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A Review on Scaling Up Successful Agricultural Extension Techniques for Global Benefit

Ananda K R [a++*], Ankit Pal [a++], Anamika Sharma [b++], Ramesh Chand Bunkar [c++], Sulekha [d#], Mohammed Umar Ali [e†] and Lalit Upadhyay [f‡]

[a] Division of Agricultural Extension, ICAR-IARI, New Delhi, India.
[b] Department of Agricultural Communication, G.B. Pant University of Agricultural and Technology, Pantnagar, Uttrakhand, India.
[c] Division of Dairy Extension, ICAR- National Dairy Research Institute, Karnal (Haryana), India.
[d] School of Agricultural Science & Engineering, IFTM University Moradabad Delhi Road, NH-24, Lodhipur Rajput, Uttar Pradesh- 244102, India.
[e] University of Southern Queensland, Australia.
[f] Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, India.

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[++] Ph.D. Scholar;
[#] Assistant Professor;
[†] M.Sc. Agricultural Sciences;
[‡] Scientist (Agroforestry);

**Corresponding author: E-mail: anandakr1999@gmail.com;*

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ABSTRACT

Agricultural extension services are important for enhancing agricultural productivity, food security, and rural development. Examination of future and research needs highlights the significance of innovative approaches and emerging technologies, such as digital agriculture, precision farming, artificial intelligence, blockchain technology, and biotechnology, in transforming extension services. These technologies offer the potential to optimize resource use, increase yields, and improve supply chain transparency. Comprehensive impact assessments, including randomized controlled trials and mixed-methods approaches, are essential for evaluating the effectiveness of extension programs and understanding their long-term impacts on productivity, food security, and livelihoods. Supportive policy development and advocacy efforts are crucial for creating an enabling environment that promotes innovation, collaboration, and sustainable practices. This includes establishing regulatory frameworks, providing financial incentives, and integrating extension services into national development plans. Cross-disciplinary research and international collaboration are key to addressing the complex challenges facing agriculture, fostering the exchange of knowledge and best practices, and enhancing the capacity of national extension systems. Interdisciplinary research teams and systems thinking approaches can provide comprehensive solutions to agricultural challenges, while international research networks and development assistance programs can facilitate the transfer of appropriate technologies and practices. South-South cooperation offers additional opportunities for knowledge exchange and technology transfer between developing countries. By addressing these future directions and research needs, agricultural extension services can effectively contribute to sustainable agricultural development, improved livelihoods for farmers, and greater resilience to climate change. This approach will ensure that extension services remain responsive to the evolving challenges and opportunities in the agricultural sector, ultimately promoting global food security and economic growth.

Keywords: Digital agriculture; precision farming; biotechnology; food security; climate resilience.

1. INTRODUCTION

Agricultural extension services are crucial in promoting agricultural development by providing farmers with the necessary knowledge, skills, and technologies to improve their productivity and livelihoods. These services act as a bridge between research institutions and farmers, facilitating the transfer of scientific innovations to practical farming practices. The concept of agricultural extension has its roots in the early 20th century, with the establishment of extension services in countries like the United States and the United Kingdom. Over time, the role of agricultural extension has evolved to encompass a wide range of activities aimed at enhancing agricultural productivity and sustainability [1-4]. The importance of agricultural extension in enhancing food security and rural development cannot be overstated. Effective agricultural extension services have the potential to significantly increase crop yields and improve the quality of agricultural products [5]. This, in turn, contributes to food security by ensuring a stable and sufficient food supply. Extension services play a vital role in reducing poverty in rural areas by increasing farmers' incomes through improved agricultural practices and access to markets [6]. One of the primary goals of agricultural extension is to promote the adoption of new technologies and practices among farmers. This involves providing farmers with information on improved crop varieties, pest and disease management, soil fertility management, and water conservation techniques. Extension services also help farmers to diversify their agricultural activities and adopt sustainable farming practices. For example, the adoption of conservation agriculture practices, which involve minimal soil disturbance and the use of cover crops, has been shown to improve soil health and increase crop yields [7]. In addition to promoting agricultural productivity, extension services are essential for building the resilience of farmers to climate change. Climate change poses significant challenges to agricultural production, with increasing temperatures, changing precipitation patterns, and more frequent extreme weather events. Extension services can help farmers to adapt to these changes by providing them with

information on climate-resilient crop varieties, water management strategies, and other adaptive practices. The Intergovernmental Panel on Climate Change (IPCC) highlights the critical role of agricultural extension in enhancing the adaptive capacity of farmers to climate change [8]. Agricultural extension also plays a crucial role in promoting gender equality in agriculture. Women are often the primary food producers in many developing countries, yet they have less access to extension services compared to men. By providing targeted extension services to women, agricultural extension can help to improve their agricultural productivity and economic empowerment. Research has shown that when women have access to extension services, they are more likely to adopt improved agricultural practices and technologies [9]. Agricultural extension services contribute to rural development by fostering social capital and community development. Extension services often involve group-based approaches, such as farmer field schools and farmer groups, which facilitate the exchange of knowledge and experiences among farmers. These group-based approaches can strengthen social networks and build trust among farmers, leading to increased collaboration and collective action [10]. This social capital is essential for the sustainability of agricultural development initiatives and can enhance the overall well-being of rural communities.

