The Prospects of Digitalisation Fuelling Rise in Farm Income: Dimensions and Issues

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The size of population largely determines food production in many countries. Increase of population along with urbanization unduly stress arable land and water sources. Scientific approaches for sustainable increase in crop production through modern techniques improve efficiency and effectiveness, amplifying the magnitude of resilience even if climate change challenges. Agriculture significantly impacts employment rates in India, as approximately 58% of the workforce is involved in this sector, either directly or indirectly. Today, though India ranks among the top five largest producers and exporters of agricultural goods, the yield per hectare is low when compared to other countries. The issue of losses before and after crop harvest account for approximately one-third of the global food production. Effectively handling these losses can increase the farmers' income and ensure food security, while alleviating strain on scarce land and depleting water sources. This article discusses problems faced by Indian agriculture and examines the potential advantages and prospects of utilizing scientific knowledge and digital technologies to overcome challenges in farming. Despite the notable advancements and rapid growth in digital adoption and transformation in Indian economy, the agricultural sector is still in its nascent stage of development phase.

Keywords: agriculture, digitalisation, food production, irrigation, sustainability, food security

INTRODUCTION

The size of population largely determines food production in many countries. Increase of population along with urbanization unduly stress arable land and water sources. Scientific approaches for sustainable increase in crop production through modern techniques improve efficiency and effectiveness, amplifying the magnitude of resilience even if climate change challenges. Another issue challenging the world is crop loss (pre-harvest) and food waste (post-harvest), which is estimated to be approximately 40% of global food production, and the economic cost is over USD 1 trillion per year [1,2].

India ranks among the top five largest producers and exporters of agricultural products. Agriculture accounts for about 18% of the GDP and is critical to India’s growth as it is the backbone of employment; 58% of the population is engaged in agriculture, of which 45.4% workforce is engaged directly and the remaining indirectly. Despite these impressive records, climate-driven uncertainties, structural inefficiencies, and market failures have left most farmers poor.

This paper focuses on key issues challenging India's agriculture. It presents how scientific inputs and digitalisation can help monitor and manage farming activities and empower farmers to achieve the stated objectives of increasing farm production to meet food security. Digitalization in factories and services has caught pace, while agriculture continues to remain at a nascent stage. This paper explores the possibilities and scope for digitalization and its applications and benefits, especially in crop farming. Digitalization can also be transformative in bringing out a paradigm shift from traditional practices and established ideas to unlock possibilities for precision farming, which has the potential to significantly contribute to sustainable practices in the agriculture sector through judicial use of resources and improve farmers' income.

INDIA'S AGRICULTURE SECTOR: AN OVERVIEW

Agriculture plays a significant role in rural development in India by generating rural employment, producing food, and feed to support life, and supplying raw materials for allied industries. A report published by NITI Aayog in 2021 states that 46% of the total workforce is employed in agriculture and its allied sectors. India's geography contributes to its large, and extremely diversified agricultural economy. Its 160 Mha of arable land is the second largest after United States and its fifteen agroclimatic zones, eight distinct soil types, and forty-six sub-types define it [31]. Almost half of the country is under cultivation, yet until the mid-60s, India depended on imports of food grains and food aid due to low productivity and scarce FOREX reserves. This emphasizes the significance of agriculture land use plans for crop combinations based on soil potential and agroclimate that are guided by science.

Much like the agroclimate, freshwater availability varies across the country. This increases reliance on the monsoon for irrigation. Recurrent droughts leading to the famines in 1965 and 1966 resulted in excessive dependence on imports of food items, popularly known as *Ship to Mouth* existence. This paved the way for structural reforms [3, 5]. Subsequently, in 1980s, the policy focus shifted to agricultural diversification from cereals to high-value commodities like fruits, vegetables, oil seeds, dairy, fisheries, and livestock to meet the diverse needs [6].

India's Agrarian Revolution: From Scarce to Surplus Food

The Green Revolution was a seminal moment, encouraged by the success of Green Revolution, several initiatives have been taken to spur growth in the agricultural sector. This resulted in substantial improvements in the existing methods of farming and food processing to meet the needs of the growing population. Table 1 illustrates key initiatives taken to spur growth in agriculture in India [3, 5, 8, 9, 10, 11, 12, 13, 14].

