Online issn:2829-8268
Print issn:2829-6532

Optimizing Farmers' Income through Digital Innovation in Agricultural Supply Chains

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Abstract. Agriculture plays a very vital role in the development of the rural economy; nevertheless, a large number of farmers are found to be confronted with financial crises due to changes in market prices, inefficient practice, or a very poor awareness of modern technologies. Equipping farmers with up-to-date digital innovations along the value chain focuses on sustainable farming practices, financial literacy, and digital marketing strategies to maximize income. The general vision is to increase farmers' productivity, profitability, and resilience by equipping them with knowledge that will enable to adapt to changing markets. Participatory approaches involve farmers in workshops and field demonstrations of sustainable agriculture, digital marketing, and financial management. Farmers learn how to manage their farms more effectively by developing their e-commerce platform to market their products, using social media to access broader markets, and applying precision farming techniques. The program participants witnessed improved incomes for the farmers, enhanced access to markets, enhanced financial management, and an improvement in agricultural productivity. Application of the digital tool supported the introduction of sustainable farming practices, therefore, contributing to economic resilience in the long term, as well as environmental sustainability.

Keywords: Digital innovation, agricultural supply chain, sustainable farming, financial literacy, market access.

1. Introduction

Agriculture is a fundamental pillar of economic development, particularly in rural areas where farming serves as the primary source of income for many communities [1]. However, despite its importance, Farmers often face economic instability due to persistent challenges such as fluctuating market prices, inefficient farming practices, and limited access to modern agricultural innovations [2]. Among these challenges, climate change poses a significant threat to agricultural productivity. Extreme weather events, shifting rainfall patterns, and rising temperatures contribute to crop failures and reduced yields, exacerbating financial uncertainty for farmers [3]. Studies indicate that global agricultural productivity could decrease by 3% to 16% by the 2080s due to climate change, with developing countries facing even greater declines [4]. One of the most pressing issues is the lack of digital integration in the agricultural supply chain, which limits efficiency, increases post-harvest losses, and restricts market access. Poor feedback mechanisms hinder communication and value addition, leading to increased waste [5]. Inadequate

Online issn:2829-8268
Print issn:2829-6532

infrastructure, including poor internet and limited technology, prevents farmers from adopting Internet of Things (IoT) and data analytics, further reducing efficiency [6].

In many developing regions, farmers continue to rely on outdated agricultural methods due to limited access to costly modern inputs. This economic barrier prevents them from transitioning to sustainable and profitable farming, reducing efficiency and adaptability in the evolving agricultural landscape [7]. Limited financial resources, lack of digital knowledge, and inefficient distribution channels hinder small businesses' competitiveness in a digitalized market [8]. Financial constraints, including restricted access to capital and high borrowing costs, make growth and adaptation challenging [9]. Unlike larger firms, small businesses rely more on external financing due to limited capital reallocation options [10]. Many farmers rely on traditional intermediaries, reducing their bargaining power and income potential. In contract farming, intermediaries often hold greater influence, discouraging farmers from investing due to fears of unfair profit distribution. Studies show that when farmers perceive intermediaries as too powerful, they may avoid contracts, limit their options and force them into less favorable terms [11]. Trust is crucial in these relationships; farmers who trust intermediaries are more likely to engage in contracts. However, information asymmetry often benefits intermediaries, enabling them to exploit farmers' limited market knowledge [12]. Without proper intervention, these challenges will continue to prevent farmers from optimizing their earnings and achieving economic resilience.

Digital innovation is transforming agriculture by enhancing productivity, streamlining supply chains, and providing direct market access for farmers. Technologies like IoT, data analytics, and precision farming optimize operations, improving resource use and crop yields. IoT devices, for example, enable real-time monitoring of soil and climate conditions, allowing farmers to adapt and maximize outputs [13]. Digitalization also increases transparency and efficiency across the value chain. Technology ensures accurate tracking of products from farm to consumer, reducing food loss and improving stakeholder communication [14]. Technologies such as precision farming, e-commerce platforms, and digital financial services have been proven to improve efficiency and transparency in agricultural trade. Studies show that farmers adopting digital solutions can reduce costs, minimize risks, and increase profitability. Emerging digital agricultural insurance products help mitigate crop failure risks by providing timely information and support, reducing farmers' risk aversion [15].