2. SCOPE AND LIMITATIONS

This review covers a broad range of agricultural extension techniques, including both traditional and modern methods such as community-based and participatory approaches, and the use of digital technologies. It draws on diverse literature including academic studies, international reports, and empirical field evidence. Data availability and quality vary significantly across regions, affecting the generalizability of some findings [11]. The focus on successful cases of scaling up may introduce a positive bias, and while challenges and barriers are discussed, the review may not cover all difficulties encountered in different contexts [12]. The effectiveness of extension techniques can vary widely due to cultural, socio-economic, and environmental factors, necessitating cautious interpretation and contextual adaptation of the findings. Despite aiming for comprehensive analysis, this review may not capture all nuances and complexities of extension services, which operate in a dynamic and multifaceted environment [13].

3. AGRICULTURAL EXTENSION TECHNIQUES

The early development of agricultural extension techniques is deeply rooted in the recognition of the need to bridge the gap between scientific research and practical farming (Table 1). Agricultural extension, in its most rudimentary form, began as informal systems of knowledge transfer where experienced farmers shared their expertise with their peers. The formalization of agricultural extension services, however, can be traced back to the early 19th century, with significant developments occurring in the United States and Europe. In the United States, the establishment of agricultural extension services is often linked to the Morrill Act, which led to the creation of land-grant colleges. These institutions were mandated to teach agriculture, mechanical arts, and military tactics, providing a platform for the dissemination of agricultural knowledge. The Hatch Act further strengthened this initiative by establishing agricultural experiment stations in connection with land-grant colleges [14]. These stations conducted research and experimentation to address practical agricultural problems, and the results were disseminated to farmers through bulletins, demonstrations, and personal contacts. Europe also saw early developments in agricultural extension, particularly in the United Kingdom and Germany. In the UK, the establishment of county agricultural societies in the late 18th and early 19th centuries played a important role in promoting agricultural education and innovation [15]. These societies organized agricultural fairs, published journals, and provided practical demonstrations to farmers. Germany, on the other hand, developed a robust system of agricultural education and research institutes, which laid the groundwork for systematic extension services [16].

3.1 Key Milestones and Innovations

Several key milestones and innovations have shaped the development and evolution of agricultural extension techniques over the years. These milestones reflect the changing paradigms in agricultural extension and the continuous efforts to improve the effectiveness of extension services. One of the most significant innovations in agricultural extension is the Farmer Field School (FFS) approach. The FFS approach was developed in response to the limitations of traditional extension methods, particularly in addressing complex issues such as integrated pest management (IPM) [17]. Unlike

conventional top-down extension approaches, FFS emphasizes participatory learning, where farmers are actively involved in experimentation and problem-solving. This approach has been widely adopted in various countries and has proven effective in enhancing farmers' knowledge and skills. Participatory Rural Appraisal (PRA) emerged as a methodological innovation aimed at involving rural communities in the planning and implementation of development projects. PRA techniques include mapping, transect walks, seasonal calendars, and ranking exercises, which enable farmers to share their knowledge and priorities [18]. The use of PRA in agricultural extension has been instrumental in promoting farmer-centered approaches and ensuring that extension services are responsive to the needs of rural communities. The Green Revolution of the 1960s and 1970s marked a major milestone in agricultural extension, with the widespread adoption of high-yielding crop varieties, chemical fertilizers, and irrigation technologies. Extension services played a crucial role in disseminating these technologies to farmers and promoting their adoption [19]. The success of the Green Revolution in increasing agricultural productivity underscored the importance of effective extension services in promoting technological innovation. The advent of Information and Communication Technologies (ICTs) has revolutionized agricultural extension services in

Table 1. Agricultural extension techniques with references

Technique	Description	Success Factors	Examples/Case Studies
Farm Field Schools (FFS)	Community-based learning approach where farmers learn by doing through field demonstrations and experiments.	Active participation, hands-on learning, and locally relevant content.	Integrated Pest Management (IPM) in Andhra Pradesh.
Information and Communication Technologies (ICTs)	Use of mobile phones, internet, and other digital tools to disseminate agricultural information.	Wide reach, real-time updates, cost-effectiveness.	e-Choupal by ITC, mKisan SMS Portal, and IFFCO Kisan Sanchar Ltd.
Participatory Rural Appraisal (PRA)	Techniques that involve the community in assessing and planning for their development needs.	Community involvement, local knowledge integration, empowerment.	Watershed management projects in Maharashtra and Karnataka.
Farmer Producer Organizations (FPOs)	Collectives of farmers that work together to achieve common goals such as marketing and input procurement.	Economies of scale, collective bargaining power, access to markets.	Sahyadri Farmers Producer Company in Maharashtra, Karnataka Horticulture Federation (KHF).
Extension through KVKs (Krishi Vigyan Kendras)	Agricultural science centers providing need-based training and advice to farmers.	Location-specific research, continuous support, and follow-up.	KVK initiatives in Punjab for promoting high-yielding wheat varieties.
Public-Private Partnerships (PPPs)	Collaboration between government agencies and private companies to deliver extension services.	Shared resources, innovation, efficiency, and sustainability.	Public-private partnerships in the National Dairy Plan and the Agri-Clinics and Agri-Business Centers (ACABC) Scheme.
Integrated Pest Management (IPM)	Sustainable approach to managing pests through a combination of biological, cultural, and chemical methods.	Reduces reliance on chemical pesticides, environmental benefits, and farmer education.	IPM projects in cotton cultivation in Gujarat and paddy fields in Tamil Nadu.
Value Chain Development	Enhancing the value chain from production to consumption to improve income and sustainability.	Market linkages, quality control, and capacity building.	The success of the National Horticulture Mission in promoting fruits and vegetables across various states.
Climate-Smart	Agricultural practices that	Adaptation to climate	CSA practices in Haryana

