge these gaps, collaborations between government agencies, NGOs, agri-tech startups, and private agribusinesses have become increasingly prominent. These partnerships leverage the strengths of each sector. Public institutions offer legitimacy, reach, and agricultural research capabilities, while private players contribute technological innovation, financial investment, and agile service delivery. For example, several Indian states partnered with digital startups to deliver app-based pest and disease diagnostics, weather alerts, and market information during the

pandemic (Zirmire et al., 2025). Platforms like eNAM (Electronic National Agriculture Market), Kisan Suvidha, and AgriStack were strengthened through collaboration between public departments and private technology providers. Moreover, PPP models facilitated the creation of digital input marketplaces and logistics solutions, ensuring that farmers could access seeds, fertilizers, and equipment despite mobility restrictions. Organizations such as Digital Green and Precision Agriculture for Development (PAD) worked closely with state governments and local NGOs to scale digital advisories using interactive voice response systems and SMS campaigns, particularly targeting smallholders and women farmers. PPP-based extension frameworks have also evolved to include business incubation services, financial inclusion, and climate-smart agriculture solutions. The ability of these partnerships to provide integrated support—from information dissemination to market access and risk management—has positioned them as vital components of resilient extension ecosystems. Nevertheless, these partnerships must be governed by transparent policies and equitable benefit-sharing mechanisms to avoid marginalization of small farmers or over-commercialization of advisory services.

5.3 Role of ICT and AI

Information and Communication Technologies (ICTs), alongside Artificial Intelligence (AI), are revolutionizing agricultural extension by enabling real-time, data-driven, and customized advisory services. These technologies enhance the precision, responsiveness, and reach of extension efforts, especially in resource-constrained settings. AI and machine learning (ML) algorithms are increasingly being used to analyze satellite imagery, weather patterns, soil health data, and crop performance indicators to offer predictive insights to farmers. For instance, AI-powered platforms like Microsoft's AI Sowing App in Andhra Pradesh have demonstrated improvements in yield and input efficiency by providing personalized planting advice based on localized weather and soil data (Dev & Sheoran, 2025). Similarly, Google's AI-based flood forecasting has been integrated with agricultural advisories to mitigate risks related to climate variability.

Remote sensing and Geographic Information Systems (GIS) are now integral to monitoring crop health, detecting pests and diseases, and guiding irrigation and nutrient management. These tools support both macro-level planning and micro-level decision-making, benefiting extension agents and farmers alike. Mobile-based applications, like Plantix and CropIn, utilize image recognition and AI to diagnose crop disorders through farmers' smartphone cameras and offer instant remediation strategies. ICT platforms, such as WhatsApp groups, IVRS, YouTube channels, and mobile advisory apps, have become mainstream channels for knowledge dissemination and farmer engagement. These tools support two-way communication, peer learning, and community building—essential features of modern extension systems. Furthermore, big data analytics allows policymakers and researchers to track adoption trends, feedback loops, and the impact of interventions in near real-time (FAO, 2022).

However, the adoption of these technologies is not without challenges. The digital divide, characterized by disparities in internet access, device ownership, and digital literacy, continues to hinder the universal uptake of AI and ICT-based tools. Gender disparities and regional inequities must be addressed through inclusive digital design, multilingual platforms, and targeted digital literacy programs to ensure equitable access to technology-enabled extension (Zirmire et al., 2025). The post-pandemic extension landscape is evolving into a dynamic ecosystem shaped by hybrid service models, synergistic public-private collaborations, and powerful digital technologies. While the crisis exposed critical vulnerabilities in traditional extension systems, it also accelerated long-overdue reforms and innovations. Going forward, the challenge lies in institutionalizing these changes, ensuring digital inclusiveness, and aligning extension services with broader goals of sustainability, resilience, and equity. Strategic investments in infrastructure, human capacity, and data governance will be essential to harness the full potential of post-pandemic agricultural extension.

6. CHALLENGES IN SUSTAINING EXTENSION SERVICES

The transformation of agricultural extension services in the wake of the COVID-19 pandemic has brought renewed attention to their critical role in ensuring food security, rural development, and climate resilience. While innovations such as hybrid models and digital extension tools have created new opportunities, they have also exposed significant challenges to the

sustainability of these systems. For extension services to remain effective, inclusive, and future-ready, systemic barriers such as digital inequality, trust deficits, capacity limitations, and infrastructural shortcomings must be addressed. This section explores the multifaceted challenges that threaten the long-term sustainability of agricultural extension services.

6.1 Digital Inequality

One of the most pressing challenges in sustaining modern extension systems is digital inequality. While digital tools such as mobile applications, SMS services, and AI-driven advisory platforms have proliferated, their benefits remain unevenly distributed. Large segments of smallholder farmers—especially in low- and middle-income countries—do not have access to smartphones, stable internet connectivity, or even basic digital literacy. This digital divide reinforces existing social and economic inequalities, disproportionately affecting women, elderly farmers, and marginalized communities, including those from lower caste and tribal backgrounds in countries like India (Zirmire et al., 2025).