This program henceforth focuses on bridging the gap between conventional farming and digital solutioning with an integrated approach to agricultural supply chain management. Farmers will be empowered through focused training, workshops, and hands-on implementation in the use of digital tools. The key thematic areas are precision farming techniques, digital marketing strategies, mobile banking for financial inclusion, and data-driven decision-making in agricultural production.

This would, therefore, be the expected impact-increased agricultural productivity, improved financial management amongst farmers, good market access, and the building of a resilient and competitive agricultural economy. This also means lesser dependence on middlemen, along with value addition in processes to help farmers in their economic sustainability.

Coupled with these, the strategic approaches would transform the conventional farming into a modern, technology-driven, and economically sustainable agricultural system. The long-term vision is to create a self-sufficient farming community where efficiency, productivity, and profitability are digitally driven. Eventually, the success of this program will act as a model for other rural communities, depicting that digital integration in agriculture could act as a strong driver for economic development and resilience.

2. Methods

2.1. Program Implementation Approach

This program seeks to enable farmers to optimize their earnings by providing digital solutions to challenges in the agricultural supply chain. Specifically, this program seeks to close the gaps in farming productivity, market access, and finances through digital agriculture frameworks. By integrating technology, the program also provides training in modern financial literacy and supply chain management.

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The first step of this approach is a comprehensive needs assessment that analyzes specific problems and technology needs within the agricultural supply chain. This diagnostic stage is critical to avoid a top-down imposition of solutions and instead promote participatory planning that reflects the actual realities of farmers. Data is collected through interviews, field observations, and participatory rural appraisals (PRA) to ensure local wisdom and context-specific variables are incorporated. That way, all farmers are guaranteed that measures undertaken will meet genuine needs locally and agricultural practices are considered. This phase also identifies potential barriers to adoption, such as digital literacy gaps, infrastructure deficits, and socio-cultural resistance to technological change. Therefore, the implementation strategy is both inclusive and adaptive, enabling a tailored digital transition that empowers rural farming communities while aligning with sustainable development goals (SDGs), particularly SDG 2 (Zero Hunger) and SDG 9 (Industry, Innovation and Infrastructure).

2.2. Capacity Building and Digital Training

After the needs assessment, farmers are first introduced to the information and communication technology (ICT) infrastructure of agriculture through Digital Agricultural Training. The training includes precision agriculture, smart farming technology such as drones for crop spraying, automated irrigation equipment, and agricultural IT systems which make it possible to fully optimize land resources, increase effective labor time, and cut expenses. This component promotes a paradigm shift from traditional subsistence farming to knowledge-based agribusiness models. The novel pedagogy used is workshops, fieldwork, and practical classes, allowing every participant to learn by doing. Peer learning and community-based mentoring are also applied to enhance collective understanding and build local champions who will lead post-program sustainability. This ensures capacity is not only developed but also retained and amplified within the community.

The course also includes training modules in E-Commerce, E-Logistics, and Supply Chain Execution where farmers are taught the effective use of e-commerce and digital logistics services. Workshops, case studies, and simulations are meant to aid farmers in effectively tracing and distributing their products to wider markets where they have better price control. These modules introduce participants to integrated platforms that connect producers, aggregators, and consumers in real-time. To supplement the financial stand of farmers, the program has modules in Financial Literacy and Digital Transactions. Farmers are taught how to use the mobile and internet banking and other financial technology services for more efficient handling of transactions and credit. Interactive sessions and practical techniques provide farmers with essential financial skills that help them function independently from middlemen and strengthen their economic self-sufficiency. In many cases, partnerships with FinTech companies and local banks are pursued to facilitate access to microcredit, crop insurance, and real-time payment systems.

2.3. Encouraging New Business Models and Market Entry

The program places special emphasis on training farmers on digital marketing and selling directly to the consumers, which allows them to tap different markets. Training includes branding, social media strategies, and e-commerce which is “hands on” in nature with workshops, video and content creation, and tutoring, supported by farmers engaging with the market directly. These help farmers to build the required online and consumer base directly. In doing so, farmers are not only improving their market visibility but also strengthening their brand identity and consumer trust.