Technique	Description	Success Factors	Examples/Case Studies
Agriculture (CSA)	increase productivity, resilience, and reduce emissions.	change, sustainable practices, and risk reduction.	for resilient wheat farming and the promotion of drought-tolerant crop varieties in Rajasthan.
Agro-Advisory Services	Expert advice provided to farmers on various aspects of agriculture through multiple channels.	Timely and accurate information, accessibility, and relevance.	Agro-Advisory services by ICAR and state agricultural universities through radio, TV, and mobile applications.
Demonstration Plots	Small-scale plots used to show the benefits of new technologies or practices to farmers.	Visual learning, firsthand experience, and local adaptation.	Demonstration plots for high-density apple planting in Himachal Pradesh and System of Rice Intensification (SRI) in Odisha.
Agricultural Extension Campaigns	Large-scale efforts to promote specific agricultural practices or innovations among farmers.	Wide outreach, focused messages, and community engagement.	Swachh Bharat Mission's integration with agricultural practices and the promotion of organic farming in Sikkim.

recent decades. The use of mobile phones, internet, and other digital platforms has enabled the rapid dissemination of information to farmers, overcoming the limitations of traditional face-to-face extension methods [20]. ICT-based extension services provide farmers with access to real-time information on weather, market prices, pest outbreaks, and best practices, thereby enhancing their decision-making and productivity. In response to the changing needs and challenges of the agricultural sector, several countries have undertaken extension reforms aimed at improving the efficiency and effectiveness of extension services. These reforms often involve decentralization, privatization, and the promotion of pluralistic extension systems, where multiple service providers, including government agencies, NGOs, and private sector actors, contribute to extension delivery [21]. The extension reform movement has led to the diversification of extension approaches and the development of innovative models for service delivery.

3.2 Impact on Agricultural Productivity

The impact of agricultural extension techniques on agricultural productivity has been widely documented in the literature. Effective extension services have the potential to significantly enhance agricultural productivity by promoting the adoption of improved technologies and practices, increasing farmers' knowledge and skills, and facilitating access to inputs and markets. One of the primary impacts of agricultural extension is the increased adoption of improved agricultural technologies. Extension services play a critical role in raising farmers' awareness of new technologies, demonstrating their benefits, and providing the necessary training and support for their adoption. For example, studies have shown that the adoption of high-yielding crop varieties, promoted through extension services, has led to substantial increases in crop yields in many countries [22]. Similarly, the promotion of integrated pest management (IPM) practices through Farmer Field Schools has been associated with reduced pesticide use and increased crop productivity [23]. Agricultural extension services contribute to agricultural productivity by enhancing farmers' knowledge and skills. Extension programs provide farmers with information on best practices for crop and livestock management, soil fertility, water conservation, and other aspects of farming. This knowledge enables farmers to make informed decisions and adopt practices that improve their productivity and sustainability. For instance, a study found that participation in Farmer Field Schools led to significant improvements in farmers' knowledge and practices, resulting in higher crop yields and incomes. Extension services also facilitate access to inputs and markets, which are essential for enhancing agricultural productivity. Extension agents often play a mediating role between farmers and input suppliers, ensuring that farmers have access to quality seeds, fertilizers, and other inputs. Extension services provide farmers with market information and link them to market opportunities, enabling them to sell their produce at better prices. This improved

access to inputs and markets contributes to increased productivity and profitability [24]. The promotion of sustainable farming practices through agricultural extension is another important impact on productivity. Sustainable practices, such as conservation agriculture, organic farming, and agroforestry, contribute to the long-term productivity and resilience of agricultural systems. Extension services play a key role in educating farmers about the benefits of sustainable practices and providing the necessary support for their implementation. For example, research has shown that the adoption of conservation agriculture practices, promoted through extension services, leads to improved soil health, increased water retention, and higher crop yields [25]. Agricultural extension services are critical for building the resilience of farmers to climate change, which poses significant threats to agricultural productivity. Extension programs provide farmers with information on climate-resilient crop varieties, water management strategies, and other adaptive practices. By helping farmers to adapt to changing environmental conditions, extension services contribute to the sustainability and productivity of agricultural systems [26]. The IPCC underscores the importance of agricultural extension in enhancing the adaptive capacity of farmers to climate change [27].