TABLE 1
AGRICULTURAL REVOLUTIONS IN INDIA

Revolution Name	Aim of the Revolution	Year	Chief Architect
Green Revolution	Food grains	1967-1978	M. S. Swaminathan
Silver Revolution	Egg / poultry production	1969-1978	Indira Gandhi
White Revolution	Milk production	1970	Verghese Kurien
Blue Revolution	Fish production	1985-1990	Dr Arun Krishnan
Yellow Revolution	Oilseed production (especially mustard and sunflower)	1986-1987	Sam Pitroda
Golden Fibre Revolution	Jute production	1990s	

Golden Revolution	Honey / horticulture development	1991-2003	Nirpakh Tutej
Pink Revolution	Meat processing	2014	Durgesh Patel
Red Revolution	Meat production / tomato production	1980s-2008	Vishal Tewari
Evergreen Revolution	Integration of ecological principles in technology development to meet foreseen challenges in agriculture	2017	M. S. Swaminathan

Source: compiled by the author from multiple sources.

These science- and technology-driven initiatives harnessed the agricultural sector's potential and have been instrumental in increasing production and productivity, helping India’s transition from a severely food-scare to a food-surplus country. These actions have also triggered and altered the composition of food output in the food basket [7]. These measures played a key role in the development of physical infrastructures, including warehouses, cold storage, and all-weather roads, facilitating marketing support inclusive of export promotions. Continued scientific research contributes to innovation in processes that improve yield and quality of output, apart from creating linkages to local and regional markets and access to new markets. The combined effect of these programs served as the base for diversification, intensification, and integration to help the agricultural sector to realize its potential. Table 2 presents a comparative analysis of the notable shifts in population, agriculture sector, and economy over the past seven decades, highlighting significant developments.

TABLE 2
CHANGES IN POPULATION, AGRICULTURE AND ECONOMY BETWEEN 1950-51 AND 2021-22

Indicator	Unit	1950-51	2021-22	Increase %	CAGR
Population	in Mn.	361.1	1369	3.79	1.8
Food	Production in Mn.T	106	936	8.83	3.07
Net Sown Area	in Mha	119	141	1.18	0.23
Gross Cropped Area	in Mha	132	219.16	1.66	0.71
Net Irrigated Area	in Mha	20.85	77.72	3.73	1.84
Gross Irrigated Area	in Mha	22.56	112.23	4.97	2.25
Agri sector Income	Rs. Lakh crore at 2011-12 prices	2.91	21.15	7.27	2.79
Total Economy	Rs. Lakh crore at 2011-12 prices	4.79	136.24	28.44	4.76
Agri Worker	In Mn.	97.2	246.7	2.54	1.3
Total Worker	In Mn.	139.5	542.7	3.89	1.9
Agri Worker in %	in %	70	45.4	0.65	-0.6

Source: compiled by the author from multiple references.