The Business Model Innovation module has made provisions for managing economic diversification by fusing farming activities with contract farming, agritourism, and value-added agricultural products. For instance, farmers are encouraged to explore post-harvest processing, packaging innovations, and direct-to-consumer sales channels. This module merges business guidance with feasibility studies and cooperative workshops to promote economic diversification and new possibilities beyond the farming activities. In addition, risk management strategies such as price hedging and weather-based insurance are also introduced, equipping farmers with tools to navigate market uncertainties and climate shocks.

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2.4. Monitoring, Evaluation, and Sustainability

The sustainability plan is comprised of a robust monitoring and evaluation (M&E) framework that is anchored on focus group discussions, participant surveys, and site visits. These instruments facilitate monitoring of engagement, users' adoption of digital solutions, and the overall impact of the program. A mixed-method approach ensures both qualitative insights and quantitative performance indicators are captured, enabling continuous refinement of the intervention strategies. Furthermore, the farmers are also given mentoring and assistance towards the adoption of the digital farmer's working tool, such as mobile apps for weather prediction, crop disease identification, and market pricing. This long-term mentorship supports behavior change and helps address post-training implementation challenges.

Moreover, the program seeks to partner with local agricultural agencies, cooperatives, FinTech, and e-commerce companies for continuous support and resource provision to the farmers. By embedding the initiative into existing institutional structures, the program aspires to achieve systemic transformation in agricultural practices and rural livelihoods. These multi-stakeholder collaborations are critical to ensuring scalability, replicability, and long-term impact beyond the pilot sites. This collaborative effort is further illustrated in Figure 1, which presents the coordination mechanism with farmers on agricultural practices, highlighting the roles of each stakeholder and how digital tools are integrated into the communication and decision-making process.

Figure 1. Coordination with Farmers on Agricultural Practices

This approach allows farmers to adopt new modern productivity tools devoid of rigid sequential agricultural operations. Therefore, by increasing productivity, market outreach, and financial management, the program enhances the competitive strength of the farmers while fostering a resilient farming economy. The sequential logic of identifying, prioritizing, and addressing agricultural challenges is outlined in Figure 2, which presents the Problem Schedule Flowchart, illustrating the systematic progression from problem identification to solution implementation across different stages of the program.

Online issn:2829-8268
Print issn:2829-6532

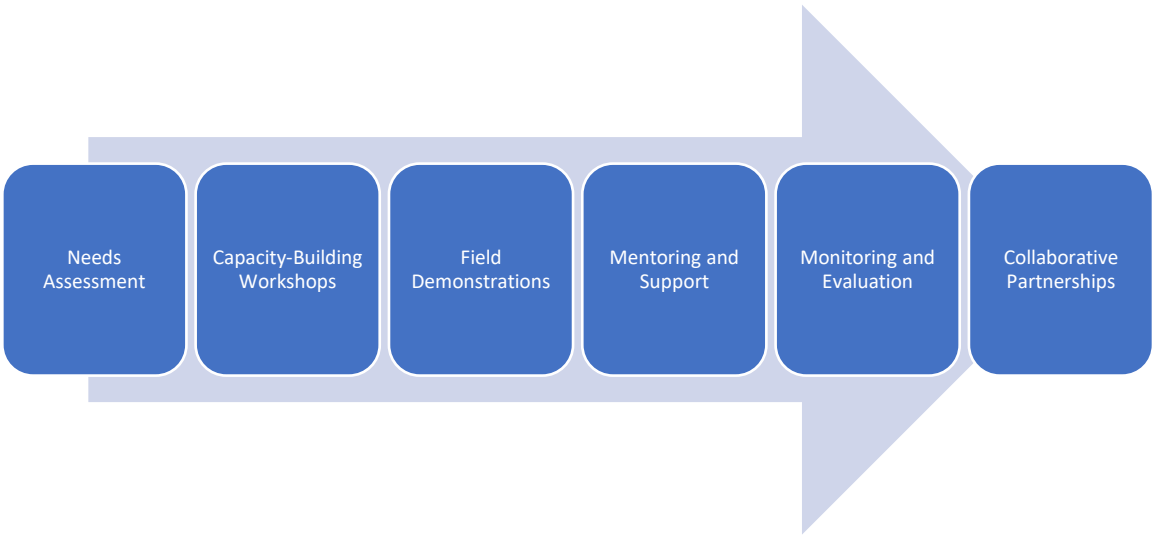

Figure 2. Problem Schedule Flowchart

3. Results and Discussion

The productivity and revenues of farmers have significantly enhanced through the structured adoption of new technologies in each step of the agri-supply value chain. Farmers, under the initiative, were not only introduced to digital technology but also guided through a structured process of capacity building where experience-based implementation, financial impact, and sustainability became the focus areas. The training equipment offered the platform to transform traditional farming systems into more efficient, evidence-based, and scalable methods, allowing farmers to react better to prevailing market demands and climatic unpredictability.