4. CURRENT SUCCESSFUL AGRI-CULTURAL EXTENSION TECHNIQUES

The concept of Farmer Field Schools (FFS) was introduced in the late 1980s as an innovative approach to agricultural extension. FFS were initially developed to address the limitations of conventional extension methods in dealing with complex agricultural issues such as Integrated Pest Management (IPM**)** (Table 2) [28]. Unlike traditional top-down approaches, FFS are characterized by their participatory and experiential learning framework. Farmers are actively involved in the learning process through hands-on field experiments and discussions, which fosters a deeper understanding and application of agricultural practices. The implementation of FFS typically involves a series of weekly meetings over a cropping season, during which a group of farmers-referred to as a "field school"-conducts experiments in a designated field plot. This plot serves as a learning laboratory where farmers can observe, analyze, and practice new techniques under the guidance of a trained facilitator [29]. The curriculum of FFS is highly adaptive and based on the local context, addressing the specific needs and challenges faced by the farmers. One of the core principles of FFS is the "learning by doing" approach. Farmers engage in participatory activities such as field observations, pest and disease identification, and the application of different pest management strategies. This process helps farmers develop critical thinking and problem-solving skills, enabling them to make informed decisions about their farming practices. FFS emphasize the importance of collective learning and community building, as farmers share their experiences and knowledge with each other. Participatory Rural Appraisal (PRA) emerged as a methodological innovation aimed at involving rural communities in the planning and implementation of development projects. PRA techniques are designed to facilitate the active participation of community members in analyzing their own situations, identifying problems, and developing solutions. The methods and tools of PRA are diverse and flexible, allowing for adaptation to different contexts and objectives [30].

5. INFORMATION AND COMMUNICATION TECHNOLOGIES (ICTS) IN EXTENSION

The advent of Information and Communication Technologies (ICTs) has revolutionized agricultural extension services by providing new and innovative ways to disseminate information to farmers. Digital platforms and mobile applications are at the forefront of this transformation, offering farmers access to real-time information on weather, market prices, pest outbreaks, and best practices [31]. One of the most successful examples of ICT in agricultural extension is the use of mobile phones. Mobile applications provide farmers with timely and relevant information, enabling them to make informed decisions about their farming practices. For instance, in Kenya, the M-Farm application allows farmers to access market prices, connect with buyers, and receive agricultural tips via SMS. This has improved market access and profitability for smallholder farmers [32]. Digital platforms, such as online forums and social media groups, also play a significant role in agricultural extension. These platforms facilitate knowledge sharing and peer-to-peer learning among farmers. For example, the e-Choupal initiative in India provides a digital platform for farmers to access agricultural information, market prices, and e-commerce services. The initiative has enhanced the efficiency of the agricultural supply chain and empowered farmers

with greater market access [33]. The efficacy and reach of ICT-based extension services have been widely documented. Studies have shown that the use of mobile applications and digital platforms leads to increased access to information, improved decision-making, and higher agricultural productivity. For example, a study conducted in Uganda found that farmers who received agricultural information through mobile phones experienced significant improvements in their farming practices and crop yields [34]. In Ghana, the use of the Esoko platform has enabled farmers to access market information and connect with buyers, leading to higher incomes and reduced post-harvest losses. Similarly, in Tanzania, the use of mobile applications for agricultural extension has resulted in better pest and disease management, increased crop yields, and improved food security [35]. The reach of ICT-based extension services extends to remote and marginalized areas, where traditional extension services may be limited. By leveraging digital technologies, extension services can overcome geographical barriers and provide timely information to farmers in hard-to-reach areas. This has been particularly important during the COVID-19 pandemic, as digital platforms have enabled the continuity of extension services despite restrictions on movement and physical interactions [36].

Table 2. Current successful agricultural extension techniques in India

Technique	Description	Success Factors	Examples/Case Studies
Farm Field Schools (FFS)	Community-based learning approach where farmers learn by doing through field demonstrations and experiments.	Active participation, hands-on learning, and locally relevant content.	Integrated Pest Management (IPM) in Andhra Pradesh.
Information and Communication Technologies (ICTs)	Use of mobile phones, internet, and other digital tools to disseminate agricultural information.	Wide reach, real-time updates, cost-effectiveness.	e-Choupal by ITC, mKisan SMS Portal, and IFFCO Kisan Sanchar Ltd.
Participatory Rural Appraisal (PRA)	Techniques that involve the community in assessing and planning for their development needs.	Community involvement, local knowledge integration, empowerment.	Watershed management projects in Maharashtra and Karnataka.
Farmer Producer Organizations (FPOs)	Collectives of farmers that work together to achieve common goals such as marketing and input procurement.	Economies of scale, collective bargaining power, access to markets.	Sahyadri Farmers Producer Company in Maharashtra, Karnataka Horticulture Federation (KHF).
Extension through KVKs (Krishi Vigyan Kendras)	Agricultural science centers providing need-based training and advice to farmers.	Location-specific research, continuous support, and follow-up.	KVK initiatives in Punjab for promoting high-yielding wheat varieties.
Public-Private Partnerships (PPPs)	Collaboration between government agencies and private companies to deliver extension services.	Shared resources, innovation, efficiency, and sustainability.	Public-private partnerships in the National Dairy Plan and the Agri-Clinics and Agri-Business Centers (ACABC) Scheme.
Integrated Pest Management (IPM)	Sustainable approach to managing pests through a combination of biological, cultural, and chemical methods.	Reduces reliance on chemical pesticides, environmental benefits, and farmer education.	IPM projects in cotton cultivation in Gujarat and paddy fields in Tamil Nadu.
Value Chain Development	Enhancing the value chain from production to consumption to improve income and sustainability.	Market linkages, quality control, and capacity building.	The success of the National Horticulture Mission in promoting fruits and vegetables across various states.
Climate-Smart Agriculture (CSA)	Agricultural practices that increase productivity, resilience, and reduce emissions.	Adaptation to climate change, sustainable practices, and risk reduction.	CSA practices in Haryana for resilient wheat farming and the promotion of drought-tolerant crop varieties in

