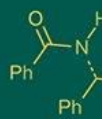


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Empowering small-scale agriculture: Effective strategies for technology transfer

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Abstract

Technology transfer in agriculture is crucial for enhancing food security and promoting sustainable farming practices, especially for small-scale farms. This article examines strategies for effective technology transfer, focusing on bridging the gap between scientific advancements and practical application. It identifies barriers such as limited access to capital and technical knowledge, and the impact of the technology gap on productivity and livelihoods. Opportunities for improvement include training programs, infrastructure development, and financial support. Key players in agricultural technology transfer include government agencies, research institutions, private sector companies, and farmer organizations. Innovative transfer models like community-based technology hubs, mobile technology clinics, farmer-to-farmer video sharing, and agri-hackathons are discussed. Information and Communication Technologies (ICTs) are emphasized for knowledge dissemination, including developing farmer-friendly mobile apps, social media, SMS-based advisory services, and interactive e-learning platforms. Building local innovation ecosystems, fostering partnerships between farmers and researchers, promoting local technology adaptation, and creating incentives for grassroots innovation are crucial steps for sustainable technology transfer.

Keywords: Technology transfer, small-scale farms, agricultural productivity, ICTS, innovation ecosystems, sustainability

1. Introduction

Technology transfer in agriculture plays a crucial role in enhancing food security and agricultural sustainability worldwide (Pandey & Pandey, 2023) ^[30]. This process involves sharing knowledge, skills, and tools from research institutions to farmers, enabling them to boost agricultural production and productivity (Rondot & Collion, 2001) ^[39]. The importance of technology transfer in agriculture cannot be overstated, as it bridges the gap between scientific advancements and practical application on farms (Roling, 2019) ^[38].

This article explores key strategies for effective technology transfer in agriculture, focusing on small-scale farms. It examines the technology gap in small-scale farming, identifies key players in the transfer process, and discusses innovative models for knowledge transfer. The piece also looks at how to leverage ICTs for better transfer ^[13], build local innovation ecosystems, and ensure the sustainability of these efforts. By understanding these aspects, stakeholders can work together to improve agricultural development and rural development.

2. The Technology Gap in Small-Scale Farming

Small-scale farms play a crucial role in agricultural production and food security, yet they often lag behind in adopting modern agricultural technologies. This gap has a significant impact on productivity and livelihoods, but also presents opportunities for improvement through effective technology transfer in agriculture (Woodhill *et al.*, 2020; Suman *et al.*, 2025) ^[49, 48].

2.1 Current state of technology adoption

The adoption of agricultural technologies among small-scale farmers in developing regions, particularly in Sub-Saharan Africa, remains relatively low (Giller *et al.*, 2021) ^[53]. This situation stems from various factors, including limited access to capital, weak supply chains,

and a lack of technical knowledge (Prusty *et al.*, 2020) ^[34]. Small-scale farmers often face barriers when it comes to implementing new technologies in a financially sustainable manner.

For instance, the high initial investment costs of acquiring and implementing technology can be a major obstacle for farmers with small budgets and limited resources (Dhillon & Moncur, 2023) ^[11]. Additionally, farmers may be hesitant to change their farming practices due to a lack of information about the profitability of new technologies or concerns about potential risks.

2.2 Impact on productivity and livelihoods

The technology gap has a profound effect on the productivity and livelihoods of small-scale farmers. Research indicates that the use of agricultural technologies has a significant impact on how increases in agricultural output affect poverty levels and environmental degradation (Zhang *et al.*, 2021) ^[51]. By adopting certain agricultural technologies, farmers could boost productivity and profitability.

However, the relatively low uptake of technologies among small-scale farms means there's limited evidence on how these innovations can enhance productivity or how long it takes for farmers to see profits after introducing a new technology (Kumari *et al.*, 2024) ^[20]. This lack of information further perpetuates the hesitation to adopt new practices.

2.3 Opportunities for improvement

Despite the challenges, there are numerous opportunities to bridge the technology gap in small-scale farming. One approach involves introducing new agricultural technologies alongside mechanisms that help farmers overcome adoption barriers. These may include training programs, infrastructure development, and financial support (Khan *et al.*, 2025) ^[19].

