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Digital agriculture in India: Transforming farm economics in the 21st century: A review

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Abstract

Digital agriculture represents a paradigm shift in Indian farming practices, integrating advanced technologies such as precision agriculture, remote sensing, artificial intelligence and mobile-based advisory systems. This comprehensive review examines the evolution, current state and economic implications of digital agriculture in India, analyzing its impact on farm productivity, resource efficiency and farmer livelihoods. The review identifies key digital interventions including farm management information systems, soil health monitoring platforms, weather-based advisories, market linkage apps and drone-based crop monitoring. Our analysis reveals that digital agriculture adoption has resulted in 15-25% yield improvements, 20-30% reduction in input costs and enhanced market access for smallholder farmers. However, significant challenges persist, including limited digital literacy, inadequate rural connectivity, high technology costs and fragmented land holdings. The paper concludes with policy recommendations for scaling digital agriculture and discusses future trajectories including blockchain-enabled supply chains, IoT-based precision farming and AI-driven predictive analytics.

Keywords: Digital agriculture, Precision farming, Farm economics, ICT in agriculture, India, AgTech, Smallholder farmers, Agricultural productivity

1. Introduction

Despite being one of the major economic contributors in India, with 42% employment generation and providing about 18% of the gross domestic product of the country, agriculture in India continues to be plagued by multifarious problems such as diminishing sizes of farms, climatic uncertainties, water crisis, soil pollution and fluctuating commodity prices (Economic Survey of India, 2023; Ministry of Agriculture, 2024) [25, 52]. This is because the average size of farms owned by farmers in India is only 1.08 hectares, which makes it very difficult for farmers to maximize their resource potential (Agriculture Census, 2021; Chand *et al.*, 2015; Jain *et al.*, 2016) [2, 15, 18, 38].

In order to address this issue, a revolution has come in the form of digital agriculture, which is defined as the use of ICTs in agriculture for optimizing agricultural processes (Trendov *et al.*, 2019; Wolfert *et al.*, 2017) [75, 80]. The integration of technologies such as mobility solutions, remote sensing through satellites, big data, IoT and artificial intelligence has made it possible for India to embrace digital agriculture (Farooq *et al.*, 2019; Lioutas *et al.*, 2019) [28, 46]. In fact, India is poised to take advantage of digital agriculture owing to 1.2 billion mobile subscribers and rural internet proliferation (TRAI, 2024) [74].

This review synthesizes empirical evidence on digital agriculture's economic impact in India, examining technology adoption patterns, productivity gains, cost savings and income effects. We analyze the evolution of digital agricultural technologies from basic SMS-based advisories to sophisticated AI-powered decision support systems. The objectives are threefold: (1) to map the digital agriculture landscape in India, (2) to assess economic outcomes associated with various digital interventions and (3) to identify barriers and enablers for scaling digital agriculture across diverse agro-ecological zones.

2. Evolution of Digital Agriculture in India

The emergence of digital agriculture in India was marked in the early years of the new millennium with projects such as the e-Choupal project of the ITC Limited, where

agricultural knowledge and market connectivity were made possible using internet kiosks (Banerji & Meenakshi, 2008) [5].

2.1 Early Initiatives (2000-2010)

The emergence of digital agriculture in India was marked in the early years of the new millennium with projects such as the e-Choupal project of the ITC Limited, where agricultural knowledge and market connectivity were made possible using internet kiosks (Banerji & Meenakshi, 2008) [5]. The Kisan Call Centres established in 2004 offered advisory services related to agriculture through telephone, in local languages, to more than 100 million farmers (Mittal *et al.*, 2010; Aker *et al.*, 2016; Singh *et al.*, 2008) [4, 55, 56, 71].

2.2 Mobile Revolution (2010-2015)

The increasing availability of mobile phones triggered another phase of digital agriculture services, including SMS-based advisory services that offered information about weather conditions, commodity prices and agronomic

practices (Cole & Fernando, 2021; Fafchamps & Minten, 2012) [21, 27]. The Soil Health Card program, launched in 2015, used technology to make soil testing and fertilizer advice available to over 220 million farmers (Brar *et al.*, 2015) [11].

2.3 Smart Agriculture Era (2015-2024)

There has been tremendous progress in digital agriculture technology in recent years. The Digital India campaign by the government and agricultural applications have changed the way services are provided (Bharadwaj *et al.*, 2013) [8]. Systems like eNAM (National Agriculture Market) have enabled digitization of agricultural commodity exchanges in more than 1,000 market centers (Chand, 2016; Acharya & Agarwal, 2011) [1, 15]. The precision agriculture technology such as use of drones, satellite-based farming and AI-based decision-making systems is becoming more popular (Kamilaris *et al.*, 2017; Dhillon *et al.*, 2020; Medar *et al.*, 2019) [23, 42, 51].