According to the International Telecommunication Union (ITU, 2022), only 43% of people in rural areas worldwide have access to the internet, compared to 74% in urban areas. In India, a country with over 100 million smallholder farmers, internet access in rural regions remains patchy, and smartphone penetration varies widely. Many farmers also face linguistic barriers, as most digital platforms are available only in dominant regional or national languages, excluding those who speak minority dialects (FAO, 2021). Gender digital inequality is particularly severe. Studies show that rural women are 20% less likely than men to own a mobile phone and 40% less likely to access mobile internet (GSMA, 2021). This gap has serious implications for inclusive agricultural development, as women play a crucial role in farming activities and household food security. Unless digital interventions are explicitly designed to bridge these gaps, they risk deepening disparities rather than democratizing access to information.

6.2 Trust and Human Connection

Agricultural extension has traditionally relied on interpersonal communication and trust-building between extension agents and farmers. These relationships are rooted in community knowledge systems, face-to-face interactions, and long-term engagement. The rapid shift toward digital advisory services—especially during the pandemic—has altered this dynamic, raising concerns about credibility, trust, and adoption. Farmers, particularly older and less literate ones, often prefer advice from trusted local sources such as peer farmers, village leaders, or familiar extension agents over impersonal SMS messages or chatbot-based advisories (Baffoe-Bonnie et al., 2021). Even when digital information is technically sound, it may not be acted upon if the farmer does not trust the source or lacks contextual understanding.

Moreover, the effectiveness of advisory services often depends on non-verbal cues, practical demonstrations, and feedback loops—elements that are difficult to replicate in purely digital formats. Community-based extension models, such as Farmer Field Schools and participatory research platforms, emphasize experiential learning and mutual trust, which are not easily replaced by digital communication (Anderson & Feder, 2007). In the post-pandemic landscape, re-establishing human connections through hybrid extension models is critical. Digital tools must be seen as complementary to—not replacements for—personal engagement. Trust in digital systems can be built over time by involving local extension agents in content dissemination, incorporating farmer feedback, and ensuring transparency in information delivery.

6.3 Capacity Building

The sustainability of extension services also hinges on the capacity of extension agents to adapt to evolving demands. Traditionally trained to conduct field visits, organize training camps, and deliver technical advisories, many extension professionals now need to acquire new skills in digital content creation, online facilitation, data analytics, and ICT tool usage. This transition requires systematic and ongoing capacity-building efforts. However, many extension systems are already under-resourced and overstretched. In countries like India, the extension worker-to-farmer ratio remains alarmingly low, with one agent often covering thousands of farmers (Glendenning et al., 2010). Expecting these professionals to embrace new digital roles without adequate training or support can lead to burnout, reduced service quality, and resistance to change.

Furthermore, capacity-building programs must be tailored to diverse learning needs. Younger agents may be more digitally fluent but lack field experience, while older staff may require foundational ICT training but bring valuable contextual knowledge. Extension institutions must develop modular, hands-on training curricula that blend digital literacy with agricultural expertise and communication skills. Collaborations with academic institutions, tech providers, and NGOs can facilitate these efforts. For instance, partnerships with agri-tech startups can help familiarize extension agents with AI-powered tools and mobile platforms. Universities can integrate digital extension modules into agricultural education, preparing future professionals for the hybrid service landscape.

6.4 Infrastructure and Funding

Another significant barrier to sustaining extension services is inadequate infrastructure and inconsistent funding. Despite the growing emphasis on digital transformation, rural areas in many developing countries still suffer from unreliable electricity, poor mobile network coverage, and limited access to digital devices. These infrastructural bottlenecks hinder both farmers and extension agents from utilizing technology-based solutions effectively. In India, the Digital India initiative has made strides in improving broadband access, but the rural-urban divide persists. In many villages, poor signal strength, frequent power cuts, and low data speeds limit the usefulness of digital advisory platforms (GoI, 2022). Even where infrastructure exists, the cost of smartphones, data plans, and maintenance remains prohibitive for many smallholder farmers. Sustaining extension services also requires long-term investment in operational and institutional infrastructure. Many public extension systems face chronic budget shortfalls, limiting their ability to hire staff, maintain equipment, or innovate. Development projects funded by international agencies or corporate CSR programs often provide temporary boosts but may not be sustainable beyond the project cycle.

Governments must therefore prioritize extension services in their agricultural development strategies, ensuring regular budget allocations, incentivizing performance, and supporting innovation. Public-private partnerships can also play a role, but they must be governed by clear frameworks that prioritize farmer welfare and data privacy. The sustainability of agricultural extension services in the post-pandemic world depends on how effectively they can navigate and overcome structural challenges. Digital inequality, trust deficits, capacity limitations, and infrastructural shortcomings remain formidable barriers. While technology has opened new avenues for outreach, inclusivity and relevance must guide the design and implementation of extension strategies. Human-centered, context-aware, and institutionally supported approaches will be key to creating resilient and sustainable extension systems that empower farmers and promote equitable agricultural development.