To make technologies more affordable, governments and development organizations can offer technical assistance, subsidies, grants, or low-interest loans to farmers for purchasing or renting agricultural equipment. For example, a low-cost voucher scheme in India led to a 30% increase in agricultural mechanization rentals. Similarly, in the Dominican Republic, vouchers reduced the purchase price of irrigation equipment, resulting in a more than 60% increase in adoption (Mishra *et al.*, 2024) ^[24].

Promotional campaigns and training for farmers, combined with incentives, subsidies, and improved access to capital, have shown success in increasing technology uptake in countries like Ethiopia, Uganda, Kenya, and the Dominican Republic (Alfaro-serrano *et al.*, 2021) ^[1]. These initiatives help address the lack of technical skills and knowledge that often hinder technology adoption.

Furthermore, there's an opportunity to leverage climate-smart technologies, such as conservation agriculture (CA), which can offer low-cost, labor-saving, and climate-friendly alternatives to conventional practices. Research shows that farmers in East Africa who adopted CA benefited from higher net returns over time, partly due to reduced labor and production costs (Ngoma *et al.*, 2021) ^[26].

By addressing issues related to affordability, knowledge, and access to support services, stakeholders can empower small-scale farmers to harness the benefits of agricultural technologies and bridge the existing technology gap.

3. Key Players in Agricultural Technology Transfer

Effective technology transfer in agriculture involves a diverse range of stakeholders working together to bridge the gap between research and practical application on farms (Dhillon & Moncur, 2023) ^[11]. These key players play crucial roles in ensuring that innovative agricultural technologies reach small-scale farmers and contribute to rural development.

3.1 Role of government agencies

Government agencies serve as pivotal players in agricultural technology transfer. They set policies, provide funding, and create frameworks for implementing technology dissemination programs (Pandey *et al.*, 2022) ^[29]. For instance, the Agricultural Technology Management Agency (ATMA) in India functions as a registered society at the district level, integrating research and extension activities. ATMA's Governing Board reviews and approves strategic plans, fosters the development of Farmers Interest Groups (FIGs), and encourages agricultural lending institutions to increase capital availability to resource-poor and marginal farmers (Singh *et al.*, 2022) ^[46].

3.2 Contributions of research institutions

Research institutions are at the forefront of generating new agricultural technologies and knowledge. They conduct studies, develop improved crop varieties, and create innovative farming techniques (Karunathilake *et al.*, 2023) ^[18]. The International Rice Research Institute (IRRI), for example, leads the way in agricultural innovations that can catalyze positive change in rice-based agri-food systems. These institutions also play a crucial role in adapting technologies to local conditions and providing technical support to extension services.

3.3 Involvement of private sector companies

Private sector companies have become increasingly important in agricultural technology transfer. They bring additional investments in infrastructure and R&D, as well as efficiencies in the agricultural value chain. Private players contribute to various aspects, including:

- Conducting research and introducing improved technologies
- Providing credit through cooperatives and self-help groups
- Creating infrastructure for seeds, fertilizers, and pesticides
- Assisting with extension services
- Disseminating accurate and timely information
- Diffusing crop insurance

Private companies also engage in contract farming, establishing farm-firm linkages that provide credit, assured markets, and extension services to small landholders (Rana *et al.*, 2023) ^[36].

3.4 Importance of farmer organizations

Farmer organizations play a vital role in facilitating technology transfer and empowering small-scale farmers. These organizations can be broadly categorized into two types:

- Community-based, resource-oriented organizations: These include village-level cooperatives or associations

that deal with inputs needed by members to enhance productivity.

- Commodity-based, market-oriented organizations: These specialize in a single commodity and focus on value-added products with expanded (Jaishi *et al.*, 2022) ^[14] markets.

Farmer organizations help in organizing different types of services for their members, including input supply, credit, technical services, and marketing arrangements. They also serve as a platform for farmers to voice their needs and

provide feedback to researchers and extension workers, ensuring that technology development and dissemination are demand-driven and farmer-accountable (Nagaraji *et al.*, 2023) ^[25].

