Alternate Pathways for Leveraging Digital Technologies in Agriculture

Globally, agriculture was on the verge of a major transformation given the prominence of digital technologies in the 2000s. Digital technologies were transforming this traditionally labour-intensive domain by offering much-needed solutions for growing food security challenges. Founded by Rikin Gandhi, Digital Green was one such initiative that had been leveraging video technology for information diffusion on sustainable agriculture, for over a decade. By 2021, the company had reached more than 2.3 million households across three continents and had successfully empowered 1.2 million farmers with knowledge on better agriculture practices.[1] Although digital technologies were becoming important for agriculture, the lack of digital adoption was becoming a serious concern, particularly among smallholder farmers. To overcome this challenge, Gandhi was contemplating to choose between one of three possible ways to leverage digital technologies: a human-augmented pathway, a tech-driven pathway or a combination of both. In the former, a human interface and a partner driven pathway would enhance credibility for better uptake of digital technologies, whereas a technology-driven pathway would instigate automation through AI-based products and processes to establish direct connectedness with farmers, he figured. While Gandhi believed that digital adoption could mitigate the existing information divide that hurts the marginalised farmers from the most, he also knew that accelerating digital adoption requires judiciously selecting the appropriate pathway, due to the complexity and diversity of the agroecosystem in India.

Introduction

With the anticipation of the world population becoming more than double by 2050 and natural resources getting depleted progressively, farmers were expected to work towards high-value yields within optimised resources. This called for precise data-driven digital agriculture that could seamlessly combine agronomic and meteorological data to deliver key insights for enhanced farm management. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) defined digital agriculture as "ICT and data ecosystems to support the development and delivery of timely, targeted information and services to make farming profitable and sustainable while delivering safe nutritious and affordable food for ALL."

Applications of precision farming using digital technologies observed a worldwide compound annual growth rate (CAGR) of over 10% during the years 2015-18 (refer Exhibit 1

[1] Digital Green. (n.d.) *Global Impact*. .https://www.digitalgreen.org/global-impact/

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for CAGR of precision farming). Besides, digital technologies could improve transparency and convenience in access to salient information such as market prices, regulatory changes, etc., thereby helping in streamlining farmers' overall efficiency. As mentioned by International Telecommunication Union (ITU) and Food and Agriculture Organisation (FAO) - "Digital agriculture has the potential to contribute to a more economically, environmentally and socially sustainable agriculture, while meeting the agricultural goals of a country more effectively" (ITU & FAO, 2020). Recognising the importance of advanced digital technologies for agricultural benefits, the Government of India (GoI) had asserted agriculture as one of its key focus areas for Artificial Intelligence (AI) intervention (Niti Ayog, 2018). However, the adoption of digital agriculture in the country was extremely low because a prominent section of farmers – the smallholder farmers, was not a proactive adopter of technology owing to inherent barriers limiting adoption.

Digital Green

Digital Green was a not-for-profit international development organisation incubated in 2006 as Gandhi's project with Microsoft Research India's "Technology for Emerging Markets" team. Since then, Digital Green had been working to significantly complement and enhance agricultural extension services through community-based video screenings for information dissemination (Gandhi et al., 2007). It also offered mobile-based training courseware for extension agents to strengthen their knowledge. Additionally, the company had digitally automated services that improved market access (Loop) and information access (using WhatsApp). These services were offered in regions where smartphone ownership and digital adoption among farmers were high. Thus, Digital Green had a fundamental goal of empowering smallholder farmers' capabilities by increasing their productivity through technology-based solutions.

The company partnered with government bodies, knowledge and implementation facilitators and technology partners which enabled it to have regulatory, informational and implementational support. Digital Green was a renowned name among the farmers of India, mainly in the states of Orissa, Bihar, Jharkhand and Andhra Pradesh. Through its various initiatives, the firm had made global footprints with prominence in South Asia and Sub-Saharan Africa. Exhibit 2 to Exhibit 5 present details about Digital Green's key constructs and accomplishments, operational model, list of partners and growth over the years, respectively.

Community-Based Video-Disseminations

For video screenings, Digital Green worked at the partner level with grassroots organisations. The partner could be an NGO, state-run, or privately held body, usually operating at a much larger scale than just an individual village. The partners facilitated -- (i) the groundwork for community mobilisation, (ii) video creation and screening and (iii) data collection within the existing community structures. Digital Green's role was to train the partners' staff on doing the same. For instance, one of its partners -- the Bihar Rural Livelihoods Promotion Society (JEEViKA), worked across 7000 odd villages of Bihar, and had Village Resource Persons (VRP) at an individual village level. JEEViKA had mobilised women's self-help groups and a few Farmer Producer Organisations (FPO) which, typically, had been first brought together for microcredit/savings purposes. There were usually 6-8 groups of 15-20 members each in every ~100 household village.