7. GLOBAL CASE STUDIES AND BEST PRACTICES

In the post-pandemic era, global agricultural extension systems have undergone substantial innovation to adapt to rapidly evolving challenges. Countries around the world, especially those with large agrarian economies or vulnerable farming populations, responded to the COVID-19 crisis with various degrees of adaptability, resilience, and technological integration. These experiences offer rich lessons and best practices that can guide the design of more inclusive, efficient, and sustainable extension services. This section highlights key global case studies and best practices in agricultural extension from India, Kenya, the Philippines, the United States, and international organizations such as FAO and CGIAR.

7.1 India: Digital Extension and Public-Private Collaboration

India's response to the disruption of traditional extension during the COVID-19 pandemic serves as a notable case of innovation under constraint. With physical extension services halted during lockdowns, the Indian government and private agri-tech startups rapidly deployed digital platforms such as Kisan Suvidha, eNAM (Electronic National Agriculture Market), and mKisan Portal to continue delivering services. These platforms provided timely advisories on weather, market prices, pest outbreaks, and logistics services (Zirmire et al., 2025). In addition, Precision Agriculture for Development (PAD) collaborated with government agencies and local partners to deliver advisory messages via Interactive Voice Response Systems (IVRS) and SMS in local languages. This helped reach smallholders with low literacy or limited internet access. The hybrid use of traditional and digital channels became a model of inclusive outreach.

Another best practice is the promotion of Farmer Producer Organizations (FPOs) as decentralized hubs for capacity building, information sharing, and input-output linkage. These FPOs worked closely with Krishi Vigyan Kendras (KVKs) and NGOs to strengthen trust and enable knowledge transfer, combining human connection with technological efficiency Kedia et al., 2020).

7.2 Kenya: Mobile Platforms and AI-Powered Advisories

In Kenya, the integration of mobile technology and AI for smallholder farmers has emerged as a successful strategy in enhancing extension delivery. One of the standout platforms is iShamba, a mobile-based service developed by Mediae Company. It offers real-time agricultural tips, market prices, and weather forecasts through SMS and call centers. iShamba has built trust among farmers by using local languages and call center agents who understand the local agricultural context (Swanson & Rajalahti, 2010). In collaboration with Twiga Foods, a digital marketplace that connects farmers directly with vendors, extension services were paired with access to inputs and guaranteed markets. This integration of advisory with value chain services proved effective in minimizing disruptions during COVID-19 lockdowns and improved farmer resilience. Kenya also leveraged partnerships with international research institutions to deploy AI-powered diagnostic tools, such as PlantVillage Nuru, an app developed by Penn State University and FAO. The app uses smartphone cameras and AI to detect plant diseases and recommend solutions. This tool democratized expert knowledge and enhanced early warning capabilities for crop health (FAO, 2021).

7.3 Philippines: Localized Digital Extension and Gender Inclusion

The Philippines provides an example of decentralized digital extension with a strong focus on gender-sensitive and community-based approaches. The Department of Agriculture, through its Agricultural Training Institute (ATI), scaled up its e-Extension Program for Agriculture and Fisheries, which includes e-learning courses, digital libraries, and mobile advisories. During the pandemic, ATI partnered with LGUs (local government units), universities, and civil society to deliver blended learning programs. Women farmers and youth were particularly engaged through mobile-based training sessions and peer-led community groups (Inutan, 2024). This inclusive model addressed digital literacy gaps and built local ownership of extension processes. In addition, the use of community radio in remote areas allowed real-time broadcasting of farming tips and pandemic-related advisories. This low-tech but effective strategy proved essential in archipelagic and disaster-prone regions with limited internet access.

7.4 United States: Extension and Emergency Response Integration

In high-income countries like the United States, the Land-Grant University Cooperative Extension System has long been a model for knowledge dissemination and community outreach. During the COVID-19 pandemic, institutions such as Penn State Extension, University of California Cooperative Extension, and Texas A&M AgriLife Extension pivoted swiftly to virtual platforms. Through webinars, YouTube tutorials, digital newsletters, and virtual office hours, these programs maintained continuity in delivering agricultural support. In addition, U.S. extension services collaborated with health agencies to disseminate COVID-19 safety guidelines, becoming a conduit for both agricultural and public health information (Baffoe-Bonnie et al., 2021). The U.S. case illustrates the importance of institutional infrastructure, digital readiness, and cross-sectoral coordination in maintaining extension services during crises.

7.5 CGIAR and FAO: Global Digital Public Goods

International organizations such as the Consultative Group for International Agricultural Research (CGIAR) and the Food and Agriculture Organization (FAO) have played pivotal roles in fostering global best practices. FAO's Digital Village Initiative aims to create digital ecosystems in rural areas by integrating e-agriculture, e-learning, and digital financial services. The initiative supports countries in building infrastructure and capacity to sustain digital extension models (FAO, 2022). CGIAR, through programs like Digital Agriculture Advisory Services (DAAS), is promoting open-source tools and digital public goods that enhance agricultural advisory systems. These include weather-based decision tools, digital pest surveillance systems, and interoperable data platforms that facilitate collaboration across stakeholders.