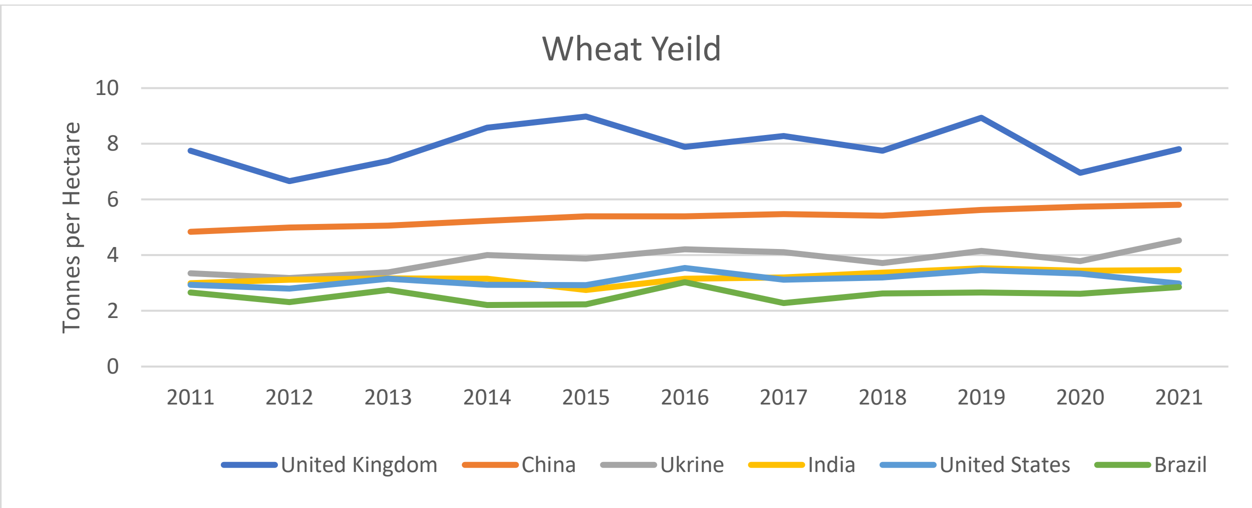
Table 2 shows that CAGR of population growth is 1.8 and food growth is 3.07. This signifies that the increase in food production has outpaced the rate of food demand, enabling the transition from food-deficit to food-surplus country. Land being the finite resource, it is impressive that India’s food production has expanded by more than 8.8 times while the cropped area has increased only by 1.66 times. The agricultural economy has also grown by 7.27 times during the last seven decades.

Today, India is the largest producer of milk, pulses, spices, and jute and the largest rice exporter for over a decade. India is the home for 58% of the cattle in the world and is the second largest producer of wheat, rice, fruits, vegetables, cash crops, and fish. Fisheries account for the single largest segment of agricultural export. Fisheries and aquaculture collectively contribute 1 percent of India`s GDP. India is also the third-largest producer of eggs (MoFPI, 2023). The success of various initiatives in the agriculture sector stands as a testament to the fact that when developmental goal unites stakeholders, they quickly change to adapt to changing environmental conditions for efficient and effective use of resources, enhance business opportunities and income, and transform the sector to make a difference to lives.

Crop Yield, Food Loss and Waste

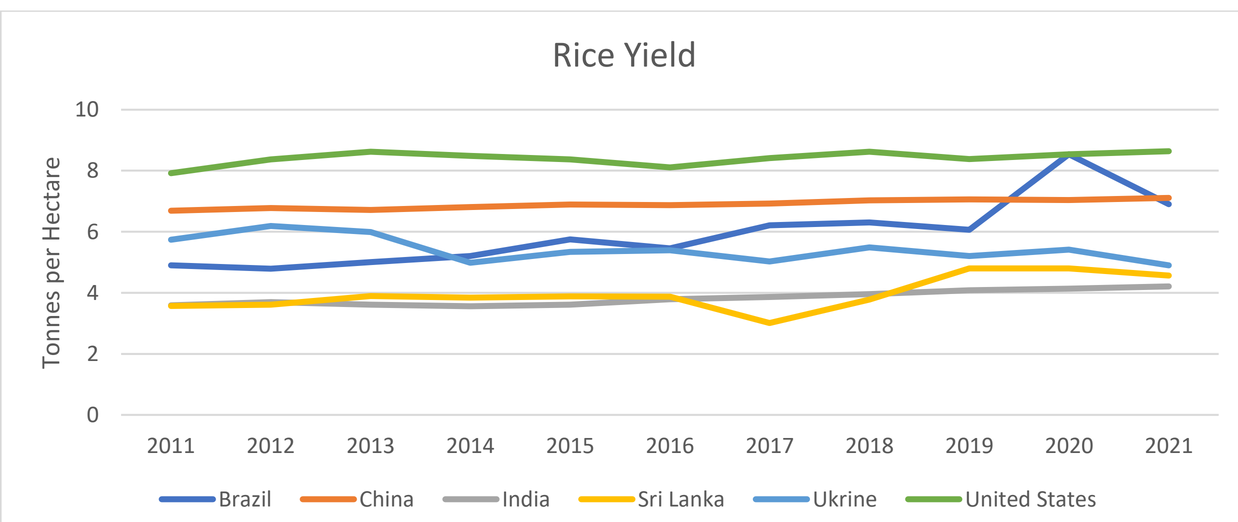
Despite the substantial progress in yield enhancement, there is still a low per-hectare yield of wheat (in tonnes) (India 3.21; China 5.36) and rice (India 3.8; China 6.9) in comparison to China. Yield increase can reduce the area under cultivation and relieve the strain from the natural resources. It also creates a surplus for domestic consumption and exports, which helps effectively manage hunger and the nutritional issues challenging mankind, increases labour productivity, and thereby increases income levels.

