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Agricultural Extension's Key Role in Modern Farming: A Review

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Authors' contributions

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

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ABSTRACT

Agricultural Extension (AE) plays a pivotal role in modern farming, as it is integral in imparting knowledge from research institutions to farmers, thereby increasing productivity and sustainability. This role is becoming increasingly crucial as climate change and fluctuating market dynamics demand agile responses and adaptation from the farming community. The effectiveness of AE lies

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in its ability to facilitate the transfer of knowledge from research labs to farmlands. Through AE, innovations in farming techniques, crop management practices, and technological advancements reach farmers, even in remote and underserved regions. It examines the role of agricultural extension in modern farming in India, highlighting its significance in communicating scientific research to farmers, facilitating skill development, advising on efficient farming methods, and promoting risk management and resilience. As India faces major challenges such as climate change and food security, the role of agricultural extension becomes increasingly pivotal. The advent of digital technologies, including artificial intelligence and virtual reality, offers novel avenues for extension practices. The deployment of these technologies must be inclusive, addressing issues of digital literacy and access among farmers. Despite the clear advantages, extension services are confronted with significant obstacles, including resource constraints, socio-cultural barriers, and policy issues. Addressing these challenges necessitates innovative approaches and comprehensive reforms. Looking to the future, the agricultural extension will remain central in addressing emerging farming challenges and leveraging opportunities for enhancing agricultural productivity and sustainability in India.

Keywords: Agricultural extension; modern farming; digital technologies; sustainability; challenges; reforms.

1. INTRODUCTION

The term "agricultural extension" has been conceptualized differently by various experts and institutions, each encapsulating unique dimensions of this field. According to the Food and Agriculture Organization [1], agricultural extension is an essential conduit for providing knowledge about agricultural practices and technologies, enhancing skills, and facilitating the exchange of information among stakeholders in the agricultural sector. It plays a pivotal role in promoting sustainable agricultural practices, increasing productivity, and improving the livelihoods of farmers. In India, a country with diverse agro-ecological zones, varying farming systems, and a substantial rural population engaged in agriculture, agricultural extension is considered a crucial instrument for disseminating knowledge and technology to farmers, thereby transforming the agricultural sector [2]. Its primary goal is to connect farmers with the advancements in agricultural sciences, assisting them in improving their farming techniques, adopting new technologies, and making informed decisions about their farm management.

The history of agricultural extension in India can be traced back to the early 20th century. During British colonial rule, the Imperial Agricultural Research Institute was established in 1905 (now known as the Indian Agricultural Research Institute), where initial efforts to link scientific research with farmers' fields were undertaken [3]. The formal agricultural extension system in India began in 1947, following independence, with the introduction of the "Grow More Food Campaign" to address food shortages. In the following decades, several models of the extension were implemented, such as the Intensive Agricultural District Programme (IADP) in the 1960s and the Training and Visit (T&V) system in the 1970s. The latter was based on the World Bank model focusing on the regular visit of extension agents to farmers for providing advice [4]. However, it was realized that this top-down extension model was ineffective for the diverse Indian agricultural system, leading to the move towards decentralized extension systems with the launch of the Agricultural Technology Management Agency (ATMA) model in 2000 [5]. ATMA aimed to integrate research and extension in a district-centric model that is flexible, participatory, and responsive to farmers' needs. It advocated the involvement of various stakeholders, including non-governmental organizations, farmer groups, and private sectors in agricultural extension [6]. Over the years, this model has evolved and been scaled up across the country, providing a more holistic approach to extension services [2].

The importance of agricultural extension in modern farming is immense. With the increasing challenges posed by climate change, population growth, and food security concerns, agricultural practices need to become more efficient, sustainable, and resilient. Agricultural extension, through its broadened scope of services, plays a vital role in addressing these challenges. It acts as a bridge between research and farmers, aiding in the dissemination and adoption of modern farming techniques and technologies, such as precision agriculture, sustainable farming practices, and climate-smart agriculture