Table 1. Consolidated summary of best practices in agricultural extension: insights from global case studies

Best Practice	Description	Key Benefits	Examples
Hybrid Extension Models	Combining digital tools (mobile apps, SMS, video calls) with traditional face-to-face methods such as field visits and demonstrations.	Inclusive outreach, greater trust, personalized support	India's KVKs and FPOs using WhatsApp plus field demonstrations; U.S. Land-Grant Universities offering webinars with physical consultations.
Localized Content and Language	Designing extension messages in local dialects using culturally appropriate visuals, formats, and examples.	Higher comprehension, increased engagement, better adoption	Kenya's iShamba and India's IVRS systems offer advisories in local languages; community radio in the Philippines provides native-language programming.
Gender and Social Inclusion	Tailoring programs for women, youth, and marginalized groups through targeted outreach and simplified digital interfaces.	Reduces inequality, empowers underserved farmers	Philippines' ATI training for women and youth; GSMA mAgri programs tailored for women; India's digital literacy workshops for rural women.
Public-Private Partnerships	Collaborating across government, NGOs, startups, and agribusinesses for integrated services including input supply, digital platforms, and market linkages.	Greater innovation, scalability, and cost-effectiveness	PAD's work with Indian governments; Twiga Foods in Kenya linking farmers to markets; CGIAR and FAO digital agriculture tools deployed globally.
Use of ICT and AI	Leveraging artificial intelligence, machine learning, mobile-based diagnostics, satellite data, and decision-support tools to deliver customized advisories.	Enhances precision, timeliness, and productivity	Microsoft's AI Sowing App (India); PlantVillage Nuru (Kenya); CropIn and Plantix apps diagnosing plant diseases using AI and image recognition.
Community Media and IVRS	Utilizing community radio, voice messaging, and IVRS to reach farmers with limited literacy or internet access.	Inclusive access, low cost, broad coverage	Community radio in the Philippines; IVRS advisories in India and Africa; Digital Green's voice-based messages for smallholders.
Capacity Building	Continuous training of extension agents and farmers in digital literacy, content development, and data management for effective hybrid extension delivery.	Strengthens human resources, improves service quality and uptake	Training by India's MANAGE, FAO e-learning platforms, U.S. extension staff workshops, ICT modules in agricultural university curricula globally.

Global experiences in agricultural extension during and after the COVID-19 pandemic illustrate that resilience, adaptability, and innovation are central to sustainability. Countries that embraced hybrid models, localized digital tools, and strong institutional partnerships were better able to continue serving their farming communities. The lessons learned offer a blueprint for future-ready extension systems that are inclusive, technology-enabled, and responsive to local needs.

8. SUSTAINABILITY FRAMEWORK FOR FUTURE EXTENSION SERVICES

The COVID-19 pandemic exposed both the vulnerabilities and potential of agricultural extension systems globally. As the sector emerges from the crisis, a sustainable and resilient framework for extension services is essential. This framework must be adaptable to future shocks, inclusive of all farming communities, and embedded in collaborative ecosystems. The key pillars of a sustainable extension system include farmer-centric approaches, digital inclusivity, public-private partnerships, and enhanced resilience planning. These elements are interdependent and together offer a blueprint for transforming agricultural extension into a future-ready system.

8.1 Farmer-Centric Approaches

The future of agricultural extension must prioritize farmers not only as recipients of information but as active participants in knowledge creation and dissemination. Traditional top-down models, where advice flows from institutions to farmers with minimal feedback, have shown limited effectiveness, particularly in addressing the diverse and localized challenges faced by smallholders (Anderson & Feder, 2007). A farmer-centric model emphasizes participatory approaches such as farmer field schools (FFS), on-farm trials, innovation platforms, and feedback mechanisms.

Participatory extension ensures that advisory content is contextually relevant and empowers farmers to experiment, share local knowledge, and build peer networks. Studies have shown that farmer-led approaches improve adoption rates and foster long-term behavioral change (Baffoe-Bonnie et al., 2021). Feedback loops — through surveys, interactive voice response systems (IVRS), or community forums — can inform continuous improvement in extension design and delivery. Moreover, recognizing the heterogeneity among farmers — including gender, caste, landholding size, and literacy — is essential. Tailoring interventions to meet the needs of marginalized groups, including women, youth, and indigenous communities, will make extension more equitable and effective (Zirmire et al., 2025).