FIGURE 1
COMPARISON OF YIELD OF WHEAT IN TONNES/HECTARE



Source: Food and Agriculture Organization of the United Nations.

FIGURE 2
COMPARISON OF YIELD OF RICE IN TONNES/HECTARE



Source: Food and Agriculture Organization of the United Nations.

India is the most populous country today and the population is predicted to rise to 166.8 crore by 2050, implying the demand for food will continue to rise. Because water is a critical and non-replaceable input for agriculture, the effects of climate change pose an immediate danger to sustainability and food security. In India, groundwater irrigates 43 Mha of land; canals irrigate 23 Mha, and 74 Mha is rainfed or 31, 16, and 53 percent, respectively of the 140 Mha net sown area. The gross cultivated area of 219.6 Mha, or 66% of the 328 Mha total geographical area of India, suggests that horizontal expansion of agriculture may not be possible. This leads to the conclusion that land will inevitably experience sustainable intensification.

Another area of concern is the pre-harvest losses during production and post-harvest waste during handling and storage, reducing the food available for consumption. It results in reduced quantity available for the farmers to market and the quantity available for the processors to value addition and retailers to sell. In addition, it lowers both quality and price, resulting in losses apart from threatening food security. Food loss and waste as reported in SDG Target 12.3 report 2023, accounts for approximately 8% of worldwide food production lost during the farming phase, 14% during the processing phase between the farm gate and the retail industry, and 17% during the retail, food service, and home in the consumption phase of the food supply chain. The total losses add up to almost 40%. Unlike pre-harvest losses at the mercy of nature, post-harvest losses can be mitigated by improving infrastructural facilities. Table 3 compares food wastage of major crops and commodities.

TABLE 3
POST-HARVEST WASTE OF MAJOR CROPS AND COMMODITIES

	Food Wastage in percent		
	2005–07	2013–14	2021–22
CROPS/COMMODITY	ICAR-CIPHET		NABCONS
Cereals	3.87–5.93	4.65–5.59	3.89-5.92
Pulses	4.28–6.04	6.36–8.41	5.65-6.74
Oilseeds	5.77–18.04	6.70–15.88	2.87-7.51
Fruits	2.75–10.06	3.08–9.96	6.02-15.05
Vegetables	6.88–12.47	4.58–12.44	4.87-11.61
Eggs	6.55	7.19	6.03
Milk	0.77	0.92	0.87
Meat (sheep & goat)	2.23	2.71	2.34
Inland fishery	6.92	5.23	4.86
Marine fishery	2.78	10.52	8.76

Source: MoFPI and WRI India.

India produces over one billion tons of agriculture produce. Due to the perishable and seasonal nature of the agricultural produces, cold chain infrastructure plays a critical role in reducing post-harvest losses. The cold chain requirement, according to a study conducted by National Centre for Cold-Chain Development (NCCD, 2015), is given in Table 4.

TABLE 4
COLD CHAIN INFRASTRUCTURE REQUIREMENTS

Sl No.	Component	Existing Capacity	Approximate Requirements	Units
1	Integrated pack houses	250	70,000	Numbers
2	Reefer trucks	<10,000	62,000	Numbers
3	Cold store (bulk & distribution hubs)	32	35	Million tonnes (Mn.T)
4	Ripening chambers	800	9,000	Numbers

Source: MoFPI, Annual Report_2023.