Digital Green trained partners for local video creation i.e. in the local language, and featured local farmers. Video content was focussed on better farming techniques and nutrition practices. Screening was carried out for the mobilised group comprising around 15 farmers. A video mediator such as JEEViKA's VRP facilitated the screening process, addressed farmers' queries and doubts, and collected their feedback as well as interest for the exhibited content. The entire process was done offline, allowing for farmers' interaction within their social network. Exhibit 6 toExhibit ***8*** present the entire process and snapshots of the video creation and screening process. In addition, Digital Green also had an online video sharing mechanism through its YouTube channel[2] and Video Library[3] (Exhibit 9 shows a screenshot of the YouTube channel). The YouTube channel had 276,000 subscribers and had attained 69 million views. All of Digital Green's offline videos were also uploaded on online platforms. Both models were successfully reducing the information gap within the farmer community.

As an organisation, Digital Green experienced benefits as well as concerns with both models. The offline model gave Digital Green an elaborated understanding of the farmer-beneficiaries however, it required a lot of groundwork, for which Digital Green was dependent on partner organisations. The online channels enhanced Digital Green's direct reach to the farmers, however, there was little information on farmers' demographics and interests. Thus, Digital Green aimed to enhance its information reach to the individual farmer level by enabling two-way communication so that there was no compromise on farmer inputs. For this, Gandhi was considering strategies to leverage digital technology, primarily, state-of-the-art smartphone applications. However, given the low digital adoption, an ultra-modern ag-tech solution was unpropitious.

Background

Agriculture and Digital Information and Communication Technologies

Agriculture, the oldest means of global livelihood, had evolved tremendously over the years. From harnessing animal power until the second industrial revolution, to the contemporary mechanised ways of farming, technological advancements had played a great role in shaping up modern agriculture. While growth in agriculture had been incremental, the future needed something more. The arable land was continuously fragmenting, limiting the use of large equipment and machinery. Moreover, the quality of natural resources -- soil, water and air, was increasingly deteriorating. Hence, generating high-value yield using existent technologies and practices had become less feasible. Due to this, newer technological developments were greatly focussed on the capture and delivery of precise information for optimised use of resources. Thus, modern agriculture involved more of an information-based approach that allowed for informed decision-making than a purely resource-based approach.

Inevitably, the concurrent emergence of digital information and communication technologies (ICT) as the most promising ecosystem for information capture, processing, actuating and storage marked their importance in information-based modern agriculture. These technologies could efficiently capture or sense structured and unstructured data and process it through advanced machine-learning algorithms for delivering information and services. Farmers could use them for better management and planning, operational efficiencies and cost reductions. Table 1 presents the areas and role of ICT in agriculture as mentioned by FAO (ITU & FAO, 2020); use cases have been added for each of them.

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[2] digitalgreenorg. (n.d.). *Home.* {YouTube channel}. https://www.youtube.com/user/digitalgreenorg
[3] Digital Green. (n.d.). *Community videos*. https://solutions.digitalgreen.org/videos/library

Table 1: Role of ICT in Agriculture

Area	Role of ICT	Use Case
Agriculture innovation systems	Bridge the gap among various agricultural stakeholders	Innovations of social, economic and environmental significance such as FarmBeats
Sustainable farming	Improve access to and knowledge of better practices	Community-based video screenings through Digital Green
Disaster risk management and early warning system	Deliver actionable information and advisory in real-time	Mobile phone application for monitoring a priority pest - Fall Armyworm (FAW) in Africa
Enhanced market access	Facilitate improved market access and trade	e-National Agriculture *Mandi*[4] (eNAM), a digital marketplace in India connecting 7000+ *mandis.*
Food safety and traceability	Deliver data having greater efficiency and reliability	IBM's Food Trust that delivered track-and-trace capabilities using blockchain technology
Financial services and insurance	Increased access to affordable services and tools	Financial inclusion through enhanced access to digital financial products and services
Capacity development and empowerment	Widen the reach of local communities, provide newer business opportunities, thereby enhance livelihood	Digital Green's model for leveraging technology for farmers' upliftment
Regulatory Frameworks	Implementation and monitoring of regulatory policies and frameworks	

Source: Compiled by authors based on FAO report and publicly available examples

Information Proximity in Agriculture

An agricultural cycle consisted of three broad stages -- pre-production, production and post-production, during which, farmers needed several types of information (Figure 1) (Department of Agriculture, Cooperation and Farmers' Welfare, 2017a). The information could be *Factual,* based on statistical and descriptive knowledge (e. g. quantity of inputs, operating a tractor) or *Analytical,* that included diagnostic (e. g. pest detection), predictive (e. g. rainfall estimates) and prescriptive (e. g. seed purchase and use) information. Farmers applied their cognitive capabilities to the received information for decision-making and problem-solving.