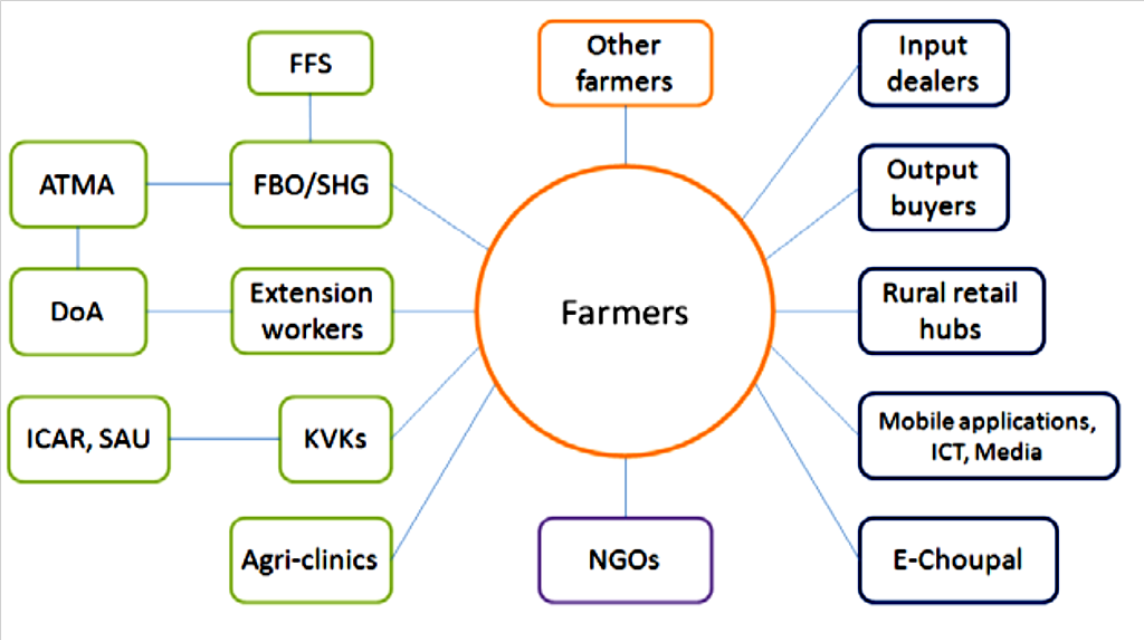

Fig. 1. Information exchange between extension and farmers in India (adapted from [9]

[7]. In the era of digitization, agricultural extension in India is undergoing a significant transformation. The introduction of ICT in agricultural extension, commonly referred to as e-extension, has opened up new avenues for reaching out to farmers more effectively. It facilitates real-time information sharing, interactive learning, and personalized advisory services, leading to more informed decision-making by farmers [8]. The objective of this review is to explore the evolving role of agricultural extension in the context of modern farming in India. It aims to analyze how agricultural extension, through various models and strategies, is facilitating the shift toward more productive, sustainable, and resilient farming practices. It will also delve into the challenges and prospects of agricultural extension in the digital age.

Notes: Information flow is the line between the boxes. Green boxes refer to the public sector and blue ones to the private sector. ATMA = Agricultural Technology Management Agency, DoA = Department of Agriculture, ICAR = Indian Council for Agricultural Research, FFS = farmer field school, FBO/SHG = farmer-based organization/self-help group, SAU = state agricultural university, KVK = Krishi Vigyan Kendra (farm science center), NGO = nongovernmental organization.

2. ROLE OF AGRICULTURAL EXTENSION

2.1 Communication of Scientific Research to Farmers

The fundamental role of agricultural extension in India is to communicate and disseminate scientific research and technology innovations to farmers. This is done through various methods, each tailored to meet the unique characteristics of different farming communities across India's vast and diverse agricultural landscape. The extension service uses tools like farmer field schools, demonstration plots, farmer meetings, and field days to communicate new farming technologies and research findings [10]. The use of Information and Communication Technology (ICT) has significantly revolutionized the delivery of extension services. Digital platforms, including mobile apps, radio, television, and SMS services, are being utilized to reach a broader audience. For instance, the Kisan Call Centers (KCCs), launched by the Ministry of Agriculture in 2004, provide farmers with immediate and reliable answers to their queries through a toll-free telephone service [11]. Similarly, the Digital Green initiative leverages locally produced videos to promote best practices among smallholder farmers [12]. The effectiveness of these methods, however, varies across different regions and farming communities. Studies have shown that the success of information

dissemination largely depends on factors such as farmers' literacy levels, access to ICT, and socio-economic conditions [13]. For instance, demonstration plots and farmer field schools have been found effective in promoting hands-on learning, while digital tools like KCCs and mobile apps have shown success in areas with good ICT infrastructure and digitally literate farmers [14].