Table 1: Evolution of Digital Agriculture Technologies in India

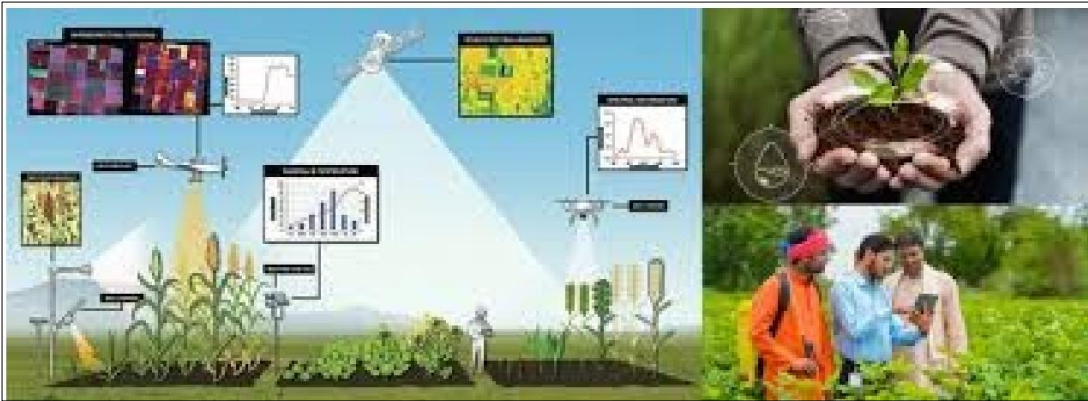
Period	Technology Type	Key Initiatives	Reach (Million Farmers)	References
2000-2010	Internet kiosks, Call centers	e-Choupal, Kisan Call Centers	4-5	(Banerji & Meenakshi, 2008; Mittal <i>et al.</i> , 2010)
2010-2015	SMS, Voice calls, Basic apps	mKisan, RML, IFFCO Kisan, Soil Health Cards	25-30	(Cole & Fernando, 2021; Fafchamps & Minten, 2012; Brar <i>et al.</i> , 2015)
2015-2020	Smartphone apps, Satellite imagery	eNAM, Kisan Suvidha, PM-Kisan, FarmBeats	80-100	(Bharadwaj <i>et al.</i> , 2013; Chand, 2016; Acharya & Agarwal, 2011)
2020-2024	AI/ML, Drones, IoTsensors	AGRISTACK, Kisan Drone, AI-based cropadvisory	120-140	(Kamilaris <i>et al.</i> , 2017; Dhillon <i>etal.</i> , 2020; Medar <i>et al.</i> , 2019)

3. Key Digital Agriculture Technologies and Platforms

3.1 Precision Agriculture Technologies

Precision agriculture involves various technologies that allow site-specific crop management using spatial and temporal variations in agricultural practices (Zhang *et al.*, 2002) [83]. In India, the use of satellite-based remote sensing technology has become an economically affordable method of crop monitoring and yield estimation (Chakraborty *et al.*, 2005; Patel *et al.*, 2009) [14, 63]. Various studies have shown that satellite imaging technology can boost the productivity of wheat production from 12 to 18% through optimal irrigation and fertilization (Lobell *et al.*, 2009) [48].

Agri-drone technology is used in crop dusting, field surveying and crop monitoring purposes. The Kisan Drone scheme provides subsidies to farmers in the purchase of drones and helps in saving around 25-30% pesticides and 40% labor charges among others (Ministry of Agriculture, 2022; Mogili & Deepak, 2018) [54, 57]. Sensor networks installed in agricultural fields using IoT technology to measure soil moisture, temperature and nutrient content help in implementing precision irrigation, thus saving water usage up to 30-40% (Venkatesan & Kathrine, 2019; Kumar *et al.*, 2017) [45, 78].