[4] *Mandi* is a Hindi word commonly used for agriculture marketplace.

Figure 1: Agricultural Cycle and Information Proximity

Pre-Production Stage	Production Stage	Post-Production Stage
• Pre-planting • Crop selection, land allocation • Seeding • Seed purchase and use • Preparing & planting • Land preparation • Seed sowing	• Growing • Quantity, quality and purchase of inputs such as fertilisers, pesticides • Pest detection and crop monitoring	• Harvesting, packing & storage • Home consumption • Harvest, package and store the yield • Marketing • Most profitable prices, markets and buyers

Source: Compiled by authors based on DFI Volume 11

Information proximity was related to the availability of relevant information within time and space vicinities, for instance, timely warnings about pest attacks in the region. The information was important as it affected farmers' choices and decisions. Further, due to the changes in climatic conditions and consumer behaviours, farmers' growing patterns required relevant information-led revamping. Information was specifically crucial for more complicated and uncertain contexts such as hilly areas. Farmers had primarily relied on self-knowledge, community knowledge and knowledge of extension services for information proximity. However, for some new farmers (e.g., tribals), ancestral knowledge was not substantial. While dependence on indigenous knowledge had been high, authenticity and reasonability were not greatly cared about. Contrarily, as digital tools were based on pre-evaluated techniques, they delivered more reliable machine intelligence than observational human knowledge. Besides, digital technologies also augmented computing capabilities of farmers by offering automated operations and simplified services. Thus, the use of digital technologies increased yields, reduced costs and minimised losses, thereby impacting the overall productivity and profitability of the farmers and ensured their sustainability.

FarmBeats

Microsoft's FarmBeats, operational primarily in the United States of America, was the digital agricultural ecosystem that enabled data-driven farming by providing farmers with relevant information using the advanced technologies of AI and the Internet of Things (IoT)[5] (refer Exhibit 11 for an overview of the FarmBeats system). With FarmBeats, farmers were able to know the precise details of their farms such as soil pH, moisture and humidity, micro-weather predictions, and livestock monitoring. The implementation of FarmBeats on 7900 acre-Nelson farms in the US reduced the application of expensive chemicals by 90% and increased cost savings by 15%.[6] These massive farms tended to have temperature differences

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[5] Microsoft. (n.d.). *FarmBeats: AI, Edge & IoT for Agriculture.* https://www.microsoft.com/en-us/research/project/farmbeats-iot-agriculture/

[6] Kapetanovic, Z, Chandra, R, Chakraborty, T & Nelson, A. (2019, July 22). FarmBeats: Improving farm productivity using data-driven agriculture. https://sinews.siam.org/Details-Page/farmbeats-improving-farm-productivity-using-data-driven-agriculture

of over 10 degrees at times; thus, FarmBeats's micro-climate predictions provided farmers with reliable weather information promptly and enhanced their farming judgments.

FarmBeats was a promising project that was appreciated by the company's higher management. Bill Gates, co-founder of Microsoft called FarmBeats a powerful tool to alleviate impoverished farmers.[7] Satya Nadella, the CEO of Microsoft considered it to be an inspiring project where technology was enhancing people's lives. He mentioned in his blog –

> Ranveer[8] and the team's work means a lot to me because it highlights something essential for our future: AI doesn't replace human knowledge; it augments it. In this case, data from low-cost sensors in soil and drones with machine learning algorithms work with farmers' knowledge and intuition to help them gather and parse data about their farms – informing what, when, and where to plant in order to drive the highest-possible yields and reduce costs.

Digital agricultural solutions such as FarmBeats were convincing and beneficial, however, their adoption was very low, especially in the rural areas of developing countries. Deepak Vasisht, a PhD student at MIT[9] and industry research fellow at Microsoft, was one of the key contributors for FarmBeats. While talking about low digital adoption in agriculture, he said,

> Adoption of digital technology in agriculture is very limited in terms of how many people are using it. There are tech enthusiastic farmers, who are early adopters or who like using technology and are getting some value out of it. So, they do continue using it and keep giving us feature requests and stuff. There are partners also, who engage with a broader set of farmers. They have also experienced this and now they are basically sort of hooked into the ag-tech. But in terms of real-world penetration, like if you think about technology, and how widely it gets adopted, a farmer is nowhere near that. Right. It's not like a smartphone that every farmer has.