By working together, these key players can create a more effective and responsive agricultural technology transfer system. This collaboration has a significant impact on how increases in agricultural output affect poverty levels and environmental degradation, ultimately contributing to improved food security and agricultural sustainability (Lakhan Lal Meena *et al.*, 2024) ^[52].



Fig 1: Dynamics of Agricultural Technology Transfer

4. Innovative Transfer Models for Small-Scale Farms

To bridge the technology gap in small-scale farming, innovative transfer models have emerged, offering tailored solutions to address the unique challenges faced by smallholder farmers (Sahoo *et al.*, 2025) ^[43]. These models aim to enhance agricultural productivity, improve food security, and promote sustainable farming practices (Kapari *et al.*, 2023) ^[16].

4.1 Community-based technology hubs

Community-based technology hubs, also known as Agro-Food Sustainability Knowledge Hubs, play a crucial role in fostering agricultural innovation and knowledge transfer. These hubs serve as centralized platforms where farmers can access information, resources, and support services (Smidt & Jokonya, 2022) ^[47]. They help in re-balancing the power structure in the agro-food supply chain by ensuring a more equal distribution of economic value among all involved actors (Badavath *et al.*, 2024) ^[3].

These hubs offer several benefits to small-scale farmers:

- Maintaining sustainable practices and preserving farmers' identity
- Addressing the lack of knowledge and asymmetric information
- Enhancing continuous research and development initiatives
- Establishing effective communication among different partners in a holistic strategic network

By integrating various services, such as storage facilities and financial support, these hubs enable farmers to overcome challenges related to post-harvest losses and market access. For instance, smart hermetic bins with integrated digital technology allow farmer communities to set up small-scale, modular grain storage units. These bins monitor grain quantity and quality remotely, enabling financial institutions to lend securely and buyers to purchase at any point during storage.

4.2 Mobile technology clinics

Mobile technology clinics have gained significant importance in agricultural development due to their simplicity, utility, and cost-effectiveness (Sharma *et al.*, 2020) ^[45]. These clinics leverage the widespread adoption of mobile phones among smallholder farmers to provide essential information and services.

Farmers can access a range of mobile applications designed specifically for agriculture, such as Kisan Suvidha, Krishi Mitra, and Pusa Krishi. These apps offer valuable information on fertilizers, subsidies, new plant varieties, pesticides, weather forecasts, and market prices of commodities in nearby markets (Prusty *et al.*, 2021) ^[33].

The benefits of mobile technology clinics include:

- Improved social cohesion and better relations between farmers and the business community
- Timely access to solutions for agricultural challenges
- Enhanced decision-making capabilities for farmers

- Increased alertness to agricultural management practices

4.3 Farmer-to-farmer video sharing

Video-based knowledge transfer has emerged as an effective method for disseminating information to farmers, particularly in reaching marginalized groups, women, and young people. Farmer-to-farmer video sharing serves various purposes, including raising awareness, stimulating demand for support, and providing training on agricultural innovations (Karubanga *et al.*, 2016) ^[17].

Different types of videos are used in this model:

- Documentary videos describing events
- Instructional videos developed by researchers
- Farmer-learning videos made with farmers
- Participatory videos created by farmers themselves

This approach has proven to be an effective alternative to conventional training methods, such as community workshops, in transferring knowledge and promoting the adoption of new agricultural practices.