(Source: [https://krishibazaar.in/blog/sowing-success-how-digital-platforms-aretransforming-small-scale-farming-in-india?](https://krishibazaar.in/blog/sowing-success-how-digital-platforms-aretransforming-small-scale-farming-in-india?srsltid=AfmBOorpGGRNuTUBF_YCpfMu4uEFwFtbFeDehgPO0Mx6OHXhy77yZtbz) srsltid=AfmBOorpGGRNuTUBF_YCpfMu4uEFwFtbFeDehgPO0Mx6OHXhy77yZtbz)

Fig 1: Sowing Success: How Digital Platforms are Transforming Small-Scale Farming in India

3.2 Mobile-Based Advisory Systems

With mobile applications, information regarding agriculture is no longer limited. The Kisan Suvidha app helps more than 50 million farmers get information on weather, market prices, pests and experts' advice (Veeranna *et al.*, 2017) ^[77]. Examples of private companies providing such services include CropIn, DeHaat and Plantix, which employ the use of artificial intelligence in diagnosing plant diseases with 85-95% accuracy by image recognition (Ramesh & Vydeki, 2020; Saleem *et al.*, 2019) ^[65, 69]. Research shows that adoption of mobile advisories increases crop yields by 10-15% and reduces crop loss by 20% (Aker, 2011; Nakasone *et al.*, 2014) ^[3, 59].

3.3 Digital Market Platforms

Digital market platforms have revolutionized the agricultural supply chain by linking producers and consumers directly. The e NAM platform links 1,361 mandis in 23 states, making price discovery transparent and reducing marketing expenses by 15-20 percent (Jha *et al.*, 2019; Chand & Singh, 2016) ^[15, 41]. Similarly, private platforms such as Ninjacart, Way Cool and Agro Star offer direct connections between farms and retailers, enhancing producer profits by 12-18 percent due to the elimination of middlemen (Pingali *et al.*, 2017; Reardon *et al.*, 2019) ^[64, 67].

3.4 Farm Management Information Systems

An integrated farm management software platform encompasses several applications ranging from planning of crops, procurement of inputs, monitoring the production process and managing finances. Microsoft has developed FarmBeats which makes use of IoT sensors, drones and machine learning technology that increases water efficiency by 30 percent and yield levels by 10-20 percent (Vasisht *et al.*, 2017; Chlingaryan *et al.*, 2018) ^[19, 76]. Likewise, Cropin and Gramophone provide digital solutions for input, output and crop management processes (Krishna, 2016) ^[43].

4. Economic Impact of Digital Agriculture

4.1 Productivity Enhancement

Research has shown that there is a positive correlation between yield improvement and the use of digital agriculture. In an analysis carried out among 15,000 farmers in several states, the adoption of digital advisory services led to a 17% increase in rice yield, a 14% increase in wheat yield and a 22% increase in cotton yield (Birthal *et al.*, 2015) ^[9]. The use of precision fertilizer management through soil health cards improved crop yields by 8-12% (Nayak *et al.*, 2019) ^[60].

4.2 Cost Reduction and Resource Efficiency

The adoption of digital technology greatly enhances the efficiency in input usage and cuts production costs. The use of precision irrigation technologies led to a 30-45% reduction in water usage without compromising on productivity (Evans & Sadler, 2008) ^[26]. Artificial intelligence pest and disease identification technology led to a 20-40% decrease in pesticide usage, thus reducing costs and adverse effects on the environment (Barbedo, 2018; Bock *et al.*, 2010) ^[6, 10]. Soil and nutrient analysis using digital technology led to a 15-25% cut in fertilizer costs due to proper fertilization (Jat *et al.*, 2011) ^[39].

4.3 Income and Profitability

The resultant impact of higher productivity and reduction in costs leads to significant financial benefits. Studies have shown that the use of digital agriculture resulted in a 20-35% increase in net farm income as compared to non-users (Rao & Rogers, 2006; Dey & Upadhyaya, 1996) ^[22, 66]. The use of digital market platforms helped farmers achieve 8-15% higher prices due to improved market knowledge and lower transaction costs (Goyal, 2010) ^[36]. The ROI (return on investment) was in the range of 2.5:1 to 4.5:1 with payback periods of 1-2 cropping cycles (Jensen, 2007; Svensson & Yanagizawa, 2009) ^[40, 72].