As per FAO, these areas lacked the three basic conditions for digital transformation – IT infrastructure and network; educational attainment, digital literacy and employment; and policies and programmes for enabling digital agriculture (Trendov et al., 2019). The inequity in the adoption and use of digital applications caused certain farmer segments (typically, progressive urban farmers) who were digitally more proficient, to be computationally more capable than others. The low digital adoption among smallholder farmers was a major challenge in an agrarian developing country like India. The country had 54.6% of the total workforce dependent on agriculture for its livelihood, out of which, more than 85% were smallholder farmers. Considering digital agricultural technologies as an enabler of a secured future, the GoI was promoting ag-tech R&D, encouraging partnerships and incentivising start-ups. However, establishing credibility for accelerated digital adoption among farmers was a tough task.

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[7] Gates, B. (2018, October 9). *Can the Wi-Fi chip in your phone help feed the world?* https://www.gatesnotes.com/Development/FarmBeats

[8] Ranveer Chandra, Managing Director, Research for Industry Partner Manager, Networking Research CTO, Agri-Food, was the initiator and leader of FarmBeats.

[9] Massachusetts Institute of Technology is a research university in Cambridge.

The Complex Case of Indian Agriculture

Owing to its glorious history of overcoming post-independence famine with the successful Green Revolution, White Revolution and the likes (refer

Exhibit ***13*** for information on agricultural revolutions in India), in 2021, India was not only self-sustained in terms of food production but also a notable agri-exporter. Consequently, the agriculture and allied sector significantly impacted economic development by contributing 17% to the country's Gross Value Added (GVA) (Department of Agriculture, Cooperation and Farmers' Welfare, 2017b). The sector had grown at around 3.4% per annum from 2004-05 to 2016-17, and the GoI was aiming at a future rate of over 4%(Niti Ayog, 2018). Given that the growth in agriculture directly influenced rural prosperity, the sector was of key concern for the upliftment of 66% of the rural Indian population. Undeniably, "digital" could be the next revolution in agriculture, however, the agricultural domain was complex, Indian geography was diverse and farmer-beneficiaries were divided (refer Exhibit 14 for information related to Indian agriculture).

Information Sourcing for Indian Farmers

ICT in agriculture had facilitated effective modes of information dissemination using electronic devices, mobile devices and networks (Figure 2). Information could be delivered in voice (IVR – Interactive Voice Response), text (SMS – Short Message Service) or graphics (image or video). Based on these, there were various sources of information proximity for Indian farmers. *Krishi Darshan* (English: Agriculture Vision) was a television programme where experts provided information on technological advancements and cultivation practices. *Kisan* (English: Farmer) call centres offered interactive dialogue exchange with farmers in the local language for information dissemination. Digital Green offered video screenings to a group of farmers and had a local farmer as the coordinator. There were also various websites (Farmer Portal) and mobile applications (mKisan) that farmers could access for information sourcing. Non-ICT sources included a number of *Krishi Vigyan Kendras* (English: Farm Science Centres). These were agricultural extension centres, usually associated with a local agricultural university which farmers could visit for expert advice. Additionally, farmers had fellow-farmer networks for consultation and advice.

Figure 2: Information Sources for Indian Farmers

ICT Sources

- Television-based E.g. *Krishi Darshan*
- Telephone-based E.g. *Kisan* Call Centre
- Video-based E.g. Digital Green
- Mobile application-based E.g. mKrishi

Non-ICT Sources

- Local community and fellow farmers' knowledge
- Experts' knowledge and advisories E.g. *Krishi Vigyan Kendra*