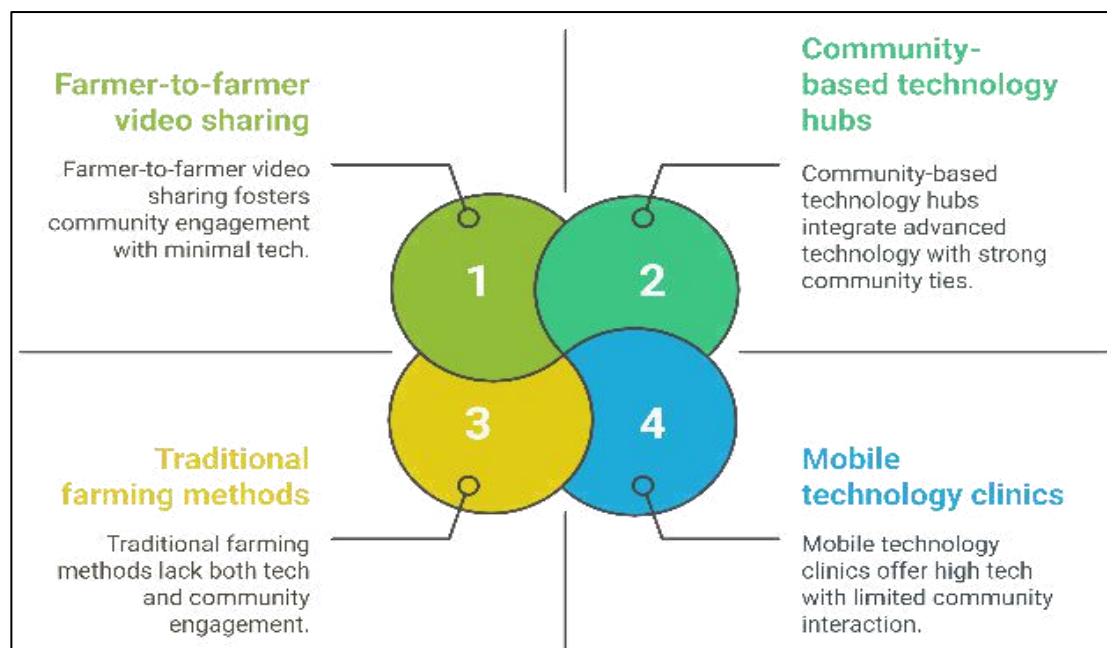


Fig 2: Innovative Models for Small-Scale Farming

4.4 Agri-hackathons and innovation challenges

Agri-hackathons and innovation challenges have become popular platforms for fostering creativity and developing solutions to key challenges in the agricultural sector (Chaudhary & Suri, 2024) ^[6]. These events bring together students, researchers, innovators, and farmers to create innovative solutions and potentially launch agritech start-ups.

The objectives of these events include:

- Identifying and nurturing innovations in agriculture and allied sectors
- Highlighting funding opportunities for scaling up promising solutions
- Organizing competitions to address societal problems in agriculture
- Bridging the gap between rural and urban communities

Participants in these events are encouraged to develop prototypes of their solutions, focusing on affordability, accessibility, efficiency, and user experience across the agricultural value chain. Successful innovations may receive incubation support, seed funding, and networking opportunities to further develop and implement their ideas (Nuthalapati *et al.*, 2020) ^[27].

By implementing these innovative transfer models, stakeholders can effectively bridge the technology gap in small-scale farming, leading to improved agricultural productivity, enhanced food security, and sustainable rural development.

5. Leveraging ICTs for Effective Transfer

Information and Communication Technologies (ICTs) play a crucial role in bridging the technology gap in small-scale farming. By harnessing the power of ICTs, stakeholders can enhance the effectiveness of technology transfer in agriculture, leading to improved agricultural productivity and rural development (Mapiye *et al.*, 2023; Pradhan *et al.*, 2024) ^[21, 3].

5.1 Developing farmer-friendly mobile apps

The increasing penetration of budget-friendly mobile phones and internet access has opened up new avenues for farmers in remote areas. Mobile applications have become essential tools for disseminating agricultural information and providing valuable services to farmers. These apps offer a range of features, including crop management, soil quality assessment, weather forecasting, and pest control measures. For instance, the Meghdoot app, a joint initiative of various Indian agricultural institutions, delivers critical information to farmers through a simple and easy-to-use interface.

5.2 Using social media for knowledge dissemination

Social media platforms have emerged as valuable channels for connecting farmers and promoting discussions about agricultural practices and technologies. Platforms like Twitter, YouTube, and WhatsApp have gained popularity among farmers for sharing experiences, learning from peers, and accessing expert advice (Paredes-Labra *et al.*, 2018) ^[31]. However, it's important to note that while social media has

expanded the reach of farmer networks, it remains underutilized in the dissemination of knowledge about smart farming technologies (SFT).

