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Smart farming solutions in India: Exploring agritech service delivery models

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Abstract

Smallholders play a critical role in driving agricultural productivity and ensuring food security. Agritech Smart farming solutions have the potential for improving the lives of smallholders by enhancing access to quality inputs, markets, and information, while also reducing risks and providing a range of other valuable products and services. The Digital Agriculture Mission of the Government of India is envisioned as a comprehensive umbrella program aimed at supporting diverse digital agriculture initiatives by Central and State Governments, as well as Academic and Research Institutions. One of the major challenges of the Agritech adoption is the lack of awareness among the majority of small and marginal farmers. Addressing this issue requires prioritizing capacity building, which is essential for achieving the sector's envisioned goals. The primary objective of this paper is to explore the Agritech landscape in India, analyze business delivery models, and identify challenges that need to be addressed. This will help the Agritech sector unlock its potential to support smallholder farmers in enhancing farm productivity and contributing to sustainable and profitable agrifood systems. This review offers a comprehensive overview of the current state of agritech smart farming solutions in agriculture and provides valuable insights for policymakers, industry stakeholders, and researchers engaged in this field.

Keywords: Smart farming solutions, Agritech, India agriculture

1. Introduction

Smart Agritech farming solutions have the potential to transform the agriculture sector and drive the professionalization of smallholder farming by automating on-farm decision-making. These technologies can empower smallholder farmers to boost productivity and enhance disaster resilience. By providing access to essential assets and mechanization, optimizing the use of inputs, labor, and natural resources, and minimizing crop and livestock losses and waste, smart farming can significantly improve agricultural outcomes (GSMA, 2022) [15]. Agri-tech startups are transforming traditional farming by integrating modern technologies to enhance efficiency and yields while minimizing environmental impact. These innovative startups utilize cutting-edge technologies like artificial intelligence (AI), the Internet of Things (IoT), blockchain, and precision farming methods to develop sustainable agricultural ecosystems.

The agtech ecosystem has the potential to boost Indian farmers' incomes by 25-35% and contribute $95 billion to the Indian economy (McKinsey, 2023) [20]. This growth can be achieved through reduced input costs, increased productivity, better price realization, access to affordable credit, and alternative income opportunities. Agri-tech start-ups empower farmers by providing innovative digital solutions that enable data-driven decision-making, modern farming practices, and access to real-time information. These advancements help farmers achieve higher profit margins. Additionally, they offer access to high-quality inputs and scientific guidance. By introducing high-yield seed varieties and technology-driven tools such as tractors, drones, and robots, these start-ups significantly enhance operational efficiency and overall productivity (Aravind Kumar, 2024) [4].

Rationale

Highlighting that technology alone cannot serve as a panacea, the emphasis shifts towards capacity building, particularly for under-educated small and medium farmers. Therefore, bridging the awareness gap and enhancing the skills of farmers, especially those with limited education, becomes imperative for ensuring the success of the digital transformation in agriculture and achieving a more efficient and equitable food system. Farmers need a strong foundation in technical skills, capacity building and support of Agricultural Extension Services to effectively leverage the agtech solutions available to them (Birner 2021, Bethi and Deshmukh, 2023, Chowdhury & Gow 2024, Ravi 2024, and Ishaka 2025) [7, 6, 9, 30, 16]. This paper begins by examining various schemes and programs initiated by the Government of India for digital agriculture, along with the service delivery models adopted by both government and private agritech providers. Additionally, it highlights the challenges associated with digital agriculture. This article is based on analysis of secondary data and information obtained from published literature.

1.1 Agricultural issues in India

Smallholder farmers in India face numerous challenges of unpredictable weather, the effects of climate change, pest

infestations, and declining crop yields. Deficiencies in irrigation, market, and transport infrastructure significantly increase farmers' operational costs and they are often burdened by high-interest loans from local lenders. The absence of effective delivery mechanisms results in crop wastage, inadequate logistics, and limited market access, leading to as much as 40% of produce being lost (WEF, 2024) [36]. Additionally, fluctuating market prices and difficulties in meeting quality standards further compound their hardships.

Almost 50 per cent of India's total population consists of small farmers and their families, and 85 per cent of all farms are less than two hectares. Plainly the situation of small farms is of enormous importance to the overall social wellbeing of India. The Agricultural Census 2015-16 classifies about 86 per cent farmers as small and marginal having less than one (1) hectares of land and relatively low income than their consumption expenditure (DAC, 2020) [10]. For digital agriculture to be scalable and accessible to the majority of Indian farms, it must be tailored to meet the needs of a typical Indian small farm.