Source: Compiled by authors based on publicly available data

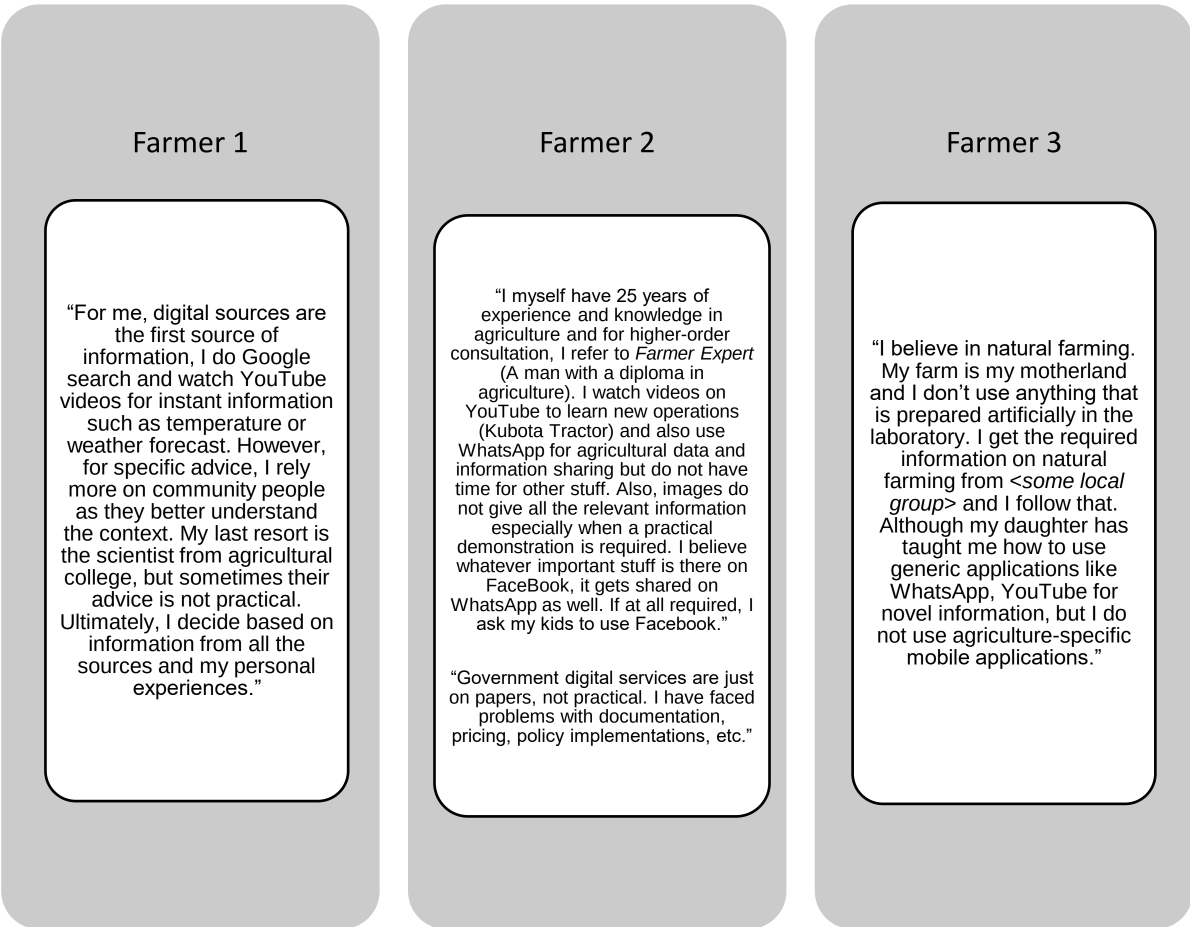
Talking about the inherent ways farmers used for information, Gandhi said,

> In the normal situation, a farmer's human behaviour is to ask his neighbours or his family members about what he is doing in terms of what crops he is growing or what practices he is following. If he has a crop disease or a pest attack, he will go to, like the *Krishi Vigyan Kendra*, or he will call the *Kisan* call centre or something, and try to get some remedial information. But that's in a crisis situation. That social network of peer-to-peer exchange is I think what we all do, no matter what domain or class that we might be in.

Information Processing by Indian Farmers

While there were various sources of information, there were also several inherent biases that led to the difference in information processing. Farming communities were closely knit within their clusters and relied heavily on community knowledge and practices. Thus, the bias of better learning through peer knowledge often rendered digital channels just a source of ancillary information for farmers. Sometimes, farmers also found technologies to be underdeveloped or unremunerative for their needs and thus abstained from their use. This created an information gap within farming communities. Figure 3 presents what different types of farmers had to say about their way of information acquiring and processing. Refer Exhibit 15 for farmer profiles.

Figure 3: Information Processing Among Different Farmers



Source: Compiled by authors

Barriers to Digital Adoption

Nearly 86% of the total farmland was cultivated by small and marginal farmers. These farmers typically belonged to the resource-deprived rural regions that hosted around 70% of the country's poor population.[10] The average monthly household income of small farmers was INR 6426, and over 51% of the households were indebted (Directorate of Economics & Statistics, 2019). The mean years of education of small and marginal farmers was –- 3.6 and 2.9 as compared to 4.1 of medium and large farmers; the numbers were even lower for females. Thus, the smallholder farmers were characterised by financial, infrastructural and skill deficits as compared to large-scale farmers which characterised them as non-progressive farmers. Pritam Kumar Nanda, State Head-Andhra Pradesh & Telangana, Digital Green had this to say about his experiences with the farmers of Bihar and Andhra Pradesh states,

> The socio-economic conditions of farmers as we saw was like -- farmers in Bihar, are at a little disadvantage in terms of the processes and the policies, whereas farmers in Andhra Pradesh are probably a little better off. In Bihar, there are more small-landholding farmers, with poor transportation connectivity, very less mobile penetration, and very little market information compared to Andhra Pradesh. Here, mobile penetration is high and they are aware of markets, and APMC[11] is doing a good job in disseminating information regarding these markets. But still, here there are constraints like aggregation and transportation.