Technique	Description	Success Factors	Examples/Case Studies
			Rajasthan.
Agro-Advisory Services	Expert advice provided to farmers on various aspects of agriculture through multiple channels.	Timely and accurate information, accessibility, and relevance.	Agro-Advisory services by ICAR and state agricultural universities through radio, TV, and mobile applications.
Demonstration Plots	Small-scale plots used to show the benefits of new technologies or practices to farmers.	Visual learning, firsthand experience, and local adaptation.	Demonstration plots for high-density apple planting in Himachal Pradesh and System of Rice Intensification (SRI) in Odisha.
Agricultural Extension Campaigns	Large-scale efforts to promote specific agricultural practices or innovations among farmers.	Wide outreach, focused messages, and community engagement.	Swachh Bharat Mission's integration with agricultural practices and the promotion of organic farming in Sikkim.

(Source- [11], [13], [21])

6. FACTORS INFLUENCING THE SUCCESS OF AGRICULTURAL EXTENSION TECHNIQUES

Education and literacy levels play a critical role in the success of agricultural extension techniques. Farmers with higher levels of education and literacy are generally more capable of understanding and adopting new technologies and practices introduced through extension services. Literacy enables farmers to access and comprehend written materials, including extension leaflets, manuals, and digital content, which are essential for the dissemination of agricultural knowledge [37]. Studies have shown that educated farmers are more likely to participate in extension programs and adopt improved agricultural practices. For instance, a study conducted in Kenya found that farmers with higher education levels were more likely to adopt soil fertility management practices promoted by extension agents [38]. Similarly, research in Bangladesh demonstrated that literacy significantly influenced the adoption of Integrated Pest Management (IPM) techniques among rice farmers [39]. Economic conditions and the availability of funding are crucial determinants of the success of agricultural extension techniques. The economic status of farmers influences their ability to adopt new technologies and practices. Farmers with better economic resources are more likely to invest in improved seeds, fertilizers, irrigation systems, and other agricultural inputs promoted by extension services [40]. The success of extension programs is also heavily dependent on the availability of adequate funding. Sufficient financial resources are necessary to support the training of extension agents, development of educational materials, organization of field demonstrations, and deployment of ICT tools. Government funding, donor support, and private sector investments are critical sources of financing for agricultural extension services. A well-funded extension system can provide comprehensive support to farmers, including technical advice, market information, and access to credit and inputs [41]. Conversely, inadequate funding can severely limit the reach and effectiveness of extension services. In many developing countries, agricultural extension services are underfunded and understaffed, leading to insufficient coverage and low-quality service delivery. For example, in sub-Saharan Africa, the ratio of extension agents to farmers is often very low, resulting in limited access to extension services for many smallholder farmers [42].

6.1 Environmental Factors

Climate and geographical factors are significant determinants of the success of agricultural extension techniques. The diversity of climatic conditions and geographical landscapes across regions necessitates tailored extension approaches that address local environmental challenges and opportunities. Extension services must consider the specific agro-ecological zones, weather patterns, and geographical features of the target areas to provide relevant and effective advice to farmers [43]. Climate variability and change pose considerable challenges to agricultural production and extension services. Changes in temperature, precipitation patterns, and the frequency of extreme weather events can impact crop yields and livestock productivity. Extension services play a critical role in helping farmers adapt to these climatic changes by promoting climate-resilient practices and

technologies. For example, the introduction of drought-tolerant crop varieties, efficient water management techniques, and climate-smart agriculture practices are essential components of extension programs aimed at enhancing farmers' resilience to climate change [44]. Geographical considerations, such as soil types, topography, and altitude, also influence the success of agricultural extension techniques. Different regions have unique soil characteristics that affect crop suitability and productivity. Extension services must provide site-specific recommendations for soil fertility management, erosion control, and land use planning to address these geographical variations. For instance, in hilly and mountainous areas, extension programs may focus on terracing, agroforestry, and soil conservation practices to prevent soil erosion and improve agricultural sustainability [45]. Natural resource management is a critical factor influencing the success of agricultural extension techniques. Sustainable management of natural resources, including soil, water, forests, and biodiversity, is essential for long-term agricultural productivity and environmental health. Extension services play a important role in promoting sustainable practices and educating farmers on the importance of conserving natural resources. Soil fertility management is a key area where extension services can make a significant impact. Degraded soils, resulting from continuous cropping, overgrazing, and deforestation, pose a major challenge to agricultural productivity. Extension programs that promote the use of organic matter, cover crops, crop rotation, and conservation tillage can help restore soil health and enhance its fertility. For example, the adoption of conservation agriculture practices, which emphasize minimal soil disturbance and the use of cover crops, has been shown to improve soil structure, increase organic matter content, and enhance water retention [46]. Water management is another critical aspect of natural resource management. Efficient use of water resources is essential for sustainable agriculture, especially in regions prone to water scarcity. Extension services can promote water-saving techniques, such as drip irrigation, rainwater harvesting, and mulching, to optimize water use and improve crop yields. In addition, extension programs can provide training on watershed management and the construction of small-scale water storage structures to enhance water availability during dry periods [47].