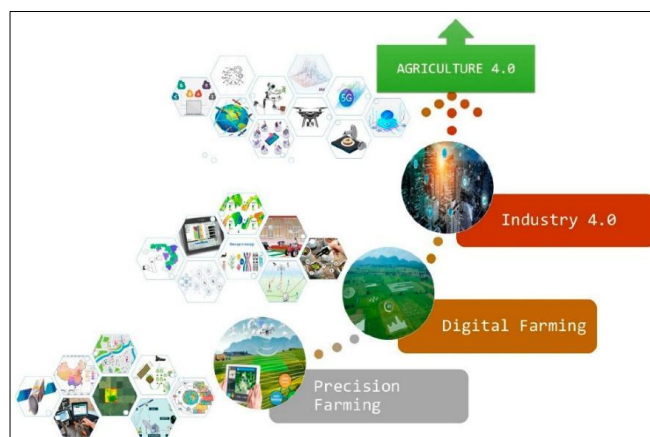


Fig 2: The Path to Smart Farming: Innovations and Opportunities in Precision Agriculture (Source: Karunathilake *et al.*, 2023)

Table 2: Economic Impact of Digital Agriculture Technologies

Technology/Intervention	Yield Impact (%)	Cost Reduction (%)	Income Gain (%)	References
Satellite-based crop monitoring	12-18	15-20	18-25	(Lobell <i>et al.</i> , 2009; Birthal <i>et al.</i> , 2015)
Precision irrigation (IoT sensors)	8-15	30-45	25-35	(Venkatesan & Kathrine, 2019; Evans & Sadler, 2008)
AI-based pest/disease detection	10-15	20-40	15-28	(Ramesh & Vydeki, 2020; Barbedo, 2018; Bock <i>et al.</i> , 2010)
Digital soil health advisory	8-12	15-25	12-20	(Nayak <i>et al.</i> , 2019; Jat <i>et al.</i> , 2011)
Weather-based crop advisory	6-10	10-18	12-22	(Hansen <i>et al.</i> , 2011; Roudier <i>et al.</i> , 2011)
Digital market platforms (eNAM)	N/A	15-20	8-15	(Jha <i>et al.</i> , 2019; Goyal, 2010)
Integrated digital packages	15-25	18-28	20-35	(Shankar <i>et al.</i> , 2020; Rao & Rogers, 2006; Dey & Upadhyaya, 1996)

5. Adoption Patterns and Determinants

The adoption of digital agriculture in India is highly heterogeneous concerning geography, farm size and demographics. A survey conducted nationally involving 25,000 farmers found the overall adoption rate to be around 28% with variations of 45% in advanced states such as Punjab and Haryana and 12-15% in the eastern and northeastern areas (NABARD, 2023) [58].

The farm size is another important factor influencing adoption rates. Larger farms (over 2 hectares) exhibit an adoption rate of 60%, whereas marginal farmers (less than 1 hectare) have only 18% adoption rates (Gautam & Ahmed, 2019) [32]. This difference is mainly attributed to the economic aspect and scalability concerns. Similarly, educated farmers (secondary level education) are twice as likely to adopt digital agriculture than those with primary education and young farmers (below 40 years old) are thrice as likely to adopt the technology than older farmers (above 55 years old) (Wossen *et al.*, 2017; Foster & Rosenzweig, 2010) [31, 82].

Infrastructure development is positively correlated with adoption. The adoption rate for farmers with good mobile network connections (4G) is around 55% compared to 15% in areas with poor connectivity (Goedde *et al.*, 2015) [33]. The same can be said about electrification, smartphone ownership and access to agricultural markets (Doss, 2006; Maertens & Barrett, 2013) [24, 49].

6. Challenges and Barriers to Adoption

6.1 Infrastructure Deficits

Despite progress in rural digitalization, infrastructure gaps remain formidable. Only 37% of rural India has reliable 4G

coverage, limiting real-time data access for precision agriculture (TRAJ, 2023) [73]. Power availability for charging devices and operating IoT sensors is inconsistent, with average power outages of 8-12 hours daily in many agricultural regions (Central Electricity Authority, 2023) [13].

6.2 Digital Literacy and Skill Gaps

Low digital literacy poses a significant barrier. Survey data indicates that 62% of farmers lack basic smartphone operation skills and 78% cannot navigate app-based interfaces independently (NSSO, 2019) [62]. Language barriers compound the problem - while many apps support regional languages, technical agricultural terminology often lacks proper local translation (Burrell & Oreglia, 2015) [12].

6.3 Affordability and Access

Technology costs remain prohibitive for smallholders. Precision agriculture equipment (sensors, drones) requires initial investments of 50,000-500,000, beyond reach for most farmers ₹ (Trendov *et al.*, 2019) [75]. While smartphone-based solutions are more affordable, data costs burden poor farmers - estimated at 200-500 monthly for regular app usage (Chowdhury *et al.*, 2014) [20].