Understandably, the most significant challenge in digital agriculture was to onboard smallholder farmers as they were sceptical and resistant to the adoption of new technologies and refrained from using them. These farmers typically faced four access barriers -– mental, material, skill and usage (J. A. Van Dijk, 1999; J. Van Dijk & Hacker, 2003; Venkatesh et al., 2019). Mental barriers were related to computer anxiety, lack of interest in ICT or aversion to new digital technologies; material barriers referred to not having physical access to computers and other ICTs; skill barriers corresponded to the lack of education or computer efficacy; and usage barriers were related to restricting inappropriate use of digital technologies. Due to the prevalence of these barriers, there was a significant gap in internet usage not only within farmers, but also at broader parameters including gender and age, across the world. Exhibit 15 and

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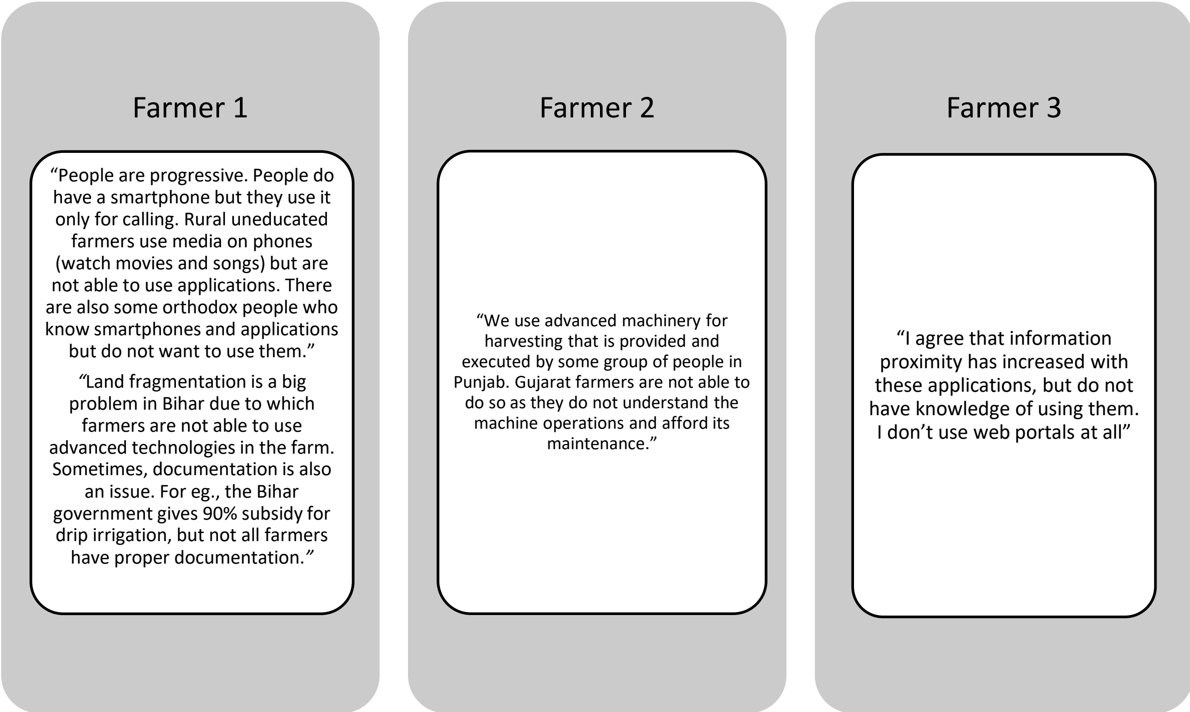
[10] The World Bank. (2012, May 17). *India: Issues and priorities for agriculture*. https://www.worldbank.org/en/news/feature/2012/05/17/india-agriculture-issues-priorities

[11] APMC - An Agricultural Produce Market Committee (APMC) is a marketing board established by state governments in India

Exhibit *16* present the internet profiles for India and the world.

In the words of farmers,

Figure 4: Farmers Statements on Access Barriers



Source: Compiled by authors

Gandhi's Dilemma

Evidently, an income-based digital divide existed between large- and small-scale farmers, and Digital Green had been working extensively towards bridging this divide. For enhancing its reach to have effective last-mile communication, Digital Green came up with the idea of utilising the extremely popular and widely used instant messaging application -- WhatsApp. Gandhi narrated Digital Green's approach:

> Standalone apps and YouTube recommendation kind of stuff works for upper-tier, kind of more progressive farmers and such. But I think for the mainstay sort of population of smallholder farmers, you've got to see it from a more human-augmented way because that's the only way that you're going to build trust and confidence in these community members to really engage.