Table 3. Challenges in scaling up agricultural extension techniques

Challenge	Description	Impact	Examples/Case Studies
Limited Funding and Resources	Insufficient financial and material resources allocated to extension services.	Inability to reach more farmers, reduced program effectiveness.	Budget constraints in state agricultural departments leading to reduced extension activities.
Inadequate Training of Extension Workers	Lack of continuous professional development and training opportunities for extension personnel.	Lower quality of advice and support provided to farmers, outdated knowledge.	Extension workers in remote areas lacking updated knowledge on new agricultural technologies.
Infrastructure Deficiencies	Poor infrastructure such as roads, communication networks, and transportation facilities.	Difficulty in accessing remote areas, delayed dissemination of information.	Inadequate road networks in rural Bihar impacting timely delivery of extension services.
Farmer Reluctance and Skepticism	Farmers' hesitation to adopt new practices due to risk aversion or mistrust in extension advice.	Slow adoption rates of new technologies, limited impact of extension programs.	Resistance to adopting hybrid seeds and fertilizers in certain regions of Uttar Pradesh.
Diverse Agro-Climatic Conditions	Variation in soil types, climate, and cropping systems across regions requiring tailored extension approaches.	One-size-fits-all recommendations often fail, reduced relevance and effectiveness of extension advice.	Different agricultural practices required for coastal regions versus mountainous areas in India.
Fragmented Land Holdings	Small and scattered landholdings making it challenging to implement large-scale extension activities.	Difficulty in achieving economies of scale, higher per-unit costs for extension delivery.	Smallholder farmers in states like Kerala facing challenges in adopting mechanized farming practices.
Lack of	Poor collaboration	Duplication of efforts,	Overlapping agricultural

Challenge	Description	Impact	Examples/Case Studies
Coordination Among Stakeholders	between government agencies, private sector, NGOs, and farmer groups.	inefficient use of resources, fragmented extension services.	extension projects by different agencies in Maharashtra without effective coordination.
Limited Use of ICTs	Underutilization of digital tools and technologies for extension purposes.	Missed opportunities for broader outreach, real-time updates, and cost-effective information dissemination.	Slow adoption of mobile-based agro-advisory services in certain rural areas due to lack of digital literacy.
Sociocultural Barriers	Traditional beliefs, gender roles, and social norms that hinder the adoption of new agricultural practices.	Exclusion of certain farmer groups, such as women and marginalized communities, from extension benefits.	Gender-specific challenges in agricultural extension services in Rajasthan, where women farmers have limited access to resources.
Policy and Regulatory Issues	Inconsistent policies and regulatory frameworks that affect the implementation of extension programs.	Uncertainty and inconsistency in extension service delivery, reduced trust among farmers.	Frequent changes in agricultural policies affecting extension programs in states like Tamil Nadu.
Monitoring and Evaluation Challenges	Lack of robust systems to monitor and evaluate the effectiveness of extension programs.	Difficulty in assessing impact, making necessary adjustments, and ensuring accountability.	Weak monitoring frameworks for agricultural extension projects funded by government and international donors.
Climate Change and Environmental Stress	Increasing climate variability and environmental degradation impacting agriculture.	Need for extension services to continuously adapt and provide relevant advice for climate resilience.	Extension services struggling to address the impacts of droughts and floods in states like Andhra Pradesh and Odisha.

6.2 Institutional and Policy Factors

Government policies and support are fundamental to the success of agricultural extension techniques. National agricultural policies, regulatory frameworks, and government programs shape the enabling environment for agricultural development and extension services. Supportive policies and strong government commitment are essential for the effective design, implementation, and scaling up of extension programs [48]. One of the key areas where government policies influence agricultural extension is funding and resource allocation. Adequate funding for extension services ensures that extension agents are well-trained, equipped, and motivated to deliver high-quality services to farmers. Governments can also provide financial incentives, such as subsidies for agricultural inputs, grants for farmer training, and funding for extension research and innovation. For example, the successful implementation of the Green Revolution in India was supported by substantial government investment in agricultural research, extension, and input subsidies [49]. Policy frameworks that promote decentralization and pluralism in extension services can enhance the effectiveness of agricultural extension. Decentralization involves the transfer of decision-making authority and resources from central to local governments, enabling more responsive and context-specific extension services. Pluralism in extension refers to the involvement of multiple service providers, including government agencies, non-governmental organizations (NGOs), private sector actors, and farmer organizations. This approach leverages the strengths of different stakeholders and promotes innovation and competition in extension service delivery [50]. The success of agricultural extension techniques is heavily influenced by the institutional frameworks and partnerships that support extension services. Effective institutional frameworks provide the organizational structure, governance, and coordination mechanisms necessary for the delivery of extension services. Partnerships among various stakeholders, including government agencies, research institutions, NGOs, private sector entities, and farmer organizations, enhance the reach, quality, and sustainability of extension programs [51]. Research institutions play a critical role in generating the scientific knowledge and innovations that underpin extension services. Strong linkages between research and extension ensure that the latest research findings are translated into practical recommendations for

farmers. Collaborative research-extension initiatives, such as on-farm trials and participatory research, facilitate the co-creation of knowledge and promote the adoption of context-specific technologies [52]. Partnerships with NGOs and civil society organizations enhance the inclusiveness and effectiveness of extension services. NGOs often have strong community ties and experience in participatory approaches, which can complement the efforts of government extension services. For example, partnerships between government extension agencies and NGOs in India have successfully promoted sustainable agricultural practices and improved the livelihoods of smallholder farmers [53].