2.2 Training and Skill Development

Agricultural extension services play a crucial role in training and skill development, which is vital in ensuring that farmers are well-equipped to adopt modern and efficient farming methods. In India, numerous training programs have been implemented by various agencies, such as the State Department of Agriculture, Krishi Vigyan Kendras (KVKs), and ATMA. These programs focus on a wide range of areas including crop production, livestock management, farm machinery, post-harvest technology, and marketing, among others [15]. The impacts of these training programs are evident in the improvement in farmers' productivity and income levels. For example, a study by Jena [16] revealed that training programs on paddy cultivation in Odisha resulted in a significant increase in paddy yields due to the adoption of improved farming practices. Similarly, in a study by Singh *et al*. [17], it was found that the farmers who participated in training programs on goat farming reported higher incomes compared to those who did not participate.

2.3 Advising on Farming Methods

Advising farmers on efficient and sustainable farming methods is another critical role of agricultural extension. Extension agents work closely with farmers to introduce them to new farming techniques and technologies that can improve their productivity while ensuring the sustainability of their farming systems. This includes advice on crop rotation, integrated pest management, organic farming, conservation agriculture, and precision farming, among others [18]. Agricultural extension facilitates the adaptation of farmers to new technologies and practices. This involves assisting farmers in understanding how the new technologies work, the benefits they offer, and how they can be integrated into their farming systems. For instance, the use of drones in precision farming has been promoted by extension services in some parts of India, helping farmers in more accurate application of inputs, thus saving costs and reducing environmental impacts [19].

2.4 Risk Management and Resilience

Agricultural extension services play a significant role in building farmers' capacity to manage risks associated with climatic variations and market fluctuations. Through training and advisory services, farmers are equipped with knowledge and skills in climate-smart agriculture, crop insurance, futures trading, and other risk management strategies [20]. Agricultural extension promotes resilience against shocks

Table 1. Role of Agricultural Extension in Modern Farming

Role	Explanation
Knowledge Dissemination	AE acts as a crucial link between research institutions and farmers, ensuring the latest findings and techniques are passed down to those who need them.
Technology Adoption	AE promotes the adoption of new technologies, such as precision farming tools, digital platforms, and mobile applications, increasing farming efficiency and profitability.
Climate Change Adaptation	AE provides farmers with information and training on climate-smart agricultural practices, helping them adapt to changing weather patterns and mitigating the impact of extreme weather events.
Entrepreneurship and Market Linkages	AE fosters entrepreneurial skills and builds market linkages, helping farmers to better respond to market trends, manage risks, and improve their income.
Customization to Local Needs	AE tailors its programs to the specific needs of local farmers, ensuring they are relevant and effective.
Capacity Building	AE plays a key role in training and upskilling extension agents, thereby enabling them to effectively support farmers in their transition toward modern farming methods.

and stresses by facilitating the adoption of resilient farming practices and systems. For instance, in the face of changing rainfall patterns, extension services have promoted the use of drought-resistant crop varieties and water-efficient irrigation technologies, thereby enhancing the resilience of farming communities to climate variability [21].

3. AGRICULTURAL EXTENSION IN THE AGE OF DIGITAL TRANSFORMATION

3.1 Role of Technology in Agricultural Extension

As the world steps into an era dominated by digital technology, agriculture is no exception. The role of technology in agricultural extension in India has evolved significantly over the past decade, marking a shift from traditional extension methods to more dynamic and interactive platforms. Various technology platforms are being used to deliver extension services in India. For instance, the Kisan Suvidha mobile application developed by the Ministry of Agriculture provides farmers with information on weather, market prices, agricultural advisories, and plant protection [22]. e-Krishi Samvad, an online interface, allows farmers, researchers, and extension workers to seek expert advice on farm-related issues [23]. Digital Green, a global development organization, uses locally-produced videos shared through social media platforms to disseminate agricultural information and practices among smallholder farmers [12]. The effectiveness of these technology platforms varies but is generally promising. A study by Mittal and Tripathi [24] found that farmers who used the Kisan Suvidha app reported improvements in crop productivity and income, thanks to timely information on weather and market prices. Meanwhile, the Digital Green approach has been reported to be ten times more effective per dollar spent than traditional extension systems, with farmers adopting new practices more rapidly after watching peer-to-peer videos [12].