About implementation, he added,

> We set up an AI chatbot on WhatsApp where farmers could give their phone number and then start interacting. It's all automated; farmers asking questions or getting push messages as per what they have selected. The chatbot would set the initial triaging of what are the queries that these farmers are asking about? What are the crops that they're interested in, etc? What we found, in that case, was very limited take-up, only take-up from the most progressive farmers, all men and relatively few who actually were able to interact inevitably, some servicemen. The contrast we did was a sort of a

> human-mediated type of approach, it was still over WhatsApp and it was still a chatbot element. However, there was a Village Resource Person -- a trained farmer from the community, already there who would get these queries and would basically see the triage results from the bot and then be able to respond to these farmers in a WhatsApp group. Farmers had the notion of 'fellow peers in my village are getting the same content', so there's a kind of a 'peer-pressure' like dynamic to it, in addition to the fact that 'it is not a bot I'm interacting with, but rather this message is coming from a particular person who I know, this village resource person who lives in my village and they're sharing with me over WhatsApp a video about the same practices that the bot was' and that engendered lots of trust and a feeling of familiarity, both to the fellow members of the group and also for this individual extension agent.

The human augmented partner-driven pathway proved to be efficient in addressing the smallholder farmers' barriers and onboarding them towards the use of the digital platforms, which eventually allowed Digital Green to interact with an individual farmer. Digital Green tried to replicate the same in their logistic smartphone-based application –- Loop.

Loop facilitated better market access to farmers at low cost and in less time. It had reached over 26,000 farmers in India and Bangladesh. It enabled a group of farmers to efficiently aggregate their yield and transport it collectively to the most profitable marketplace. The aggregation allowed farmers to have the benefits of wholesale rates through bulk dealing, and thus resulted in 15% greater income. There was a human aggregator, functionally similar to the WhatsApp chatbot mediator, who coordinated between the farmers and transporters and often decided on the best marketplace. Ashok Kumar, senior programme manager, Loop, spoke about the application's implementation in Bihar:

> We started in Bihar in 2015. At that time smartphone penetration was low there. Apart from our aggregators, there were hardly any other people who owned a smartphone. So, we had an aggregator in between, talking to farmers, collecting all the stuff and taking it to transporters, and then taking it into the *mandi*. All the things started working well. But meanwhile, the aggregators became very powerful. They would decide which *mandi* to go, whether or not to go there. In fact, they had become one more middleman and so later we decided to do it directly between the farmer and the transporter.

Thus, the human-augmented pathway had certain dependencies on the inter-mediators. Although Digital Green was able to enhance its outreach, the pathway had significant vulnerabilities and possibly would not be fully efficient for future solutions. Gandhi was contemplating on distinct novel pathways.

An Alternative Pathway - FarmBeats Model

The objective of FarmBeats was to help farmers increase their productivity and reduce their costs through increased access to digital technology in farms. This subsequently required sensing farm-level data and enhancing farm connectivity to fetch that data for processing. Thus, FarmBeats used automated data collectors such as sensors and drones in agricultural farms, data processing software at gateway and cloud, an output device such as laptop or smartphone, and the network that connected all these elements. The system incorporated AI techniques for sensor processing, computer vision and machine learning to provide insights about farm conditions, input requirements and climate changes. For eg., the precision maps of the entire farm generated by FarmBeats (Exhibit 14), suggested moisture, pH and temperature of the soil (Vasisht et al., 2017). The farmers could visualise this map either on a laptop or a smartphone. Thus, FarmBeats followed a tech-driven pathway for delivering information directly to the farmers. In addition to the farm-related information, Vashisht mentioned some anecdotal pieces of evidence where technology was used to detect alarming situations and send alerts of the farmers, without any additional human involvement. Such examples included –- cattle monitoring and animal tracking. Vasisht elaborated on these:

> Think of it as like a Fitbit for cows that you want to track and monitor cows, like how active they are. We have cameras that detect how cows are moving. If they walk more, they're more active, then they are likely to have better quality milk, more milk production. And if they walk less than just the sign is of some kind of disease or something like that.
>
> If you have animals running into your field, you can raise alarms, you can actually just have an alarm that goes off and strays animals that way. That is pretty useful consistently across the board for keeping the farms safe from unwanted insurgence of animals.

These features efficiently performed repetitive tasks that would otherwise consume the farmers’ time and efforts. Thus, the use of technology reduced farmers’ overheads and improved their prospects for better farming.

FarmBeats provided the base functionality that could be customised based on requirements. Vasisht explained how the feature of aerial imagery capture was changed for the Indian context. He said,

> FarmBeats relied a lot on drone imagery and flying drones is not as trivial in India as you have to get permission from police station and stuff. So we came up with a new sort of design for the Indian context where we had a small camera tied to a balloon, and it went in the air. Somebody walked around with a balloon to get aerial imagery. So, we use that design instead. And that was sort of a trade-off between labour and technology because, in India, labour costs are cheaper, and technologies are more expensive relatively, so we could trade off technology for labour costs instead. But in the US, labour is expensive. So if you save labour cost that's useful for the farmer.