The program's greatest advantage was its holistic training system, which featured digital literacy, precision agriculture, financial management, and digital marketing modules. Farmers were exposed to smartphone applications that provide real-time weather forecasts, pest and disease assessment, satellite imagery for crop monitoring, and accounting software. These applications allowed them to schedule planting more strategically, reduce the risk of crop loss, and optimize the use of agricultural inputs like fertilizers, pesticides, and water. This shift towards evidence-based decision-making encouraged not only improved productivity but also enhanced resilience when faced with unexpected environmental and market disturbances.

Within a period of six months, repeated use of these technologies assisted in generating a considerable increase in farmers' income between sixteen and twenty-five percent. This increase can be attributed to a number of factors: enhanced operational efficiency, reduction in post-harvest loss, access to higher-value markets, and better price control mechanisms facilitated by digital logistics platforms and online commerce. Significantly, this increase in revenue was not limited to a single category of farmer or product but observed across various groups of crops—indicative of the universal applicability and scale of the digital agriculture model.

The intersection of traceability systems for products on the web and e-commerce platforms was instrumental in enabling farmers to bypass traditional intermediaries and connect with buyers and retailers directly. Such disintermediation led to increased profit margins, faster cycles in transactions, as well as enhanced price transparency. By identifying and tracing their products on the internet—especially those bearing organic certification, geographic indications, or unique varietal attributes—farmers were also able to segment their offerings and reach niche markets with premium prices. Traceability also enhanced consumer trust, which is a prime driver in the digital era, especially for food products that need quality assurance and place of origin integrity.

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The digital marketing capacity building of the program was specially beneficial. Farmers and agricultural producers learned how to create brand identities, utilize social media platforms, engage in content marketing, and leverage digital storytelling to emotionally engage customers. These practices led to increased exposure for products and customer loyalty. Approximately 70% of the respondents reported they had more access to regional and national markets through online media channels, including social commerce groups, online farmer's markets, and agricultural e-marketplaces. These online platforms offered more secure prices, access to different groups of customers, and insurance against local market price risks. This level of market diversification hedged income fluctuations and allowed farmers to build strategic pricing models based on supply and demand information collected from platform data.

In addition to marketing and efficiency gains, the program put emphasis on financial literacy and digital finance inclusion. Farmers underwent intensive training sessions in budgeting, cost and benefit analysis, debt management, and secure online payments. Equipped with the new skills, farmers were better equipped to make intelligent investment choices, like buying better-quality seeds or investing in newer equipment, based on clear-cut financial estimates. Approximately 65% of the farmers said they had lower operating expenses, due to enhanced tracking of expenses through electronic records, less wastage of inputs, and prudent procurement based on electronic price quotations.

Also, online financial products such as mobile banking, automatic savings plans, QR-code payment, and peer-to-peer lending systems brought new credit lines and insurance programs within reach. Availability of these services was often beyond the reach of existing bank structures, particularly for smallholder farmers lacking formal collateral or credit history. Consequently, farmers started enjoying better cash flow management, working capital access, and financial shock resilience, for example, sudden increase in input prices or losses due to climate-related crop failure.

From an on-farm practice point of view, precision agriculture, intelligent irrigation systems, crop health sensors, and automated equipment were increasingly being adopted depending on their local appropriateness and affordability. These technologies helped in curbing labor inefficiencies, wastage of resources, and maximizing crop yield. Farmers observed improved crop uniformity, greater yields, better timing of harvesting, and more predictable volume of supplies. Apart from that, digital post-harvest operations—such as mobile cold storage booking, route optimization software, and inventory tracking—led to a lower rate of spoilage and facilitated faster time-to-market. The program's emphasis on real-time data usage also enabled proactive adjustments during growing seasons, such as recalibrating irrigation based on moisture data or applying targeted fertilizer treatments.