The shortage of cold chain infrastructure in India is a serious concern that results in 40% of perishables to be wasted [32] resulting in land, water and other essential inputs needed to grow crops also get wasted. It is clear from Table 4 that profitability will remain a challenge for farmers, processors, and retailers unless the increase in production is accompanied by an increase in the capacity of storage and transportation to reduce post-harvest losses.

DIGITALISATION IN INDIA: AN OVERVIEW

The journey of digitisation and digitalisation has grown at a rapid pace in India since 2015 and has established itself as a dominant player in the digital economy. This growth was largely driven by the policy initiatives. A combination of factors is responsible for the evolution and adoption of digitalisation, which includes broadband penetration, low-cost data tariffs, technological advancements in networking, smart phone adoption, public digital infrastructure, a growing online market and a thriving e-commerce industry, and the demographic dividend of a young population with a median age of 28.7 years. The young generation has a latent urge and a relatively higher willingness towards technology adoption.

To derive greater social impact given the enormous size of population, it was pertinent to adopt digitalisation to improve the delivery of public services in accessing benefits, opportunities, and efficient governance and to reduce inequalities due to income disparities. It has proven itself to deliver government services efficiently and transparently and has played a crucial role in financial inclusion through direct transfer of benefits. Likewise for enterprises, it has opportunities for improvements in efficiency, competency, competitiveness, market expansions, better customer experience, and creation of new business models as drivers of business growth. Digitalisation has the potential to address critical gaps in the value chain including infrastructure modernisation, traceability, production, productivity, post-harvest management, and quality control.

The Indian government took several initiatives to build a collection of products and frameworks, such as Aadhar (for digital identity) and UPI (for Digital Payments). The formalisation of the Indian digital economy paved the way for the convenience of millions through cashless and paperless transactions which has been instrumental in financial deepening. In addition to this, it erased the divide between those who have access to banks, financial records, and credit history and those who don’t have.

The Union Budget 2023 also emphasized the importance of digitalization in the Indian economy. It unlocks the potential to interact with economic agents involved in other processes. Access to information enables transparency to all participants, potentially improving efficiency and saving resources.

OBJECTIVES

The major objectives of the paper are:

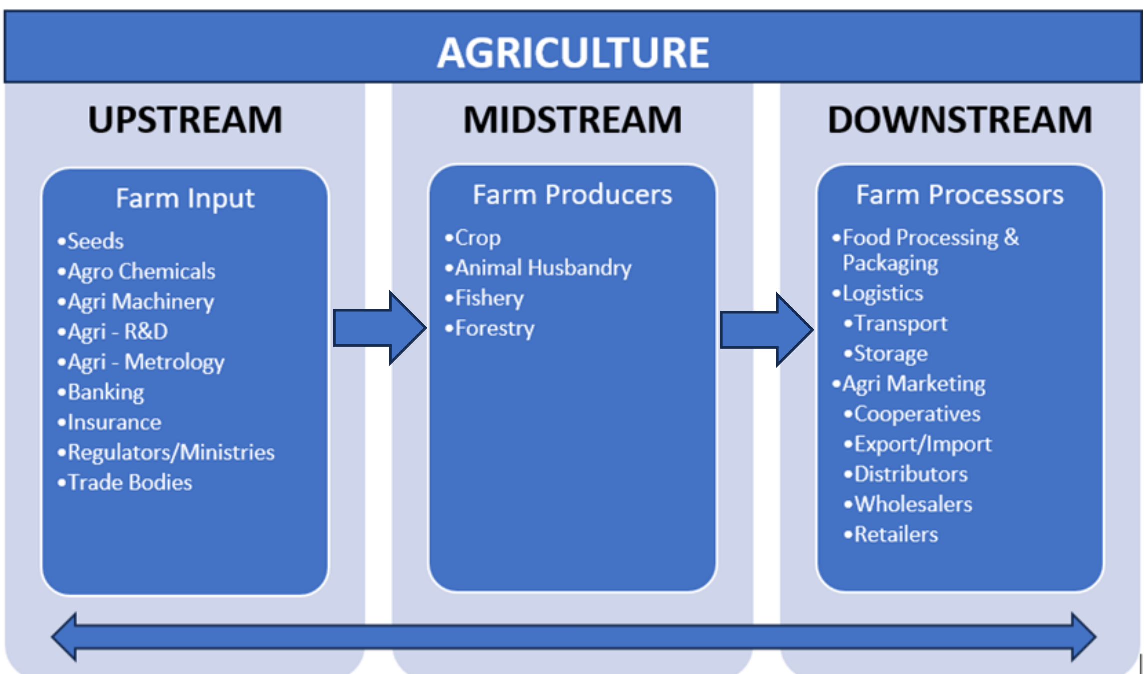
a. To understand the applicability, challenges, and complexity of implementing digitalisation in the agriculture sector.