5.3 Implementing SMS-based advisory services

SMS-based agricultural advisory services have proven to be an effective and cost-efficient method of delivering tailored and timely information to farmers. Research conducted in India and Kenya has shown that mobile phone-based extension can promote behavior change and increase farmers' yields and incomes (Fabregas *et al.*, 2019) ^[12]. For example, a study in Gujarat, India, found that nearly 90 percent of farmers with access to an advisory hotline called in for agricultural information over a two-year evaluation period, illustrating the usefulness of such services (Saha *et al.*, 2025) ^[41].

5.4 Creating interactive e-learning platforms

Interactive e-learning platforms have become increasingly important in agricultural education and technology transfer. These platforms offer a range of benefits, including:

- Providing accessible and tailored learning experiences for rural youth and working professionals
- Offering technical information and technological advice online
- Facilitating the development of agri-oriented entrepreneurship skills

For example, the Center for e-Learning (CeL) established in Kerala, India, offers online courses and an interactive web portal to make local and frontier areas of farm technology available to farmers and other agricultural stakeholders year-round, free of cost (Barman & Baishya, 2021) ^[5].

By leveraging these ICT-based approaches, stakeholders can enhance the effectiveness of technology transfer in agriculture, ultimately contributing to improved agricultural productivity, food security, and rural development. However, it's crucial to consider factors such as digital literacy, information processing capabilities, and farmers' readiness to accept information when implementing these strategies (Saha *et al.*, 2024) ^[40].

6. Building Local Innovation Ecosystems

Building local innovation ecosystems is crucial for enhancing technology transfer in agriculture and promoting rural development. These ecosystems foster collaboration between farmers, researchers, and other stakeholders, leading to improved agricultural productivity and food security. By creating an environment that encourages grassroots innovation and knowledge sharing, local communities can develop tailored solutions to address their specific challenges (Ortiz & Peris, 2022) ^[28].

6.1 Establishing rural innovation centers

Rural innovation centers serve as hubs for agricultural development and technology transfer. These centers provide a platform for farmers to access information, resources, and support services (Youtie & Shapira, 2008) ^[50]. They play a vital role in re-balancing the power structure in the agro-food supply chain by ensuring a more equal distribution of economic value among all involved actors. These hubs offer several benefits to small-scale farmers, including maintaining sustainable practices, addressing the lack of knowledge and asymmetric information, and enhancing

continuous research and development initiatives (Mapiye *et al.*, 2023) ^[21].

6.2 Fostering partnerships between farmers and researchers

Collaboration between farmers and researchers is essential for effective technology transfer in agriculture. By working together, they can develop innovative solutions that address real-world challenges faced by small-scale farmers (Saha *et al.*, 2024) ^[40]. This partnership allows for the integration of traditional knowledge with modern scientific approaches, resulting in more sustainable and locally-adapted agricultural practices (Restrepo *et al.*, 2020) ^[37]. Farmers' experimentation and innovation in response to changing conditions inherently creates greater diversity, contributing to resilience within the global food system (Prusty & Mohapatra, 2021) ^[33].

6.3 Promoting local technology adaptation and development

Encouraging local technology adaptation and development is crucial for ensuring that agricultural innovations are suitable for small-scale farms. This approach recognizes farmers as innovators rather than solely recipients of research results. By supporting farmers' seed systems, promoting traditional knowledge systems, and facilitating knowledge sharing using information and communication technologies, local communities can develop context-specific solutions that address their unique challenges (Balogun *et al.*, 2020) ^[4].

6.4 Creating incentives for grassroots innovation

Establishing incentives for grassroots innovation has a significant impact on how increases in agricultural output affect poverty levels and environmental degradation. These incentives can include providing direct financial support to farmers conducting on-farm research, increasing exposure of small-scale farmers' innovative capacity through innovation fairs and publications, and supporting the establishment of producers' cooperatives to combat risk and unpredictability associated with climate change and market volatility (Dey *et al.*, 2019) ^[10].