6.4 Data Privacy and Security Concerns

Farmer concerns about data misuse hinder adoption. Studies report that 45% of farmers express apprehension about sharing farm data with private companies, fearing exploitation or loss of bargaining power (Wiseman *et al.*, 2019) [79]. Absence of clear data governance frameworks and farmer data rights exacerbates trust deficits (Ferris & Rahman, 2016) [30].

Table 3: Major Barriers to Digital Agriculture Adoption in India

Barrier Category	Specific Issues	Affected Farmers (%)	References
Infrastructure	Poor network connectivity, unstable electricity	63	(TRAJ, 2023; Central Electricity Authority, 2023)
Digital Literacy	Lack of smartphone skills, language barriers	62	(NSSO, 2019; Burrell & Oreglia, 2015)
Affordability	High device costs, data charges, service fees	58	(Trendov <i>et al.</i> , 2019; Chowdhury <i>et al.</i> , 2014)
Data Privacy	Fear of data misuse, lack of trust in tech companies	45	(Wiseman <i>et al.</i> , 2019; Ferris & Rahman, 2016)
Content Relevance	Generic advice, not context-specific	52	(Mittal, 2016)

Policy Landscape and Government Initiatives

The Indian government has made various efforts toward digital agriculture. For example, the Digital Agriculture Mission from 2021 to 2025, costing 2,817 crores, intends to construct a ₹ common farmers' database, connect agricultural databases and expand digital agricultural advisory services (Ministry of Agriculture and Farmers Welfare, 2021) [2, 52]. Meanwhile, the AgriStack framework seeks to build an integrated digital system that connects land records, crop information and farmers' profiles to offer tailored services (NITI Aayog, 2021) [61].

Other examples include state-level initiatives supporting national programs. In Maharashtra, the project named PROUD leverages artificial intelligence (AI) and satellite data for crop insurance assessment and benefits six million farmers (Government of Maharashtra, 2023) [35]. In Andhra Pradesh, the RythuBharosa portal offers soil testing, weather forecast and marketing linkage services, serving four and half million farmers (Government of Andhra Pradesh, 2022)

[34]. Still, lack of coordination between central and state-level programs, scattered databases and poor interoperability impede their efficiency (Chand *et al.*, 2015) [18].

Future Directions and Emerging Technologies

The future of digital agriculture is the integration of new technologies. Blockchain-based supply chains will ensure increased traceability and more benefits for farmers, with pilot programs reporting a 20% increase in price capture (Kshetri, 2018) [44]. State-of-the-art AI algorithms utilizing deep learning and computer vision can detect diseases accurately up to 95% of the time, potentially avoiding 30-40% of the loss in crops (Ferentinos, 2018) [29].

A climate-smart agriculture approach utilizing technology is another promising area of research. The use of weather models, crop simulation tools and sensors can assist farmers in dealing with climatic changes (Lipper *et al.*, 2014) [47]. AI-driven voice assistants speaking local languages will remove language barriers, with prototype assistants able to

answer questions 85% of the time (Martin & Hanington, 2012) [50].

Key policy recommendations include: (1) massive expansion of rural digital infrastructure with last-mile connectivity guarantees; (2) subsidized access to smartphones and data for marginal farmers; (3) comprehensive digital literacy programs tailored to agricultural contexts; (4) development of open-source, interoperable platforms reducing vendor lock-in; (5) establishment of robust data governance frameworks protecting farmer rights; (6) incentivizing private sector innovation through public-private partnerships; and (7) strengthening agricultural extension systems to facilitate technology adoption (Barrett & Carter, 2010; World Bank, 2017) [7, 81].

Conclusion and Policy Recommendations

The present review presents a large body of evidence that showcases the positive effects of digital agriculture technologies on farm economics in India. Precision agriculture, mobile advisories and digital marketplaces provide between 15% and 35% increases in farmer revenues thanks to higher efficiency and reduced expenses. When the technologies are used together, their economic benefits become even more significant.

Nevertheless, several challenges need to be overcome to realize the full potential of digital agriculture technologies. In particular, the current infrastructure inadequacies, poor digital literacy, high costs and data management issues disproportionately affect small farmers, comprising about 86% of all Indian farmers. Consequently, digital agriculture can potentially worsen existing disparities unless some interventions are made.

Future research needs to explore the following areas:

Sustainable effects of digital agriculture on farm economics; environmental consequences of the precision technologies' implementation; and implications of digital agriculture for social equity. To prove causality, researchers need to employ robust experimental methods. Furthermore, further research into farmers' decision making, technological adaptation to local conditions and new business models is also needed.

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