1.2 Government of India initiatives for Digital Agriculture

The Digital Agriculture Mission 2021-25 by the Government of India emphasizes the crucial role of cutting-edge technologies like artificial intelligence, blockchain, remote sensing, GIS technology, drones, and robots in driving a transformation in the agricultural sector. A key component of this initiative is the India Digital Ecosystem of Agriculture (IDEA) framework, which establishes a foundation for a federated farmers' database. This framework integrates publicly available data with digitized land records, paving the way for innovative, technology-driven solution (MoA & FW, 2024).

The primary goal of the IDEA framework is to empower agriculture in India, aligning with the overarching objective of increasing farmers' income and enhancing the efficiency of the agriculture sector. Supporting this mission is the National e-Governance Plan in Agriculture (NeGP-A), which allocates funds to states and union territories for projects leveraging modern technologies such as AI, Machine Learning, Robotics, Drones, Data Analytics, and Blockchain (PIB, 2021) [27].

The 'Agriculture Infrastructure Fund,' a central sector scheme, contributes to digital connectivity and optic fiber infrastructure investments. The Central Institute of Agricultural Engineering, Bhopal (ICAR-CIAE), has developed the Krishi Yantra App to support research, operations, and technology dissemination in agricultural engineering (https://ciae.icar.gov.in)

Notably, the electronic National Agriculture Market (e-NAM) has played a significant role in addressing challenges faced by smallholders. With over 1780 million farmers, 2.62 lakh traders and 4250 Farmer Producer Organizations (FPOs) registered on the e-NAM platform, seamless integration with more than 1,389 grain markets across states and union territories has been achieved (PIB, 2024a) [25]. The increasing prevalence of the internet and smartphones holds the promise of revolutionizing the agricultural landscape, making the integration of smallholders into the digitally enabled system a necessity.

Startup India is a flagship initiative launched by the Government of India in January 2016. The program aims to foster a strong ecosystem that promotes innovation, entrepreneurship, and the growth of startups across the country. By empowering startups through innovation and design, the initiative seeks to contribute significantly to sustainable economic growth and generate large-scale employment opportunities. Under the Startup India initiative, eligible companies can get recognised as Startups by DPIIT, in order to access tax benefits, easier compliance, IPR fast-tracking and other benefits (Startupindia, 24). Startup India continues to play a pivotal role in nurturing a startup-friendly environment, driving technological advancement, and creating opportunities for aspiring entrepreneurs.

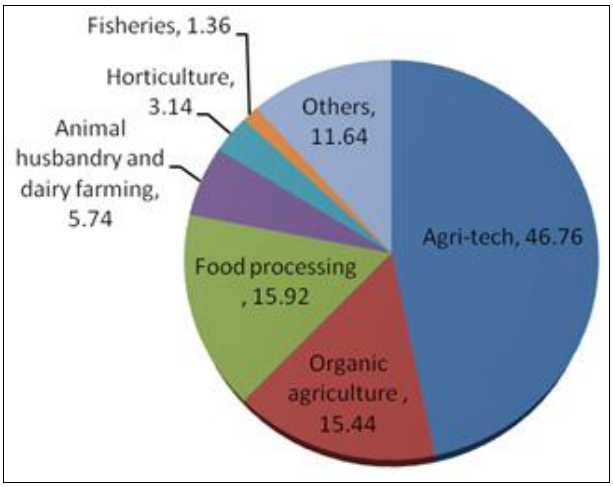
The Bharat Startup Knowledge Access Registry (BHASKAR) is envisioned as an all-in-one digital platform designed to facilitate seamless collaboration among diverse stakeholders within India's startup ecosystem. By offering a comprehensive hub for connection, knowledge sharing, and easy searchability, BHASKAR aims to empower entrepreneurs and ecosystem partners at every stage of their journey. This initiative aspires to foster a vibrant culture of innovation, driving India's ascent as a global leader in entrepreneurship and positioning the nation at the forefront of startup excellence (PIB, 2024b) [26]. The Software Technology Parks of India (STPI), operating under MeitY, supports Agri-tech start-ups through mentorship and funding across three Centers of Excellence (CoEs). This ecosystem tackles immediate challenges while promoting sustainable practices, efficient resource utilization, and rural development. The digital transformation of agriculture draws tech-savvy individuals, rejuvenating the sector and creating a more vibrant, dynamic landscape, paving the way for a brighter future for India (Aravind Kumar, 2024) [4].