By implementing these strategies, local innovation ecosystems can thrive, leading to improved agricultural productivity, enhanced food security, and sustainable rural development. These ecosystems foster a culture of knowledge exchange along the whole value chain, creating an environment ripe for innovation, especially when the industry can take advantage of experience in different regions (Del Soldato & Massari, 2024) ^[7]. Through shared research and experiences, farmers can more quickly learn and adopt techniques that promote soil health, water conservation, and biodiversity, ultimately contributing to long-term sustainability and resilience in the agricultural sector.

7. Ensuring Sustainability of Transfer Efforts

Ensuring the long-term success of technology transfer in agriculture requires a multifaceted approach that addresses various aspects of sustainability. By developing sustainable business models, building local capacity, promoting climate-smart technologies, and integrating transfer efforts with broader rural development initiatives, stakeholders can create a robust framework for lasting agricultural innovation

and growth (Athuman, 2023) ^[2].

7.1 Developing sustainable business models

To achieve sustainable technology transfer in agriculture, it's crucial to implement service-based business models. These models offer an ideal framework for transferring and upscaling new technology to potential end users (Deshmukh *et al.*, 2023) ^[9]. By providing services to farmers using innovative technologies, these business models can help young people and farmers interested in agribusiness, especially in the private extension sector. The Canvas approach, a straightforward and adaptable tool, can be applied to any new agricultural technology, facilitating the introduction and sustainable adoption of innovations.

7.2 Building local capacity for technology maintenance

Capacity building has gained prominence in agricultural development, particularly within rural areas. It represents an ongoing process that allows farmers to access information, receive facilitation, and become empowered, fostering technical advancement. By prioritizing the active involvement of individuals and rural communities, capacity building efforts can empower farmers to effectively address daily challenges and seize opportunities (Ortiz & Peris, 2022) ^[28]. This approach places community engagement at the core of interventions, promoting self-reliance among farmers and ensuring the long-term sustainability of technology transfer efforts (Meena *et al.*, 2020) ^[23].

7.3 Promoting climate-smart and resilient technologies

Climate-smart agriculture (CSA) has demonstrated its efficacy in delivering tangible benefits to farmers. Studies show that adopting climate-smart practices can increase farmers' incomes by up to 30% and enhance crop yields by 20-30%. Moreover, implementing climate-smart techniques has the potential to reduce greenhouse gas emissions from agriculture by approximately 1.5 gigatons of carbon dioxide equivalent per year (Kabato *et al.*, 2025) ^[15]. To promote these technologies effectively, it's essential to enhance small and marginal farmers' understanding of adaptation and mitigation strategies for climate change. By addressing farmers' concerns and incorporating their suggestions into promotion strategies, stakeholders can ensure the relevance and effectiveness of future climate change mitigation initiatives.

7.4 Integrating transfer efforts with broader rural development initiatives

To maximize the impact of technology transfer in agriculture, it's crucial to integrate these efforts with broader rural development initiatives. This integration can lead to improved food safety, diversified income sources for farmers, and stronger rural communities (Delgado & Siamwalla, 2018) ^[8]. By providing opportunities for sustainable income and a higher quality of life in rural areas, agricultural education and technology transfer can slow the flow of people migrating to cities in search of work (Sai *et al.*, 2024) ^[44]. Additionally, farmers who understand market dynamics and quality standards can better position their products, leading to increased local and international sales and contributing to regional and national economic growth (Meena *et al.*, 2024) ^[3].

8. Conclusion

Technology transfer in agriculture has a significant impact on enhancing food security and promoting sustainable farming practices, especially for small-scale farms. The strategies discussed in this article highlight the importance of collaboration among various stakeholders to bridge the technology gap. By leveraging ICTs, building local innovation ecosystems, and ensuring the sustainability of transfer efforts, we can create a more resilient and productive agricultural sector. To wrap up, the success of agricultural technology transfer hinges on tailoring approaches to local contexts and empowering farmers to become active participants in the innovation process. As we move forward, it's crucial to keep focusing on developing sustainable business models, building local capacity, and integrating transfer efforts with broader rural development initiatives. This holistic approach has the potential to transform small-scale farming, leading to improved livelihoods and stronger rural communities.

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