Beyond local gains, half of the farmers participating in the e-commerce component reported that they began expanding their customer base beyond nearby regions to urban centers, hospitality sectors, and even export-oriented buyers. Such market access not only increased earnings but also prompted farmers to improve product quality and comply with market-defined standards. Such behavioral changes constitute a shift towards entrepreneurial mindset, with farmers perceiving themselves as agribusiness operators with the ability for long-term strategic planning.

Significantly, the program advocated community ownership and flexibility. Training was provided in a mix of lectures, field demonstrations, peer mentoring, and problem-solving learning. This allowed farmers to incorporate concepts through learning-by-doing and disseminate them in real-time. Active feedback loops allowed the training material to evolve as a function of participant requirements, local conditions of farming, and emerging challenges. This context-based implementation model facilitated high participation, strengthened local networks, and cultivated champions in the farming communities who could work as peer facilitators and digital innovation champions.

To make these achievements tangible and observable, Table 1 below is a comparative snapshot of the main performance indicators before and after the introduction of the PKM (Pengabdian Kepada Masyarakat) program. Indicators include average monthly income, market linkages created, levels of digital literacy, access to finance, and input measures for efficiency. The table is both quantitative proof of the success of the program and an instruction manual for subsequent scaling actions.

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Table 1. Comparison Before and After PKM Implementation

Aspect	Before PKM (Program Kemitraan Masyarakat)	After PKM Implementation
Market Access	Limited to local markets; dependent on middlemen	Expanded through e-commerce platforms and direct-to-consumer sales
Financial Literacy	Low awareness of financial management and digital transactions	Improved budgeting, financial planning, and digital banking usage
Farming Techniques	Traditional methods, high dependency on chemical fertilizers	Adoption of sustainable and precision farming techniques
Technology Usage	Minimal use of digital tools and farm management systems	Integration of smart farming, automated irrigation
Revenue Stability	Highly affected by fluctuating prices and limited demand	More stable income due to diversified sales channels

3.1. Implications and Future Prospects

The success of the program highlights the groundbreaking role of digital innovation in rebuilding the agriculture industry, particularly for rural smallholder farmers. By infusing technology into the most important agricultural processes from production planning, finance management, and market access through post-harvest logistics the program has shown that even traditionally disadvantaged groups of farmers can realize significant gains in income, efficiency, and economic resilience. These results demonstrate that digitalization is not a luxury but a necessity to develop sustainable and competitive agricultural systems in the modern era.

The program's first implication is the direct impact on the livelihood of farmers by increasing productivity and diversification of income. As seen in the data above, farmers who had previously relied on local markets and informal supply chains have been empowered to tap into broader digital ecosystems, selling to consumers across locations and even participating in new digital value chains. This not only improves their bargaining power but also reduces their exposure to market volatility, middlemen exploitation, and climate-induced disruptions. Furthermore, increases in financial literacy and digital transactional skills have enhanced farmers' autonomy in budgeting, accessing credit, and reinvesting profits for long-term growth.

More generally, the program also offers a template for scaling up digital agriculture interventions to other rural and peri-urban populations across the country. Its success proves that with the right combination of training, infrastructural support, and institutional collaborations, the same effects can be replicated at scale. At the heart of this scalability is the program's flexible and modular design—allowing it to be adapted to various agricultural commodities, climatic conditions, and sociocultural contexts. By leveraging digital tools, policymakers and practitioners are better positioned to overcome structural inefficiencies in rural economies and create more inclusive development pathways.

Looking ahead, future iterations of the program must explore more advanced digital agriculture technologies, including artificial intelligence (AI) for real-time crop monitoring, Internet of Things (IoT) sensors for soil and weather monitoring, blockchain for product tracing, and automated supply chain platforms for seamless logistics coordination. These technologies will enable a shift from basic digitization

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to data-driven agriculture, wherein data captured from the field directly converts into decision-making, risk management, and yield improvement.

Furthermore, merging cooperative models and farmers' networks will be central to upcoming digital agriculture evolution. Group participation not only allows knowledge and resource sharing but also improves access to larger-than-usual procurement contracts, group financing facilities, and collective bargaining in e-commerce ecosystems. Enabling the formation of digital cooperatives and offering them technical and governance assistance can solidify long-term sustainability and resilience of such interventions.