Agri-tech startups hold significant potential to create innovative solutions for addressing current agricultural challenges. In India, the rapidly growing agri-tech sector offers immense opportunities for expansion, supported by initiatives like Make in India and Digital India. As on January 10, 2025, over 158,707 start-ups in India have been recognized by the Department for Promotion of Industry and Internal Trade (DPIIT) (startupindia.gov.in, 2024) [33] accessed on January 10,2025.

1.3 Sector-wise Breakup of Agri-startups in India

As of January 10,2025, India boasts an impressive total of 158,707 agri-startups officially recognized by the Department for Promotion of Industry and Internal Trade (DPIIT). Figure 1 highlights the sectoral distribution of these startups, showcasing the diverse entrepreneurial activities within the agricultural domain. Agri-tech stands out as the leading category, accounting for 46.76% of the total startups. This dominance underscores a strong emphasis on technological innovations aimed at improving agricultural productivity and efficiency. Organic agriculture and food processing startups follow with significant shares of 15.44% and 15.92%**,** respectively, reflecting growing consumer demand for organic products and value-added food items. Smaller yet vital contributions come from startups in animal husbandry and dairy farming (5.74%), which address the increasing need for protein-rich food,

along with ventures in horticulture (3.14%) and fisheries (1.36%), focusing on crop cultivation and seafood production. The remaining 'Others' category encapsulates startups pursuing diverse, niche agricultural ventures (Startupindia, 2024) [23] This distribution showcases a vibrant and evolving entrepreneurial ecosystem driven by factors such as technological advancement, sustainability concerns, and shifting consumer preferences within India's agriculture sector.



Source: Startupindia, 2024 [23]

Fig 1: Sector-wise Breakup of Agri-startups in India

1.4 Awareness generation for Agritech Programs and Services

Addressing challenges in the agricultural sector, a significant hurdle lies in the lack of awareness among the majority of small and marginal farmers. Overcoming this obstacle necessitates a focus on capacity building, emerging as a crucial aspect in achieving the envisioned objectives. While acknowledging the inevitability of a data-driven revolution in agriculture, it's essential to recognize that the inherent complexities of the sector require a multifaceted approach. Digital technologies offer solutions that can transform the way we produce, distribute, and consume food.

The critical issues in Agri-tech start-up growth in India were analysed by Chaudhary and Suri (2022) [8] and they emphasized the need for low-interest and innovative financing models, the availability of infrastructure and incubation support, the development of cross-domain quality solutions with diverse feature levels, fostering a supportive mindset among business customers and partners, and enhancing farmers' skills through training and capacity-building initiatives.

Access to digital technology offers significant advantages to smallholder farmers and rural businesses, enabling them to connect with workforce talent, access support services, and establish strategic partnerships for resources such as training, financing, and legal support (More and Aslekar, 2022) [22]. The success of Digital Agriculture in India hinges on several key factors such as reducing technology costs, providing user-friendly portable hardware, adopting pay-per-use rental models, ensuring robust policy support, and leveraging the strength of farmer collectives (Abhishekh, 2020) [3]. Agri-startups drive innovation and promote sustainability within the agricultural sector, empower smallholder farmers and help in advancing Sustainable Development Goals (SDGs) related to food security, poverty reduction, and environmental sustainability (Kumar, Babu and Deshmukh, 2024) [18].

1.5 Agritech Landscape in India

The Agritech Landscape in India can be broadly categorised as those services catering to the provision of Farm inputs, Financial services, Precision Agriculture, Hydroponics, Market Linkage and Farm Advisory. Described below is an overview of categories of Agritech smart farm solutions, thier potential impact on business models for smallholder farmers(SHF), the challenges addressed by the solutions for SHF and the potential agencies, government/private entities which can provide these services.