Table 2. Technologies used in agricultural extension in India

Technology	Description
Mobile Phones	Used for delivering real-time agricultural information and advisory services to farmers. Various government programs like Kisan Call Centres (KCC) use this technology for extension.
Farmer Portals	Digital platforms provide a multitude of services like weather updates, market prices, crop advisories, government schemes, etc. An example is the National Agriculture Market (eNAM) for online trading.
Krishi Vigyan Kendras (KVK)	These are agricultural extension centers created by the Indian Council of Agricultural Research (ICAR) for providing various types of farm support to the agricultural sector. They employ various modern and traditional technologies for extension.
Remote Sensing Technology	Used for large-scale land mapping, monitoring of crop patterns, prediction of agricultural outputs, etc. ISRO's Bhuvan portal offers geospatial services and products for free.
Geographic Information System (GIS)	Used in precision farming to manage fields based on variability in factors like soil type, nutrient levels, and pest infestation. It is also used in watershed development, land resource mapping, etc.
Mobile Apps	Various mobile apps such as 'Kisan Suvidha', 'Agri App', and 'Pusa Krishi' provide information about weather, market prices, agricultural advisories, etc.
Drones	Used for mapping and surveying farmland, monitoring crop health, applying fertilizers or pesticides, and even planting seeds. However, drone usage is still evolving and subject to regulatory frameworks.
E-learning Platforms	Online courses and digital learning materials are increasingly used to train farmers in modern farming techniques. For example, the Digital Green Foundation uses video-based learning for farmer training.

3.2 Digital Literacy and Access among Farmers

Despite the promise of technology, the digital divide remains a significant challenge. The level of digital literacy among farmers in India varies widely. According to a report by the Internet and Mobile Association of India [25], about 48% of rural Indians have internet access, and only a fraction of them use digital tools for agricultural activities. The report highlights significant gaps in digital literacy, particularly among older farmers and women. This limited digital literacy, along with issues related to access, affordability, and relevance of content, often impedes the effective use of technology for agricultural extension [26]. To address these challenges, the Government of India has launched several initiatives such as the Pradhan Mantri Gramin Digital Saksharta Abhiyan (PMGDISHA), aimed at making six crore rural Indians digitally literate [27]. In the context of agricultural extension, efforts have been made to provide digital literacy training to farmers through Krishi Vigyan Kendras and Farmer Producer Organizations [28].

3.3 Case Studies of Successful Digital Agricultural Extension Models

Several digital agricultural extension models have shown success in India. One of them is the aAQUA (almost All Questions Answered) platform, developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the Indian Institute of Technology Bombay. It's an online forum where farmers can ask questions related to agriculture and receive answers from experts within 24 to 72 hours. An evaluation study reported that farmers using the aAQUA platform were able to reduce costs, increase yields, and improve income [29]. Another successful model is the Kisan Call Centres (KCCs), which provide farmers with a toll-free telephone service to ask questions related to agriculture. The effectiveness of KCCs in disseminating agricultural information has been widely recognized, with several studies reporting improved farming practices and income among users [30]. The digital transformation has opened up new possibilities for enhancing the effectiveness and reach of agricultural extension in India. Efforts need to be made to address the challenges related to digital literacy and access and to ensure that technology serves the needs of all farmers, including the most marginalized.

4. IMPACT OF AGRICULTURAL EXTENSION ON MODERN FARMING

4.1 Impact on Farming Efficiency and Productivity

Agricultural extension services play a critical role in enhancing farming efficiency and productivity by facilitating the transfer of knowledge and technology from research institutions to farmers. Numerous studies in India indicate that these services significantly contribute to improved crop yields and farming efficiency. For instance, a study by Kumar et al. [31] found that farmers who regularly interacted with agricultural extension agents had higher crop productivity due to their adoption of improved farming practices. Similarly, Birthal et al. [32] reported that the participation of farmers in extension programs led to a significant reduction in yield gaps for several crops in India. These findings suggest that agricultural extension services can effectively disseminate farming knowledge and technologies, leading to more efficient farming practices and improved productivity. They underscore the importance of these services in meeting the increasing demand for food in India, especially given the challenges posed by climate change and land and water constraints.