b. To unearth potential benefits for the sector like optimization of productivity through information transparency and its potential to iron out inefficiencies and transform the farmers' work life.
c. To make recommendations that will catalyze growth in the adoption of digitalization.

PROBLEM STATEMENT

Agriculture is a priority sector with the strategic objective of achieving food security. Hence, like in the other industries, there exists a need to deploy digital platforms to support agriculture and its allied industries in helping to remove the problem of information asymmetry. There is an inherent need for a system for monitoring and ensuring compliance by the regulators. A latent need for real-time monitoring for proactive identification of regressive trends helps with reasonable assessment for the development of appropriate innovative technological measures to counter risks. An integral need for establishing electronic interactions among the stakeholders to draw their attention to pertinent information ensures orientation and confirms greater coordination in streamlining operational activities. The availability of such a system can go a long way in solving problems immediately as and when they arise and catalyze the development of the agriculture industry. Figure 3 gives the classification of stakeholders based on operations in the value chain.

FIGURE 3
AGRICULTURE STAKEHOLDER CLASSIFICATION



The users of the platform are envisaged to be the Agri-Industrial complex like farm input producers and traders, farm producers, and entities who are processors and supply chain entities, trade bodies and cooperatives, scientific community associated with agriculture (agricultural scientists, metrologists, etc.), financial institutions, and regulatory bodies like Ministry of Agriculture, etc. This concentration of all the stakeholders unlocks the potential for interactions, cooperation, and collaborations (ICC), all of which can help improve the effectiveness of all the stakeholders.

This model would facilitate the formation of a centralized registry that captures details of all the stakeholders, production, yield, consumption, export-import and potential markets, prices, and purchases.

Laced with Artificial Intelligence (AI) and Machine Learning (ML) and other analytical tools, it can also be used for forecasting, scientific planning, and modeling of land use and crops to grow for the season including simulating the digital twins to practice drills that will help respond faster, forecasting and fulfilling demand for agro-chemical, seeding, and harvesting, recognizing, incentivizing and subsidizing those who follow recommendations on environmental conservation and sustainable practices.

Since the bulk of the agriculture is financed from informal sources, this platform could extend the opportunity to formalize these non-institutional financers and regulate their practices. As co-lending has been approved, they can bridge the gap to act as the conduit and continue to operate as the intermediary with the benefit of partially hedging their risks.

Adoption of digitization in agriculture has the potential to improve efficiency, save resources and can be effective in meeting the stated goal of food security. Despite the envisioned benefits of digitalization, it is currently focused only on managing factories and the service sector.

SCOPE FOR DIGITALISATION OF AGRICULTURE

In 2018, NITI Aayog predicted the Indian economy to grow at 8-10% and agriculture needs to grow at 4%; it suggested that AI will be able to add significant value to the agriculture value chain [15, 16, 17, 18]. In April 2022, Government of India launched Digital Agriculture Mission to leverage digital technologies in agriculture, integrating modern technologies like AI & ML, remote sensing, and drones for higher productivity and efficiency.