7. CHALLENGES IN SCALING UP AGRICULTURAL EXTENSION TECHNIQUES

Scaling up agricultural extension techniques is crucial for improving agricultural productivity, food security, and rural development (Table 3). Several challenges impede widespread adoption and effectiveness. Financial constraints significantly hinder the scaling up of agricultural extension techniques. These services require substantial funding for training, materials, infrastructure, and personnel, which many developing countries cannot adequately provide. Dependency on donor funding, which is often temporary and project-specific, jeopardizes the continuity of extension services when donor projects end. Moreover, smallholder farmers, who dominate the agricultural workforce in developing countries, often lack the financial resources to pay for extension services, making cost-recovery models impractical. Innovative financing mechanisms, such as public-private partnerships and community-based funding, are needed to enhance financial sustainability [54]. Integrating Information and Communication Technologies (ICTs) into agricultural extension has the potential to revolutionize knowledge dissemination. However, technological barriers and the digital divide pose significant challenges. Many rural areas lack the necessary infrastructure, such as reliable internet connectivity and access to digital devices. Low digital literacy rates among smallholder farmers, especially older individuals and women, hinder the effective use of ICT-based extension tools. Addressing these challenges requires investments in rural ICT infrastructure, digital literacy training, and the development of user-friendly digital tools tailored to local contexts [55]. Cultural and social barriers significantly affect the adoption and scaling up of agricultural extension techniques. Resistance to change, rooted in a preference for traditional methods and skepticism about new technologies, is a major challenge. Gender norms also restrict women's access to extension services, as cultural norms often limit their mobility and participation in public spaces. Social hierarchies and power dynamics within communities can lead to elite capture, preventing marginalized groups from benefiting from extension services. Addressing these barriers requires participatory approaches, gender-sensitive extension methods, and engagement with community leaders to build trust and support [56]. Institutional and policy challenges are significant barriers to scaling up agricultural extension techniques. Lack of coordination among different extension service providers can lead to inefficiencies and inconsistencies in service delivery. Many national extension systems are under-resourced, with insufficient numbers of trained extension agents and inadequate infrastructure. Supportive policies are essential for creating an enabling environment for extension services, but agricultural policies are often not aligned with the needs of extension services. Decentralization and pluralism in extension services, involving multiple service providers, can enhance responsiveness and effectiveness. Political instability and governance issues can also disrupt the delivery of extension services, making it essential to ensure stable and effective governance structures [57].

8. GLOBAL BENEFITS OF SCALING UP AGRICULTURAL EXTENSION TECHNIQUES

Scaling up agricultural extension techniques has far-reaching global implications and benefits, particularly in the areas of food security and nutrition improvement, poverty alleviation and economic growth, sustainable agricultural practices and environmental conservation, and enhancing resilience to climate change. This comprehensive examination elucidates the important role of agricultural extension in addressing some of the most pressing challenges facing global agriculture and rural development. One of the primary benefits of scaling up agricultural extension techniques is the significant increase in agricultural productivity. Extension services provide farmers with access to the latest scientific knowledge, improved crop varieties, and best practices for

crop management. This, in turn, leads to higher yields and more efficient use of resources. For instance, extension programs that promote the adoption of high-yielding crop varieties and improved farming techniques have been shown to substantially increase crop production in various regions [58]. The Green Revolution is a historic example of how agricultural extension can drive productivity gains. In the mid-20th century, the introduction of high-yielding varieties of wheat and rice, combined with the dissemination of modern agricultural practices through extension services, led to dramatic increases in food production in Asia and Latin America. These productivity gains were instrumental in preventing widespread hunger and improving food security in many developing countries. Agricultural extension also plays a critical role in reducing post-harvest losses, which are a significant barrier to food security. Extension programs that educate farmers on proper post-harvest handling, storage, and processing techniques can minimize losses and ensure that more food reaches the market and consumers. For example, in sub-Saharan Africa, extension services that promote improved storage technologies, such as hermetic bags and metal silos, have been effective in reducing grain losses and improving food security [59]. Beyond increasing food production, agricultural extension can directly contribute to improved nutritional outcomes. Extension programs that promote the cultivation of diverse crops, including fruits, vegetables, and legumes, help to improve dietary diversity and nutritional intake among farming households. For instance, in Malawi, agricultural extension programs that encourage the cultivation of nutrient-rich crops such as orange-fleshed sweet potatoes have led to improved vitamin A intake among children and women [60].