4.2 Impact on Sustainability and Environmental Conservation

Sustainable farming is a farming methodology that focuses on maintaining agricultural productivity while minimizing environmental impact, preserving biodiversity, and promoting the equitable distribution of resources. It is a critical component of sustainable development, given that agriculture plays a central role in many environmental issues, including climate change, deforestation, and water scarcity [33]. Agricultural extension services have an important role to play in promoting sustainable farming practices. They can encourage farmers to adopt techniques that enhance productivity while conserving natural resources, such as agroforestry, organic farming, conservation agriculture, and integrated pest management. For instance, an evaluation of the National Initiative on Climate Resilient Agriculture (NICRA) in India revealed that extension services had effectively encouraged farmers to adopt climate-smart agricultural practices, leading to increased productivity and reduced environmental impact [34].

4.3 Impact on the Socio-Economic Status of Farmers

The agricultural extension also has significant socio-economic implications for farmers. Various studies in India have highlighted the positive impacts of agricultural extension services on farmers' income and living standards. Birthal et al. [35] found that farmers participating in extension programs had higher incomes due to improved productivity. Similarly, a study by Narayanan [20] reported that farmers who received extension services were more likely to diversify their farming activities, leading to increased income and improved livelihood resilience. The role of agricultural extension in these improvements is substantial. By facilitating the adoption of improved farming practices and technologies, these services enable farmers to increase their productivity and market competitiveness. By promoting diversification and risk management strategies, extension services can help farmers enhance their income stability and resilience to shocks, thereby contributing to poverty reduction and rural development.

5. CHALLENGES AND LIMITATIONS OF AGRICULTURAL EXTENSION

5.1 Resource Constraints

Despite the significant role of agricultural extension in modern farming, it is not without its challenges. A prominent issue is the constraint of resources. The extension system in India often suffers from inadequate funding, resulting in limited outreach, poor quality of services, and a lack of necessary infrastructures such as training centers and demonstration farms [36]. Besides, there is also a severe shortage of trained extension personnel, which limits the ability to provide personalized, regular, and in-depth support to farmers [37]. To address these resource constraints, innovative models of extension have been proposed. Public-private partnerships, for example, can pool resources from different stakeholders to enhance extension services [38]. Farmer Field Schools and Farmer Producer Organizations are other examples of low-cost, farmer-led approaches to an extension that leverage peer learning and collective action [39].

5.2 Socio-Cultural Barriers

Socio-cultural factors can also impede the effectiveness of agricultural extension. For example, gender and caste disparities can limit access to and benefit from extension services. Women farmers, despite their significant role in Indian agriculture, often receive less extension support than men [40]. Similarly, marginalized groups such as scheduled castes and tribes may face discrimination or exclusion in extension activities [41].

Overcoming these barriers requires a socially inclusive approach to agricultural extension. Gender-sensitive extension strategies, for example, can ensure that women farmers receive tailored support that acknowledges their unique needs and constraints [42]. Similarly, pro-poor extension strategies can ensure the inclusion and empowerment of marginalized farmers [4].

5.3 Policy and Institutional Challenges

Policy and institutional factors can also pose challenges to agricultural extension. Fragmented and inconsistent policies, lack of coordination among various extension providers, and the absence of clear guidelines on the use of new extension approaches are some of the issues that impede the effectiveness of extension in [2]. Addressing these policy and institutional challenges requires a comprehensive reform of the extension system. This can involve the formulation of coherent and supportive policies, the establishment of a national coordination mechanism for extension, and capacity building for extension organizations and personnel [43]. Participatory and decentralized approaches to extension can ensure that policies and programs are responsive to farmers' diverse and evolving needs.

6. FUTURE OF AGRICULTURAL EXTENSION

6.1 Projections of Future Challenges in Farming (Climate Change, Food Security, etc.)

The future of farming in India faces significant challenges, primarily due to climate change, increasing population, and food security concerns. Climate change, with its erratic rainfall patterns, extreme weather events, and increasing temperatures, threatens agricultural productivity and sustainability [44]. Coupled with the pressure of feeding an increasing population, this constitutes a substantial challenge for Indian agriculture in ensuring food security [45].

Climate change poses significant challenges to Indian agriculture. Rising temperatures, erratic rainfall patterns, increased frequency of extreme weather events like droughts and floods, and changing pest and disease dynamics threaten crop production and productivity. Heat stress on crops like wheat and rice, water scarcity, and sea-level rise affecting coastal agriculture are among the key concerns. Similarly, Latin America faces climate change impacts that vary across countries [46]. The region experiences changing rainfall patterns, increased frequency of droughts, rising temperatures, and more intense hurricanes and storms [47,48]. These factors affect agriculture by reducing water availability, causing crop losses, and disrupting ecosystems. The vulnerability of small-scale farmers is a shared concern in both regions [47].