8.2 Digitally Inclusive Infrastructure

Digital technologies have revolutionized agricultural extension by improving outreach, reducing costs, and enabling real-time communication. However, digital inclusion remains a significant barrier, particularly in low-income and remote rural areas. A sustainable extension framework must ensure that digital innovations do not widen existing inequalities. Digital inclusion involves three key dimensions: infrastructure, affordability, and literacy. First, governments and development partners must invest in reliable rural internet connectivity, electricity supply, and mobile network coverage. Without these basic enablers, the benefits of mobile apps, SMS services, and online platforms remain inaccessible to many farmers (FAO, 2022).

Second, affordability of digital devices and data plans must be addressed through subsidies, shared access points (e.g., community kiosks), or bundled services offered by cooperatives and farmer producer organizations (FPOs). Third, building digital literacy — not just functional skills but the ability to critically interpret digital information — is vital. Training programs for both farmers and extension agents should include modules on using smartphones, accessing digital content, and interacting with advisory platforms. Inclusive digitalization also requires content to be developed in local languages, culturally appropriate formats, and user-friendly interfaces. Using low-tech solutions like IVRS, community radio, and voice-enabled apps can bridge the gap for farmers with limited literacy (Swanson & Rajalahti, 2010).

8.3 Public-Private Synergy

Collaboration across public, private, and civil society actors is essential for sustaining extension services. The pandemic demonstrated the critical role that agri-tech startups, non-governmental organizations (NGOs), and farmer groups can play in supporting government-led

efforts. A sustainable model leverages the comparative strengths of different actors — research institutions bring scientific credibility, startups offer technological innovation, NGOs provide grassroots outreach, and agribusinesses contribute market access and logistics. Public-private partnerships (PPP) can take various forms: co-development of digital platforms, shared delivery of training programs, bundled service provision (e.g., input supply plus advisory), and market linkage facilitation. For instance, organizations like Digital Green, Precision Agriculture for Development (PAD), and e-Choupal in India have demonstrated how PPPs can scale extension services while maintaining relevance and quality (Kedia et al., 2020). To ensure accountability and alignment with farmer needs, PPP frameworks should be guided by clear governance structures, transparent data policies, and shared monitoring systems. Governments must play a regulatory and enabling role — providing incentives for private actors, safeguarding farmers' data rights, and promoting open standards and interoperability.

8.4 Enhancing System Resilience

The COVID-19 crisis underscored the importance of building resilience into agricultural extension systems. Future threats — including climate change, pandemics, geopolitical conflicts, and economic shocks — are likely to disrupt food systems and require agile responses. A resilient extension framework should include contingency planning, decentralization of services, and multi-hazard early warning systems. For example, mobile advisories can be rapidly reprogrammed

Table 2. Strategic enablers for building resilient and scalable post-pandemic agricultural extension systems

Strategic Enabler	Function in Extension Transformation	System-Level Objective	Post-COVID Innovation Need
Institutional Resilience	Reorganizing extension structures to adapt to shocks and maintain service continuity	Ensure uninterrupted delivery under crisis conditions	Develop decentralized, contingency-ready extension architecture
Digital Governance	Creating policy frameworks for data use, privacy, digital rights, and interoperability	Foster trust and coordination among public-private actors	Build legal-regulatory frameworks for responsible digital extension
Agroecological Intelligence	Using data analytics, AI, and GIS for agro-climatic and risk-sensitive advisories	Enhance precision, sustainability, and local relevance	Integrate weather, soil, and remote-sensing data into tailored extension messages
Multi-Stakeholder Ecosystem	Aligning efforts of research, academia, startups, NGOs, and FPOs	Expand reach, co-innovation, and scale	Formalize innovation platforms and consortia for extension co-creation
Financial Sustainability	Securing long-term funding, blended finance, and private sector participation	Maintain consistent investment in extension innovation	Leverage agri-tech investment, CSR, and green finance channels
Human Capital Development	Continuous upskilling of agents and youth involvement in digital agriculture	Build a modern, tech-savvy extension workforce	National digital agri-extension capacity building missions
Behavioral Change Systems	Designing behaviorally informed extension content and delivery	Promote technology adoption and resilient farming behaviors	Use nudges, gamification, and locally trusted influencers in communication
Monitoring Intelligence	Data-driven, real-time M&E integrated into extension systems	Improve feedback loops, accountability, and impact visibility	Use mobile dashboards, AI-powered analytics, and participatory M&E tools

to deliver emergency information during floods, pest outbreaks, or lockdowns. Training extension agents in crisis communication, disaster risk reduction, and mental health first aid can enhance preparedness at the local level.

Decentralized extension models — anchored in farmer organizations, cooperatives, or community-based facilitators - can maintain continuity when centralized institutions are strained. These models also enhance social capital and local accountability (Baffoe-Bonnie et al., 2021). Moreover, resilience can be reinforced by integrating climate-smart agriculture (CSA) practices into extension curricula, encouraging diversification of crops and income sources, and promoting sustainable resource management. Global institutions such as FAO and CGIAR advocate for systems thinking in extension - understanding that resilience requires coordination across sectors including health, education, environment, and finance. Extension should thus be part of broader rural development strategies and national adaptation plans.