Table 1: Overview of Categories of Agritech smart farm solutions

	Definition	Potential impact on SHF business models	Challenges addressed by solutions for SHF	Potential agency/service providers
Advisory and Information Services	Farm management software and data analytics platforms to collect, store, and analyze the data, external data sources such as weather forecasts, market prices, and pest/disease alerts to make informed choices	Increase productivity More efficient resource use, reduced environmental impact. Improved overall sustainability in agriculture.	Improved access to technical assistance and information on certifications Training on data collection and record keeping	KVKs, ICAR-institutes, (SCSP/TSP project activities) State Department of Agriculture (AOs, AEOs) NGOs, CSR initiatives, service providers (ITCMAARS super app, Digital Green
Market Linkages	Solutions that enable farmer's access to input markets (fertilizers, seed materials, machinery, labor, and technical knowledge) and sales (B2B, B2C, and global trade)	Availability of inputs at lower costs and better quality products Stable prices by suppliers and buyers	Information on current price of inputs Information on market prices Cutting down the intermediaries	Input supply agencies, marketing services(e-NAM, De Haat, Tractor Junction, Agrizy)
Supply Chain Management	Solutions that enhance competitiveness of farming by better information flows, minimizing operational inefficiencies, and greater transparency, traceability and accountability	Increase bargaining power of farmer's, reduce production loss and build stronger commercial relationships	Lack of sufficient storage & transport infrastructure	Infrastructure funds of Central &State Governments along with service providers like Ex:Arya.org, Ecozen, Aquaconnect
Financial Access	Solutions that enhance access to financial and capital markets, to ensure the growth	Promotes the economic stability of farmers,	Lack of operational funds	SCSP&TSP schemes of GOI and service providers like

	and viability of the farming business	enhances their ability to manage risks, and widens their potential for growth.	inadequate financial services Lack of land ownership	Samunnati, Kivi, ayecart, Jai Kisan, nurture.farm, YONO Krishi app
Macro Agricultural Intelligence	Solutions that integrate data sources across the value chain and provide analysis at the sector regional and country wide levels	Market knowledge is improved and policy and sector regulations are enriched, climate risk assessments can be strengthened	Addresses climate change & environmental issues	Agricultural Statistics departments of Agricultural Universities & Institutes along with service providers like Cropin, Agrotech

Source: Adapted from Tsan *et al*., 2019 [34] and Dalberg, 2023 [11]

2. Business delivery models for Agritech smart farm solutions

Agtech startups operate using diverse business models, including hardware, software, and service-based approaches. While some focus on developing innovative technologies, others work to enhance existing farming practices. Their profitability is influenced by factors such as market demand, competitive landscape, and regulatory conditions. AgTech companies employ diverse business models, generating revenue through external funding, service fees, or impact sales to third-party organizations. (Dalberg, 2023) [11]. The choice of model depends on factors such as the size of the end-users, the business volume per user, and the ease of access to these users. For instance, Boomitra uses the B2B2C model in the Indian market, while adopting a B2C approach in South American markets where farms span thousands of hectares. Additionally, many agtech firms utilize a "Phygital" model, combining both physical and digital market presence. An example is Agrivijay, a digital marketplace for solar-powered farm equipment, which operates physical stores in its service areas alongside an app-based platform to connect with farmers (Atal Innovation Mission, NITI Aayog & UN Capital Development Fund (2023) [5].

The Digital Agri Hub team has identified six unique business models employed in implementing smart farming in low- and middle-income countries. (Digital Agri Hub, 2022) [12]. Six main business models are being implemented by smart farming solution providers. These are not mutually exclusive as providers may rely on different models to target different customer segments. For example, a provider may rely on upfront purchases for their business to-business (B2B) channel but on Pay-As-You-Go (PAYG) for their business-to-consumer (B2C) channel. The integration of disruptive technologies in Agri Food-Tech models focuses on leveraging technological innovation to enhance food quality, safety, and security, while promoting "smart farm" production and sustainable, environmentally friendly practices.

These models also aim to improve customer experiences. A key challenge lies in achieving complete traceability of production, products, and services across a networked value chain. Advancing the digitalization of the Agri Food industry for long-term sustainability requires a continuous evolution of ideas. This evolution should be grounded in the analysis of past organizational activities, networks, and start-up initiatives, identifying their strengths and weaknesses to refine implementation strategies.

2.1.1 Upfront purchase or asset transfer

Smallholder farmer, enterprise or NGO pays upfront for all the hardware installed onsite (sensors, gateways, etc.), as well as any monthly fees associated with ongoing data connectivity and service fees for ongoing support and advisory. The purchaser maintains ownership of the asset and is generally responsible for all maintenance fees and repairs after the initial warranty period. Service providers choosing the upfront purchase or asset transfer model can sell through B2C, B2B or B2B2C channels. Sell directly to farmers (B2C), to large agribusinesses and donors/ NGOs (B2B) and to agribusinesses that then bundle the solution with other digital solutions to offer smallholders a more holistic solution (B2B2C). Otipy, Fasal and Agrizy, fall under this business model.