Like machines, and regulatory mechanisms, digitalisation is also a tool. Digitalisation is an enabler to address the key issues of lack of information, transparency, and enforcement of legal policies that can affect long-term behaviour change. It can also help vertical and horizontal integration of the value chain and drive innovations with strong forward linkages and innovations drive revolutions [19]. However, to fully harness digitalization's power of digitalisation it is also required to integrate it with emerging technologies like AI & ML and Data Analytics.

DISCUSSION: DIGITALISATION ITS APPLICATION AND BENEFITS IN AGRICULTURE SECTOR

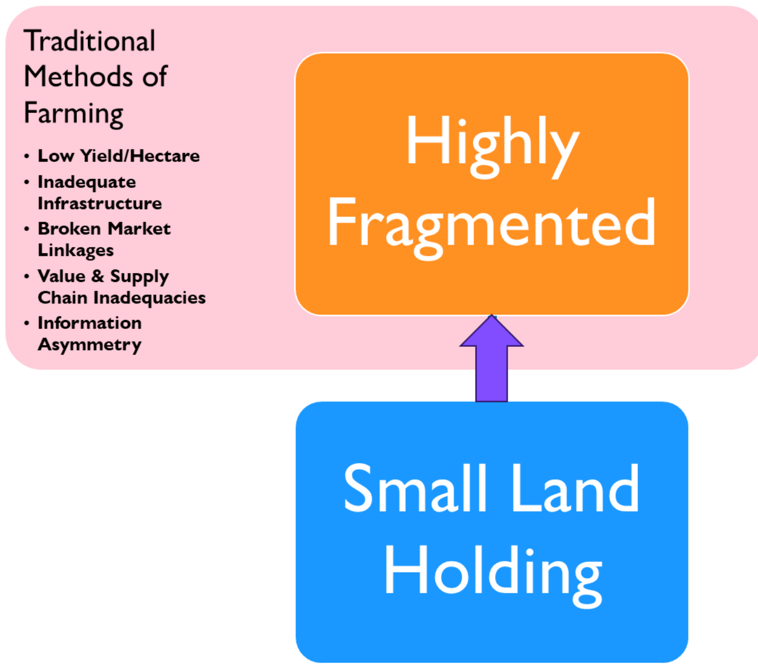
There are various opportunities available for digitalisation that exists within the agriculture sector.

Highly Fragmented

Agriculture in India is fragmented. The average farm size or household ownership has declined from 2.3 ha in 1970-71 to 1.23 ha in 2005-06 to 1.08 ha in 2015-16. In total, 68.5% of the 146 million landholdings fall under the marginal holding (<1 ha); the average landholding size is small at 0.38 ha [27]. High fragmentation results in wasting fertile land in providing boundaries that reduces the farm size. Securing access to water for irrigation is a daily challenge and often lead to conflicts due to its limited availability. A small land parcel also results in loss of income opportunity as it may produce only for the self-subsistence, pushing it further leads to overcultivation and reduction in soil quality. At the same time, it also exacerbates the problems associated with highly fragmented farming. Figure 4 highlights the issues of highly fragmented farming due to small landholding.

Remote sensing can be applied along with geo-referencing of land parcels for soil mapping, soil moisture estimation and quality, crop identification, crop damage due to pest and disease, weed infestation, water resource mapping, and crop yield modelling. These data can help forecast geographies of defective fragmentation leading to farmer and rural distress. This can help plan support mechanisms through regular workshops for local farmer groups. These sessions can educate farmers on minimizing the problems associated with fragmentation and convince and enrol them for consolidation, explaining the potential benefits of cooperative farming, precision farming, including crop selection, crop diversification through multi-cropping and intercropping to preserve soil quality, and optimising resource utilisation like water consumption for irrigation, reduce input cost of seeds, measuring agrochemical persistence, farmland realignment, and adoption of agroecology for sustainable farming.

FIGURE 4
ISSUES OF FRAGMENTED FARMING



To leverage the insights driven by digitalization, farmers might favor the adoption of cooperative farming with real-time monitoring using satellites and drones for measurement of soil quality, climatic conditions, crop condition, disease outbreaks, pest attacks, week management, water management, and farming practices that can improve agricultural production and productivity, enabling farmers for supplementary activities to earn more.