Designing a sustainability framework for future agricultural extension services requires a holistic, inclusive, and dynamic approach. Placing farmers at the center of the system ensures relevance and ownership. Bridging digital divides through targeted infrastructure and capacity building prevents marginalization in the digital age. Cross-sector collaboration enables innovation, resource pooling, and efficiency, while resilience planning prepares systems to withstand future disruptions. Such a framework not only supports food security and rural livelihoods but also strengthens the overall agricultural ecosystem. As countries invest in post-pandemic recovery and digital transformation, embedding these principles into extension policies and programs will be critical for sustainable agricultural development.

9. POLICY IMPLICATIONS AND RECOMMENDATIONS

The rapid transformation of agricultural extension services in response to the COVID-19 pandemic has highlighted both the potential and the limitations of existing systems. The crisis accelerated the adoption of digital tools, prompted collaboration among diverse stakeholders, and reinforced the critical importance of agricultural knowledge dissemination. However, to make these advances sustainable and equitable, robust policy support is essential. This section explores the key policy implications and provides comprehensive recommendations in four major areas: support for digital extension, capacity development, monitoring and evaluation, and localization of services.

9.1 Policy Support for Digital Extension

Government policies play a pivotal role in shaping the future of digital agricultural extension. As digital platforms, mobile applications, and artificial intelligence tools increasingly become part of the extension landscape, policies must evolve to create enabling environments for innovation and inclusivity. One of the foremost policy priorities is investment in rural digital infrastructure, including broadband internet, mobile connectivity, and electricity access. Without these foundational investments, digital extension cannot be scaled to reach the majority of smallholder farmers, especially in low- and middle-income countries (FAO, 2022). Policies should also incentivize public-private partnerships (PPPs) that harness the innovation capacity of agri-tech startups, private firms, and research institutions. These partnerships can lead to the development of user-friendly digital tools, bundled service offerings (e.g., advisory plus market linkage), and scalable platforms. In India, the government's Digital India and National e-Governance Plan in Agriculture (NeGP-A) have laid the groundwork for digital transformation in agriculture by supporting ICT infrastructure and mobile-based services (Zirmire et al., 2025). Further, data governance policies must ensure that farmer data privacy, consent, and ownership are protected. Clear regulations should define how extension platforms collect, store, and use data, with mechanisms for redress and transparency. The promotion of open-source digital public goods — tools and platforms that can be adapted and used freely — can accelerate innovation and reduce duplication across states and countries (Swanson & Rajalahti, 2010).

9.2 Capacity Development

Digital transformation in extension services requires not only technological tools but also skilled human resources. Extension agents, who have traditionally focused on in-person advisory and field demonstrations, must now develop competencies in using digital platforms, producing multimedia content, facilitating virtual interactions, and managing data. This necessitates a systematic, ongoing policy

commitment to professional development. Governments should mandate and fund regular training programs for extension workers, covering digital literacy, communication skills, participatory methods, gender sensitivity, and the use of artificial intelligence tools. These trainings should be modular, practical, and tailored to different levels of proficiency. For example, while some agents may need basic smartphone training, others may benefit from advanced data analytics or content creation workshops. Capacity development should also target institutional leadership. Senior officials in agricultural departments and research institutes must understand the strategic value of digital tools and allocate resources accordingly. Furthermore, partnerships with academic institutions, international organizations, and the private sector can provide technical expertise, training materials, and platforms for learning exchange (Baffoe-Bonnie et al., 2021). It is equally important to build the digital capacity of farmers, particularly women, youth, and marginalized groups. Policies should support digital literacy programs, creation of digital hubs, and peer-led training models in rural areas. Incentives such as subsidized smartphones, free data packages, or rewards for digital engagement can accelerate adoption among low-resource farmers.

9.3 Monitoring and Evaluation

A major gap in many extension systems is the lack of robust monitoring and evaluation (M&E) mechanisms. Without reliable data on service reach, effectiveness, equity, and impact, policymakers cannot make informed decisions or justify investments. Therefore, a sustainability-oriented extension policy must prioritize the creation of strong M&E frameworks. These frameworks should include real-time data systems that track user engagement, feedback, and outcomes across different channels — digital, in-person, and hybrid. Dashboards and analytics tools can help visualize trends, identify underserved groups, and flag issues in service delivery. For instance, digital extension platforms can track message open rates, app usage patterns, and user satisfaction surveys to refine strategies. Extension M&E should go beyond output indicators (e.g., number of messages sent) to include outcome and impact indicators, such as changes in farmer knowledge, productivity, resilience, or income. Participatory monitoring approaches that involve farmers in assessing extension services can provide richer insights and foster trust. At the policy level, governments should integrate extension M&E into national agricultural data systems and align them with broader rural development goals. Regular public reporting and open data policies can promote accountability and stakeholder collaboration (FAO, 2021).