2.1.2 PAYG model (Pay-as-you-go)

The PAYG is an asset financing model whereby smart farming solution providers finance the acquisition of an asset over time, typically 12 to 60 months. The solution provider generally requires a down payment ranging from 20 to 50 per cent, with the remainder billed in monthly instalments, often paid through a mobile money platform. The solution providers either extend financing themselves or team up with a financial service provider (FSP). For example, Hello Tractor, uses a PAYG model for tractor owners and cooperatives to acquire mechanisation equipment (GSMA, 2022). [15]

2.1.3 Smart farming-as-a-service or pay-per use (SaaS)

This model is also termed as shared asset model. The smallholder farmer gains access to an asset by paying a monthly or per-use fee to use it. Unlike the PAYG model, the smallholder farmer does not own the asset. Rather, it is owned by the solution provider in the case of the shared asset *"uber" model*, by a third party. Drone-as-a service, smart irrigation-as-a-service (e.g. Seabex), cold-storage-as a-service, smart greenhouse-as-a-service, fish feeding-as-a-service (e.g. e-Fishery) and smart livestock management-as-a-service SuggiVeer, complete crop harvester, AgriRain, Inera, Upaj Vegrow, WayCool and ONO are a few examples (GSMA, 2022; RICH-BeST-BCKIC, 2024; Akshit Pushkarna, 2024) [15, 31, 2].

2.1.4 Freemium or tiered model

The freemium or tiered business model, solution providers offer a free or low-cost entry point for farmers. This enables them to enjoy the basic functionalities of the service while offering a path to adopt more advanced services over time. The underlying assumption is that the free or basic version of the service will help the smallholder improve performance and allow them to access financing that otherwise might not be available. Through improved performance and financing, the farmer can then access the

premium version of the service. AgriEdge, Seabex, Sat2Farm, Sat4Agr and JALA upsell their services from Basic to Premium by adding additional costs to the platform (AgriEdge, 2025; JALA, 2025; & Seabex, 2025) [1, 17, 32].

2.1.5 Service bundling model

Along with smart farming technologies (IoT systems, cold storage, water pumps, etc.) the farmers require access to financing to obtain technology, advisory services to maximize the benefits of their tools, procurement solutions to enhance on-farm management, and marketplaces to sell their crops at the best possible prices. MyFugo, AquaRech, Zenvus, MyAgro, Kituvo, Tulaa, SunCulture are a few providers falling under this business model (GSMA, 2022) [15].

2.1.6 Data or insights monetisation model

Smart farming solutions collect vast amounts of data, which are used to provide farmers with tailored recommendations for activities like feeding, irrigation, and other farm operations. These data points can also benefit financial service providers (FSPs) in assessing a farmer's creditworthiness, help input suppliers evaluate the performance of products like fertilizers or fish feed, and assist tractor manufacturers in optimizing their equipment's efficiency. Monetizing these data and insights is made possible through advanced technologies such as AI, big data, and machine learning**.** Zenvus is a Nigeria-based D4Ag provider (GSMA, 2022) [15].

2.17 Successful business delivery models

The ideal business model effectively meets customer needs, ensures sustainable revenue, and supports long-term growth and scalability for the Agritech startup. A sustainable business model is one that remains adaptable, allowing for the integration of new innovations driven by technological advancements (Vlachopoulou *et al*., 2021) [35]. The most successful smart farming services in achieving scale have leveraged PAYG (Pay-As-You-Go) or smart farming-as-a-service business models. These approaches reduce entry barriers for smallholder farmers while fostering ongoing relationships that enable service providers to maintain control of customer interactions and offer additional services over time. Companies like eFishery and SunCulture have effectively utilized these models to expand their user base and attract investor interest.

However, to implement these models successfully, the service providing Agritechs need to have adequate funding to provide financing directly to smallholders or build partnerships with financial institutions which are capable of offering such financing.

3. Assessment criteria and rating scheme for Agritech Smart Farm Solutions

The Business Model Canvas (BMC) framework as proposed by Osterwalder and Pigneur (2005) [24] is a tool to rate the business models for their innovativeness, uniqueness, and competitive advantage. It represents the nine following modules/blocks that build the main business parts and we can effectively rate the business models of the various service providers based on these criteria.