However, such ambitious goals will require firm policy underpinnings and infrastructure development, particularly in digital connectivity, rural electrification, and digital identity verification. Most rural settlements still suffer from patchy internet connectivity and lack of digital infrastructure, limiting the scope and coverage of digital interventions. The governments, in collaboration with the private sector and development organizations, must invest in these fundamental building blocks to ensure that no farmer is left behind in the digital transformation.

Moreover, regulatory support will be needed in creating an enabling environment for digital agriculture to flourish. This includes the creation of standards for e-commerce in agriculture, data privacy regulations for digital farmer profiles, and incentive programs that reward innovation for agri-tech startups. Cybersecurity, transparency, and trust in digital platforms are also crucial to triggering adoption and repeat use by farmers who may be potentially skeptical or unfamiliar with digital interfaces.

In the long term, the program envisions a self-sustaining digital agricultural ecosystem wherein farmers will not only be users, but also contributors and innovators to the system. Through continuous learning, mentoring via peers, and integration with larger agri-food value chains, farmers will be able to manage their own financial and business transactions without compromising on quality, productivity, or profitability. Such an ecosystem would include local service providers, digital extension agents, agri-tech startups, and reactive feedback loops that render the innovation cycle inclusive and dynamic.

Briefly, this program is not just one intervention but a replicable prototype of agricultural transformation, one that resonates with national development goals and global demands for inclusive digitalization. It underscores the power of harnessing grassroots mobilization, digital technology, and strategic partnerships to release the full potential of rural communities. As global challenges such as climate change, food security, and economic disparities intensify, initiatives like this provide hope that sustainable solutions are not only possible but already within reach if supported with the right vision, resources, and commitment.

4. Conclusion

In accordance with the findings of this project, it is clear that even relatively small-scale digital innovations have led to a clear increase in farmers' income by 16% to 25% on average. Farmers' income growth is primarily triggered by farmers' enhanced ability to enter wider markets through e-commerce platforms, traceability systems of transparent logistics, and direct-to-consumer sales channels. Consequently, farmers have not only gained improved market access but also improved control over distribution and pricing with much increased margins for profit.

Apart from marketing improvement, the program has also enhanced the effectiveness of farmers' financial management. Through intensive training for financial planning, budgeting, and use of digital financial tools such as mobile banking and electronic credit facilities, nearly 65% of farmers indicated reductions in operating expenses as well as enhanced cash flow management. This goes to highlight the significance of digital financial literacy in promoting greater economic resilience among farmers as well as higher levels of financial independence, which otherwise would have been impeded by traditional market forces and middlemen.

Furthermore, the project facilitated the implementation of satellite and internet technologies to increase agricultural production through smart farming, precision farming, and automated irrigation. These technologies were typified by optimizing yields and reducing post-harvest losses. Implementation of these technologies has enabled farmers to achieve more stable and consistent harvests compared to the past,

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reducing risks with climatic uncertainty and technical inefficiencies. More than half of the farmers involved in e-commerce activities also reported expanding their customer bases beyond local markets, opening new income streams that were previously inaccessible.

With widespread internet access and new mechanized farming techniques, farmers have increasingly turned to fewer traditional middlemen. This has not only increased their short-term income but also given them better market leverage and less financial risk. Approximately 70% of farmers have successfully accessed broader and more stable markets, significantly improving income security and farm management becoming more professional and market oriented.

The sustainability of success for these programs largely depends on the ongoing support of government agencies, active involvement of finance institutions in providing tailored digital financing solutions, and ongoing interest by agricultural communities to take up and scale digital innovations. Efficient feedback mechanisms, continuous education, and regular mentoring schemes are essential for ensuring efficient and sustainable adoption of these technologies.

On top of that, the development of digital inclusive infrastructure and connectivity in rural areas is vital so that rural farmers can also derive equal benefit from this digital transformation. Facilitating collaboration among all stakeholders—like government entities, private sector entities, banks, and farming communities—will be vital in ensuring that resilient, adaptive innovations are developed in response to evolving needs in the agricultural sector.

So, this program not only offers a short-term solution to increase farmers' income and efficiency of operations but also opens the door for an innovative, inclusive, and sustainable agriculture system. Synchronized digital integration will be the foundation on which the progression of the capacity of the agricultural sector to adapt to global challenges such as climate change, market instability, and environmentally friendly production of food can be realized. Expanding the coverage of this program to other regions and continuously improving farmers' capacities should be prioritized in aiming to achieve national food security and overall well-being among farmers.

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