9.4 Localization of Services

The success of extension services hinges on their relevance to the local context. Agricultural practices vary widely by agro-ecological zone, soil type, cropping pattern, socio-economic status, and cultural norms. Therefore, extension content must be localized to meet the specific needs and realities of target communities. Policies should mandate the development of region-specific content in local languages and dialects, using culturally appropriate visuals, metaphors, and communication styles. This is especially critical for engaging farmers with low literacy levels or unfamiliarity with mainstream media. Use of community radio, folk storytelling, and video tutorials in local languages can significantly enhance comprehension and retention. Localization also involves customizing advisory content based on real-time, location-specific data, such as weather, pest outbreaks, and market prices. Integration of ICT tools like geographic information systems (GIS), satellite imagery, and AI-powered analytics can enable personalized and predictive recommendations. Extension delivery should also be decentralized, empowering district and village-level institutions to adapt content, select delivery channels, and respond to local feedback. For example, India's Krishi Vigyan Kendras (KVKs) and Farmer Producer Organizations (FPOs) can act as nodes for localized content development and dissemination (Kedia et al., 2020). Moreover, policies should support inclusive localization by involving women, youth, indigenous leaders, and disabled farmers in content co-creation, feedback collection, and peer training. This ensures that extension reflects the diversity of farming communities and enhances ownership.

As agricultural extension services continue to evolve in the post-pandemic world, strong and forward-looking policies will be vital to sustain progress and ensure equity. Support for digital innovation, inclusive infrastructure, and public-private collaboration can drive transformation, but only if backed by skilled personnel, responsive monitoring systems, and culturally relevant content. Policymakers must recognize

that extension is not just a technical function but a vehicle for empowerment, innovation, and rural development. A comprehensive policy framework that integrates digital inclusivity, capacity development, M&E, and localization can help build resilient, future-ready extension systems capable of navigating global challenges and advancing sustainable agriculture.

10. CONCLUSION

The COVID-19 pandemic served as a stress test for agricultural extension systems, revealing both latent weaknesses and transformative potential. Traditional models, heavily reliant on face-to-face interactions and rigid bureaucratic structures, proved unsustainable in times of crisis. In response, many countries adopted hybrid and digital approaches, fostering innovation, speed, and adaptability. However, these advances were unevenly distributed due to infrastructural, socio-economic, and gender-based barriers. The transition to digital platforms exposed a stark digital divide, particularly among marginalized rural populations. To build sustainable extension systems for the future, it is imperative to invest in inclusive digital infrastructure, continuous capacity development, robust monitoring systems, and localized service delivery. Public-private partnerships and community-based platforms must be institutionalized to ensure outreach, equity, and innovation. Policy frameworks should prioritize resilience, responsiveness, and farmer engagement. Extension systems must not only disseminate information but also empower farmers to co-create and adapt knowledge in real time. As food systems face climate change, market instability, and health crises, resilient extension services will be foundational to agricultural sustainability and rural development. This comprehensive analysis advocates for a proactive, inclusive, and technology-enabled extension ecosystem equipped to serve the diverse and evolving needs of farmers in a post-pandemic world.

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 writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Adjognon, G. S., Bloem, J. R., & Sanoh, A. (2020). The Coronavirus Pandemic and Food Security: Evidence from West Africa. *Policy Research Working Paper* (No. 9474). https://documents1.worldbank.org/curated/en/594491605102982608/pdf/The-Coronavirus-Pandemic-and-Food-Security-Evidence-from-West-Africa.pdf

Anderson, J. R., & Feder, G. (2007). Agricultural extension. In R. Evenson & P. Pingali (Eds.), *Handbook of Agricultural Economics* (Vol. 3, pp. 2343–2378). Elsevier. https://doi.org/10.1016/S1574-0072(06)03086-7

Arulmanikandan, N., Mishra, A., Shehrawat, P., & Malik, J. S. (2024). Empowering farmers through digital agricultural practices — A review. *Journal of Community Mobilization and Sustainable Development, 19*(1), 9–16. https://doi.org/10.5958/2231-6736.2024.00002.4

Baffoe-Bonnie, A., Martin, D. T., & Mrema, F. (2021). Agricultural extension and advisory services strategies during COVID19 lockdown. *Agricultural & Environmental Letters, 6*(4). https://doi.org/10.1002/ael2.20056

Cortignani, R., Carulli, G., & Dono, G. (2020). COVID-19 and labour in agriculture: Economic and productive impacts in an agricultural area of the Mediterranean. *Italian Journal of Agronomy*. https://doi.org/10.4081/ija.2020.1653

CSTD & FAO. (2024). Commission on Science and Technology for Development (CSTD) & Food and Agriculture Organization. Submission by Food and Agriculture Organization. In *Twenty-seventh Session [Report]*. https://unctad.org/system/files/non-official-document/wsis2023_c08_fao_en.pdf

Davis, K. (2008). Extension in sub-Saharan Africa: Overview and assessment of past and current models, and future prospects. *Journal of International Agricultural and Extension Education, 15*(3), 15–28. https://doi.org/10.5191/jiaee.2008.15302

Dev, K., & Sheoran, S. (2025). Sowing innovation: The role of artificial intelligence in transforming India's agricultural landscape. *International Journal of Research Publication and Reviews, 6*(6), 7253–7257.

https://ijrpr.com/uploads/V6ISSUE6/IJRPR48557.pdf

Epse Taku-Forchu, N. (2019). Linking smallholder farmers to markets: The role of extension in market information distribution for poverty reduction in Fako, Cameroon.