1. The segments of customers a company wants to offer value are covered in the customer segments block.
2. The company's bundle of products and services; quantitative (e.g., price, speed of service) or qualitative (e.g., design, customer experience). innovation (technology related), performance, customization, accessibility, cost and risk reduction, and convenience/usability issues are included in the value propositions block.
3. The different touch points with the customers are described in the communication, distribution and sales channels block
4. The established and maintained relationships with each customer segment are explained in the customer relationships block.
5. The revenue flows of a company are described by the revenue streams block.
6. The most important assets required to make a model work are outlined by the key resources block.
7. The most important things a company must do to make its business model operate are defined by the key activities block.
8. The network of suppliers and partners required to optimize the business model, acquire resources and reduce risk are explained by the key partnerships block
9. All the costs incurred to make the model operational are outlined in the cost structure block

3.1 Assessment criteria and rating scheme for Agritech Smart Farm Solutions

The Green and Climate Smart Technology Assessment Tool (GC-STAT), an Excel-based tool can be employed to rate the different Agritech smart farm solutions using the adaptable evaluation scores and criteria (FAO, IFAD and IsDB, 2024) [13]. The assessment criteria to evaluate the Agritech smart solution enables assigning different weights to the seven criteria, viz. Affordability, Reliability, Easy-to-use, Green and environmentally friendly, Potential to be scaled and mainstreamed throughout the crop value chain, Enabling environment and social acceptance and empowerment potential. For instance, if the goal is to prioritize cost-effective technologies, greater weight can be allocated to affordability compared to the other criteria. It is important to ensure that the total weights across all criteria sum to 100 percent.

Table 2: Assessment criteria and rating scheme for Agritech Smart Farm Solutions

Assessment criteria	Rating (1 = Low, 5 = High)
Affordability	1: Very expensive, not cost-effective 2: Moderately expensive, limited cost-effectiveness. 3: Reasonably priced, fair cost-effectiveness. 4: Affordable, good value for money. 5: Highly affordable, excellent cost-effectiveness.
Reliability	1: Frequently fails or is unreliable. 2: Occasional reliability issues. 3: Generally reliable with few issues. 4: Very reliable, consistently performs well. 5: Extremely reliable, nearly flawless performance.
Easy-to-use	1: Very complex, difficult to use. 2: Moderately complex, requires some effort to use. 3: User-friendly, easy for most users. 4: Very easy to use, intuitive. 5: Exceptionally easy, no expertise required.
Green and environmentally friendly	1: Harmful to the environment. 2: Some environmental impact, not entirely green. 3: Moderately eco-friendly, some positive environmental aspects. 4: Very eco-friendly, minimal environmental impact. 5: Exceptionally green, highly beneficial to the environment
Potential to be scaled and mainstreamed throughout the crop value chain	1: Very limited scalability, difficult to mainstream. 2: Some scalability, challenges in mainstreaming. 3: Moderate scalability, can be mainstreamed with effort. 4: High scalability, easily mainstreamed in the value chain. 5: Exceptional scalability, seamlessly mainstreamed throughout the value chain.
Enabling environment	1: Highly unsupportive or restrictive environment. 2: Some challenges in the environment, not fully supportive. 3: Moderately supportive environment, some facilitative elements. 4: Very supportive environment, conducive to success. 5: Exceptionally supportive, ideal for implementation and growth
Social acceptance and empowerment potential	1: Low social acceptance, limited empowerment. 2: Somewhat accepted, minor empowerment potential. 3: Moderately accepted, fair empowerment potential. 4: Widely accepted, significant empowerment potential. 5: Universally accepted, maximizes social empowerment

Source: FAO, IFAD and IsDB, 2024 [13]

4. Challenges to Agritech Smart Farming Solutions

Agritech, the integration of agriculture and advanced technology, has the potential to transform food production. However, its success depends on effectively tackling key challenges. Agri-tech start-ups often face both supply and demand side challenges such as limited access to reliable data for testing their products/services and their validation by experts as well as difficulties in securing funding and access to infrastructure. Additionally, the diverse agro ecosystem of Indian farms and the complexities of agricultural supply chains and regulatory frame works are some of the major challenges too (Mukesh Ramagoni, Vijay Nadiminti and Jonathan Philroy 2023) [23]. Bridging the gap between farmers, agricultural professionals, and AI researchers is crucial for developing and customizing smart farming solutions that align with the resources and capabilities of farmers (Abbasi, Martinez and Ahmad (2022) [29]. High initial investment costs and the need for ongoing training and education can pose significant barriers to the widespread adoption of these technologies (Porciello, J *et al*. 2022, Li, F *et al*. 2023 and Fuentes-Peñailillo *et al*.2024) [28, 19, 14]. Below are some key challenges that must be addressed to fully realize the potential of agritech solutions.