9. POVERTY ALLEVIATION AND ECONOMIC GROWTH

Agricultural extension services play a vital role in increasing farm incomes by promoting the adoption of improved technologies and practices that enhance productivity and profitability. For example, extension programs that introduce better crop varieties, efficient irrigation techniques, and integrated pest management (IPM) practices can lead to higher yields and reduced input costs, thereby increasing farmers' incomes. In Kenya, the introduction of Farmer Field Schools (FFS) has been associated with significant income gains for participating farmers. By adopting improved farming practices learned through FFS, farmers have achieved higher crop yields and better quality produce, resulting in increased marketable surpluses and higher incomes [61]. Agricultural extension also contributes to poverty alleviation by creating employment opportunities in rural areas. Extension programs that promote value-added activities, such as agro-processing, marketing, and agribusiness development, can generate new jobs and diversify income sources for rural households. For instance, in Nigeria, agricultural extension services that support the development of small-scale agribusinesses have created employment opportunities for women and youth, contributing to poverty reduction and economic empowerment [62]. Extension services that facilitate better access to markets can also play a crucial role in poverty alleviation. By providing farmers with market information, linkages to buyers, and training in market-oriented production, extension programs help farmers to obtain better prices for their produce and increase their incomes. In Ethiopia, the Agricultural Growth Program (AGP) has successfully linked smallholder farmers to markets, resulting in improved livelihoods and reduced poverty levels [63]. The impact of agricultural extension extends beyond individual farmers to the broader rural economy. By increasing agricultural productivity and incomes, extension services stimulate demand for goods and services, creating a multiplier effect that drives rural economic growth. The increased economic activity generated by higher agricultural productivity can lead to the development of rural infrastructure, improved access to education and healthcare, and overall better living standards in rural areas [64].

10. SUSTAINABLE AGRICULTURAL PRACTICES AND ENVIRONMENT

Agricultural extension is essential for promoting sustainable farming practices that conserve natural resources and protect the environment. Extension programs that educate farmers on sustainable land management, soil conservation, and water management techniques can help to prevent land degradation, enhance soil fertility, and ensure the sustainable use of water resources. For example, in Ethiopia, extension services that promote sustainable land management practices, such as terracing and agroforestry, have led to significant improvements in land productivity and environmental conservation [65]. Extension services that promote the adoption of

environmentally friendly technologies and practices can reduce the negative impact of agriculture on the environment. This includes the promotion of integrated pest management (IPM) to reduce the use of chemical pesticides, conservation agriculture to minimize soil disturbance, and organic farming to reduce reliance on synthetic inputs. In Bangladesh, the adoption of IPM practices through Farmer Field Schools has led to reduced pesticide use, improved pest control, and enhanced environmental sustainability. Agricultural extension can also contribute to biodiversity conservation by promoting the use of diverse crop varieties and agroforestry systems. Agroforestry, which integrates trees and shrubs into agricultural landscapes, enhances biodiversity by providing habitats for various species and supporting ecosystem services such as pollination and pest control. In Kenya, extension programs that promote agroforestry have resulted in increased tree cover, improved soil health, and greater biodiversity on farms [66]. Climate-smart agriculture (CSA) practices, which aim to increase productivity, enhance resilience to climate change, and reduce greenhouse gas emissions, are critical for sustainable agricultural development. Agricultural extension services play a key role in promoting CSA by educating farmers on practices such as conservation tillage, crop diversification, and efficient water use. In Zambia, extension programs that promote climate-smart practices have helped farmers to adapt to changing climatic conditions and improve their resilience to climate shocks [67].

11. RESILIENCE TO CLIMATE CHANGE

Agricultural extension services are crucial for building the adaptive capacity of farmers to cope with the impacts of climate change. Extension programs that provide information on climate risks, adaptive practices, and early warning systems help farmers to anticipate and respond to climate variability and extreme weather events. For example, in India, the Climate-Smart Villages (CSV) initiative uses extension services to disseminate climate information and promote adaptive practices, enhancing the resilience of farming communities [68]. The adoption of climate-resilient technologies, such as drought-tolerant crop varieties, efficient irrigation systems, and soil moisture conservation techniques, is essential for enhancing agricultural resilience to climate change. Agricultural extension services that promote these technologies can help farmers to maintain productivity and food security under changing climatic conditions. In Africa, the dissemination of drought-tolerant maize varieties through extension services has significantly improved the resilience of smallholder farmers to drought [69]. Diversification of crops, livestock, and income sources is a key strategy for managing climate risks and enhancing resilience. Extension services that encourage diversification can help farmers to spread risks and reduce their vulnerability to climate shocks. For example, in Nepal, extension programs that promote crop diversification and integrated farming systems have improved farmers' resilience to climate variability and enhanced food security [70]. Agricultural extension services that foster social capital and community resilience can enhance the overall adaptive capacity of rural communities. Extension programs that promote group-based approaches, such as Farmer Field Schools and farmer cooperatives, can strengthen social networks, facilitate knowledge sharing, and build collective action for climate adaptation. In Bangladesh, community-based extension programs have successfully built social capital and improved the resilience of farming communities to climate-related risks [71].

12. CONCLUSION

The future of agricultural extension is poised for transformation through innovative approaches and emerging technologies, comprehensive impact assessments, supportive policy development, and cross-disciplinary and international collaboration. Embracing digital agriculture, AI, blockchain, and biotechnology can revolutionize extension services, enhancing productivity and sustainability. Comprehensive evaluations and longitudinal studies will ensure the long-term effectiveness of these programs. Policy reforms that create enabling environments, coupled with advocacy and stakeholder engagement, are crucial for scaling up these innovations. Cross-disciplinary research and international cooperation will facilitate the sharing of best practices and foster global agricultural advancements. By addressing these future directions and research needs, agricultural extension can play an important role in ensuring food security, economic growth, environmental conservation, and resilience to climate change, ultimately improving the livelihoods of farmers 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 writing or editing of manuscripts.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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