FAO & ITU. (2023). *Digital excellence in agriculture report – FAO-ITU regional contest on good practices advancing digital agriculture in Europe and Central Asia*. Budapest, FAO. https://doi.org/10.4060/cc4764en

FAO. (2021). *Agricultural livelihoods and food security in the context of COVID-19: Results from household surveys in 11 countries with high pre-existing levels of food insecurity – Cross-country monitoring report, May 2021*. Rome. https://doi.org/10.4060/cb4747en

FAO. (2022). *Digital Village Initiative*. Food and Agriculture Organization of the United Nations. https://www.fao.org/digital-agriculture/digital-villages

Glendenning, C. J., Babu, S., & Asenso-Okyere, K. (2010). *Review of agricultural extension in India: Are farmers' information needs being met?* IFPRI Discussion Paper 01048. International Food Policy Research Institute. https://doi.org/10.2499/9780896291650

GoI. (2022). *Digital India: Journey and achievements*. Government of India. https://www.digitalindia.gov.in/

GSMA. (2021). *The mobile gender gap report 2021*. GSMA. https://www.gsma.com/r/wp-content/uploads/2021/07/The-Mobile-Gender-Gap-Report-2021.pdf

Inutan, S. M. B., Dujali, I. L., Bacus, M. S., Quijano-Pagutayao, A. S., & Sarita, V. B. (2025). The role of agricultural extension in farmers' technology adoption for sustainable agricultural practices in Davao Oriental, Philippines. *International Journal of Research and Innovation in Applied Science, X*(IV), 342–354. https://doi.org/10.51584/ijrias.2025.10040028

ITU. (2022). *Measuring digital development: Facts and figures 2022*. International Telecommunication Union. https://www.itu.int/en/ITU-D/Statistics/Documents/facts/FactsFigures2022.pdf

Kedia, S., Sinha, R., Pandey, R., Bhattacharjya, S., Syiemlieh, J. D., Chaudhury, S., Juneja, M., Anand, M., Ganeshan, S., & Bajpai, N. (2020). *Greening post COVID-19 economic recovery in India*. The Energy and Resources Institute, National Institute of Public Finance and Policy, & Global Green Growth Institute. https://www.teriin.org/sites/default/files/2020-06/GER_dp_0.pdf

Mbo'o-Tchouawou, M., & Colverson, K. (2014). *Increasing access to agricultural extension and advisory services: How effective are new approaches in reaching women farmers in rural areas?* Nairobi, Kenya: International Livestock Research Institute (ILRI).

Ojha, P. K., & Mishra, D. (2021). Mobile technology: Concept, framework and implications in agro-advisory services. *Informatics Studies, 8*(1), 57–64. https://www.informaticsstudies.org/

Ojha, P. K., Ojha, R. A., & Gireesh, P. (2023). Virtual Museum Builder (VMB) and Augmented Reality (AR) for developing Cultural Heritage Information System (CHIS).

Rivera, W. M., & Sulaiman, R. V. (2009). Extension: Object of reform, engine for innovation. *Outlook on Agriculture, 38*(3), 267–273. https://doi.org/10.5367/000000097893968810

Siankwilimba, E., Hiddlestone-Mumford, J., Hoque, M. E., Hang'ombe, B. M., Mumba, C., Hasimuna, O. J., Maulu, S., Mphande, J., Chibesa, M., Moono, M. B., Muhala, V., Cavaliere, L. P. L., Faccia, A., & Prayitno, G. (2023). Sustainability of agriculture extension services in the face of COVID-19: A study on gender-specific market systems. *Cogent Food & Agriculture, 9*(2). https://doi.org/10.1080/23311932.2023.2284231

Swanson, B. E., & Rajalahti, R. (2010). *Strengthening agricultural extension and advisory systems: Procedures for assessing, transforming, and evaluating extension systems*. World Bank. https://openknowledge.worldbank.org

Venkattakumar, R., Venkatesan, P., Senthil Vinayagam, S., Venkateshwarlu, G., & Srinivasa Rao, Ch. (2024). *Strengthening farmer-centric extension system in India*. ICAR-National Academy of Agricultural Research Management. Hyderabad, India. P.18.

Zirmire, J., Chungkham, D., Jagtap, P. D., Tamuly, G., Panotra, N., Saurabh, N., & Hazarika, P. P. (2025). Agricultural

extension in post-COVID era: Lessons learned and path forward. *Archives of Current Research International, 25*(5), 645–660. https://doi.org/10.9734/acri/2025/v25i51241

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