Lack of Access to Modern Technology and Tools

Small landholdings limit mechanization usage, and the marginal farmers lack financial capacity to access and source technology-intensive modern scientific methods. These factors keep the yield per acre low relative to China, the USA, and the EU. Embracing new technology and practices will also necessitate retraining and upskilling from traditional practices. Since, these two aspects significantly complement each other, cost of adoption is prohibitively high.

Crop Finance and Insurance

Economic Survey 2022 states that since 1998 only 3.89 crore Kisan Credit Cards have been issued. The logical deduction is for many marginal and small farmers involved in crop farming; credit from formal institutions remains inaccessible. This can limit access to modern technology and the adoption of mechanization and modern practices that can improve yield, productivity, income, and profitability. Around 11.3 crore farmers had benefited from the April-July 2022-23 tranche as stated in the Economic Survey 2022-23. This indicates that the coverage is not yet 100%. Digitalization allows for greater inclusion in accessing benefits like direct benefit transfers and improves credit flow from formal financial institutions. Social and economic inclusion propels growth and development and is an indicator that provides confidence that the economy is working for all.

Factors Affecting Self-Sufficiency

Traditional methods of farming practiced on small land parcels are one of the reasons for low yield. Agriculture becomes unviable due to rising input costs and un-remunerative prices. This issue gets compounded due to inclement weather, pest attacks, weed infestation, and disease outbreaks, which further reduce the production and farmers' income that lead to rural distress. Transportation costs are also relatively high per unit for low volumes. Inadequate storage facilities result in post-harvest losses to both the farmer and the processor. All these significantly impact the goals of self-sufficiency and food security.

Connecting Agri Research and Farming

Digitalization can provide critical inputs to the scientific community regarding soil and crop condition, pest identification, weed management, weather anomalies, etc. Seed selection supported by scientific validation can substantially improve yield, productivity, income, and profitability at a modest additional cost and significantly reduce pre-harvest losses. Likewise optimal usage of other inputs can also be determined to save costs in sowing seeds, irrigation, and fertilizers, thereby reducing environmental impact while increasing profitability. Savings can be further enhanced by improving accuracy of variable rate application in sowing seeds, irrigation, fertilizers, and herbicides assisted by satellite imagery/drones/optical sensors to create heat maps and use GPS for better positioning.

Connecting Policy Makers and Farmers

Digitalization is uniquely positioned to draw data even from remote locations. These data will help policy makers to gain an extensive understanding of challenges at grassroots levels. Since, the entire data are available, it overcomes the limitations of the sample surveys and will help them design and implement policies that benefit the farmers and industries. For example, digitalization would help to enhance water use efficiency by monitoring the irrigation infrastructure like dams and irrigation canals that are built at a huge cost.

Digitalisation Drives Market Linkages

Profits and technical aspects, apart from value proposition and its capture, determine service orientation. Higher production will increase demand for development in physical infrastructure including dams and irrigation canals, warehouses, cold storages, integrated pack houses, all-weather roads, development of food processing industries, and facilitating marketing support inclusive of export promotions.

CONCLUSION

The applications of digitalization in agriculture crop farming are myriad. The needs of segment within the agricultural sector are unique. Hence, adopting a scientific approach to cropping and digitalisation of the farming activities has the potential to radically influence and transform the entire value chain and enhance the ecosystem of the agricultural sector.

Enhancing farmers' productivity, production and income, and improving sustainability and resilience can help bridge the rising income gap between farmers and farm workers and the rest of society.

The disconnect between development in agricultural research and farming practices gets considerably reduced as digitalization improves the scope for process orientation and collaboration through periodic sharing of information on process progress and direction.

RECOMMENDATIONS

a. A hub is to be established in every village to identify, recognize, and escalate the problems related to agriculture in the respective village.
b. Increased participation of agronomists in identifying and addressing key challenges.
c. Bridging the gap in storage infrastructure to minimize the pre-harvest and post-harvest waste.

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