4.1 Upfront Costs

The implementation of agritech is often challenging due to the substantial upfront costs of acquiring and deploying new technologies. Advanced equipment such as GPS-enabled tractors, drones, moisture sensors, and variable-rate irrigation systems require significant capital investment, which can be prohibitive for many farm enterprises. Additional expenses for data management systems, technical support, and networking infrastructure further increase the financial burden. Even when long-term benefits are evident; these costs may be unattainable for small to medium-sized farms. Innovative financing solutions could play a key role in overcoming this barrier to adoption.

4.2 Connectivity Issues

Addressing connectivity and power limitations is essential to unlocking the full potential of data-driven, networked agricultural technologies across the farming landscape as unreliable or limited internet and cellular connectivity remains a significant barrier to agritech adoption in rural areas. Precision farming relies on real-time data transfer from the field to operate automated machinery and inform decision-making, but inconsistent coverage often disrupts these processes. Investments in rural broadband infrastructure are crucial to ensure cutting-edge technologies perform as intended. Similarly, inadequate electricity access on remote farms poses challenges for powering and charging technological tools

4.3 Technology Integration
The adoption of new technologies in traditional farming operations often faces resistance or resource limitations. Challenges such as system compatibility and interoperability can further hinder innovation. Establishing standardization across the farming industry is essential to address these issues. Additionally, education initiatives and financial incentives play a critical role in overcoming these barriers and promoting widespread adoption.

4.4 User friendly tools for data management
Agritech's vast datasets demand user-friendly tools designed specifically for farmers, enabling the transformation of raw data into actionable insights. Ensuring access to agricultural data while respecting privacy and competitive concerns can fuel innovation and promote sustainable practices across the industry. This dual approach enhances decision-making for farmers while driving progress and environmental responsibility within the broader agritech sector.

4.5 Financial limitations
Innovations in agritech often demand significant funding, posing a challenge, particularly for smaller players and startups. Support from both government and the private sector is essential to drive the growth of promising agritech ventures.

4.6 Regulatory issues
Emerging agricultural technologies, such as gene editing and drone applications, often encounter regulatory challenges. Additionally, the use of fertilizers is increasingly scrutinized for its environmental and climate impacts. Policymakers must find a balance between fostering innovation and ensuring public safety and environmental sustainability.

4.7 Education and Training of farmers
Farmers' education for digital and technical literacy is vital for the effective adoption of technology. Comprehensive training materials on using agritech tools are possible through regular webinars and workshops on agricultural technology. Moreover, the farmers' need dedicated customer support to assist them in leveraging agritech tools. Public-private partnerships, online courses, and customised training courses are essential for upskilling. Collaboration through resource sharing and cross-sectoral knowledge transfer is essential to drive progress.

4.8 Scaling up concerns
Smart farming solution providers encounter several challenges in scaling their operations. These include limited digital and technical literacy among smallholder farmers, the high costs associated with devices, connectivity, and ongoing services, as well as insufficient mobile and IoT network coverage in rural areas.

5. Conclusion
Agricultural technology, or agtech, holds the key to driving India's transformation into a global farming powerhouse. Agtech can serve as a significant boost for India's farmers, enhancing their profitability and increasing agriculture's contribution to the nation's economy. India's Digital Agriculture Mission and several other affirmative programs highlight the transformative potential of advanced technologies in revolutionizing the agricultural sector. A significant number of startups in India have been recognized by the DPIIT. A range of agritech services focused on farm inputs, financial services, precision agriculture, hydroponics, market linkages, and farm advisory are being provided by both the government and private entities with different service delivery models to suit the smallholder farmers. The challenges of interoperability, financial constraints, and low digital literacy and market linkages need to be addressed to tailor the agritech solutions to meet the needs of the smallholder farmers and for the sustainable growth of the farming sector of the country.

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