Water Scarcity and Irrigation: Water scarcity is a significant challenge for agriculture in India. Dependence on monsoon rains, inefficient irrigation practices, and depleting groundwater reserves exacerbate the issue. Climate change further intensifies water scarcity, necessitating improved irrigation techniques and water management practices. Water scarcity is also a concern in Latin America, particularly in arid and semi-arid regions [49]. Some areas in Mexico, Brazil, Chile, and Venezuela experience water stress, impacting agricultural productivity. Efficient water management systems, including better irrigation practices and water conservation strategies, are essential to address this challenge [50].

Food Security: Food security remains a critical challenge in India due to a growing population, limited arable land, and changing consumption patterns. Climate change-induced crop losses, post-harvest losses, and inadequate storage and distribution infrastructure further complicate the issue. Ensuring sufficient food production, improving storage facilities, and enhancing market access for small farmers are vital for food security. While Latin America is known as a major food exporter, ensuring food security within the region remains a challenge. Issues such as unequal access to land, limited technology adoption, and market access gaps affect small farmers' ability to produce and access nutritious food [51,52]. Addressing income disparities, promoting sustainable farming practices, and improving infrastructure for storage and transportation are essential to enhance food security [53]

While there are commonalities in the challenges faced by India and Latin America in the context of farming, it is important to note that the specific issues and priorities can vary within each region and country. The implementation of tailored strategies and policies based on local conditions, scientific research, and stakeholder engagement is crucial to address these challenges effectively.

Role of agricultural extension in addressing challenges: Given these projected challenges, agricultural extension has a crucial role to play. The extension system can support farmers in adapting to climate change by promoting climate-smart agricultural practices [54]. Extension services can also address food security issues by improving farmers' productivity through the adoption of efficient and sustainable farming practices and technologies [55]. The agricultural extension can contribute to resilience building among farming communities. Facilitating access to information and resources can empower farmers to better manage risks and uncertainties associated with climate change, market fluctuations, and other shocks [56].

When comparing agricultural extension studies in Latin America, it is important to consider the diverse contexts and agricultural systems within the region. Different countries have implemented extension programs with varying emphases and approaches [57]. Some studies focus on evaluating the impact of specific extension interventions, such as training programs or technology demonstrations, on farmers' productivity and income [58]. Others examine the institutional frameworks and policies that support or hinder effective extension services.

Additionally, Latin American countries have unique socio-economic, environmental, and cultural factors that influence the design and implementation of extension programs. These factors include land tenure systems, access to resources, gender dynamics, indigenous knowledge, and rural-urban dynamics. Comparative studies in Latin America may explore these contextual factors to identify best practices and lessons learned from extension initiatives across countries.

Potential advancements in agricultural extension practices: In terms of technological advancements, artificial intelligence (AI), virtual reality (VR), and other digital technologies offer exciting opportunities for transforming agricultural extension. AI, for instance, can enhance

decision-making by extension by enabling the analysis of vast amounts of data on weather, soil, crops, and pests to generate precise and timely advice for farmers [59]. Similarly, VR can enhance training and learning by extension by providing immersive and interactive experiences, such as virtual farm tours or equipment demonstrations [60]. While these technologies offer promising prospects, it's crucial to ensure their appropriate and inclusive use. This requires addressing challenges related to digital literacy, access, and affordability among farmers, as well as building the capacity of extension organizations and personnel in using these technologies [61].

7. CONCLUSION

Agricultural extension services are integral to modern farming in India, facilitating sustainable, efficient farming practices, and enhancing farmers' socio-economic status. With the advent of digital technologies, the potential for extension services has significantly expanded, though issues of digital inclusivity must be addressed. Despite benefits, extension services face challenges such as resource constraints, socio-cultural barriers, and policy issues. Tackling these requires innovative, comprehensive reform strategies. Looking ahead, agricultural extension remains crucial in addressing emergent farming challenges and leveraging opportunities to boost productivity and sustainability. Ongoing efforts are vital to strengthening extension services, ensuring they respond effectively to India's evolving agricultural landscape.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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