Vasisht elaborated on the FarmBeats functional model as,

> So, we either work with tech enthusiastic farmers, who would be interested in technology, or we would collaborate with other partner organisations. We have a base set of functionalities in the FarmBeats. But like, whenever a partner takes it to the farmer, they can build on top and customise it to let's say, their geography or their own farm and customers. So, there are a lot of partnerships. There are two levels of partnerships. One is the hardware partnership where somebody sells you the drone or the sensor. So that's like the hardware partner that Microsoft would engage with and provide them the base technology. And then there is another level of technology, which is the information partnership. So FarmBeats will ingest the data from the

> sensors, give them through an API and then a developer can go and say that, okay, like, this is how I want to use it within the app of the farmer. So there is a lot of flexibility in that. And, this is just like Microsoft's model of how things operate in FarmBeats.

FarmBeats catered to the farmers of the US, who were distinctly different from the farmers of India. However, Gandhi considered the approach because –- (i) it was partner-driven, and could help Digital Green leverage existing partnerships, and (ii) it was customisable and could give Digital Green the flexibility of implementation in complex Indian agriculture.

The Way Forward

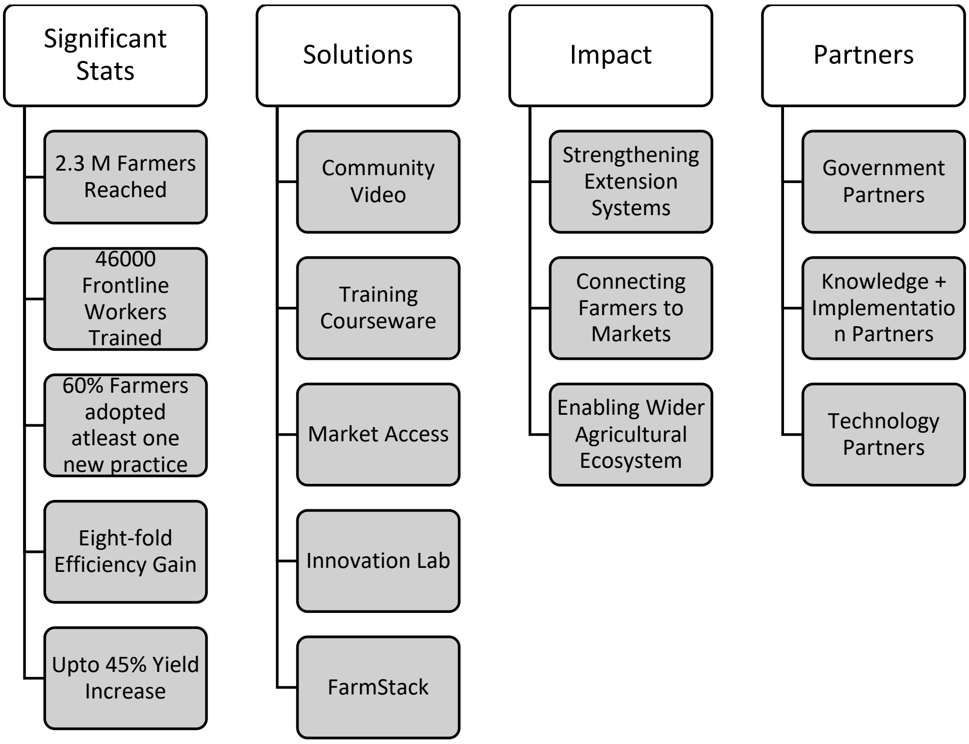
Digital Green had been a harbinger of the welfare of smallholder farmers through technology intervention. However, the lack of adoption of digital technologies among smallholder farmers inhibited their cognitive capabilities and impeded their productivity. Gandhi was contemplating on two pathways to leverage digital technologies –- human-augmented, which Digital Green had already implemented, and the tech-driven, which appeared to be promising. Given the complexity and diversity of Indian agriculture, another point of concern was whether the independent or collaborated implementation pathway would be beneficial. Holistically, can technology enable self-dependence among even the most marginalised farmers?

Exhibit 1: Compound Annual Growth Rate (CAGR) of Precision Farming[12]

	Precision spraying	Field monitoring	Data management	Precision irrigation	Precision fertilisation	Precision planting	Other
CAGR 2018 - 2025	15.38%	14.72%	14.57%	12.91%	11.89%	11.70%	14.06%

Source: BIS Research, Statista

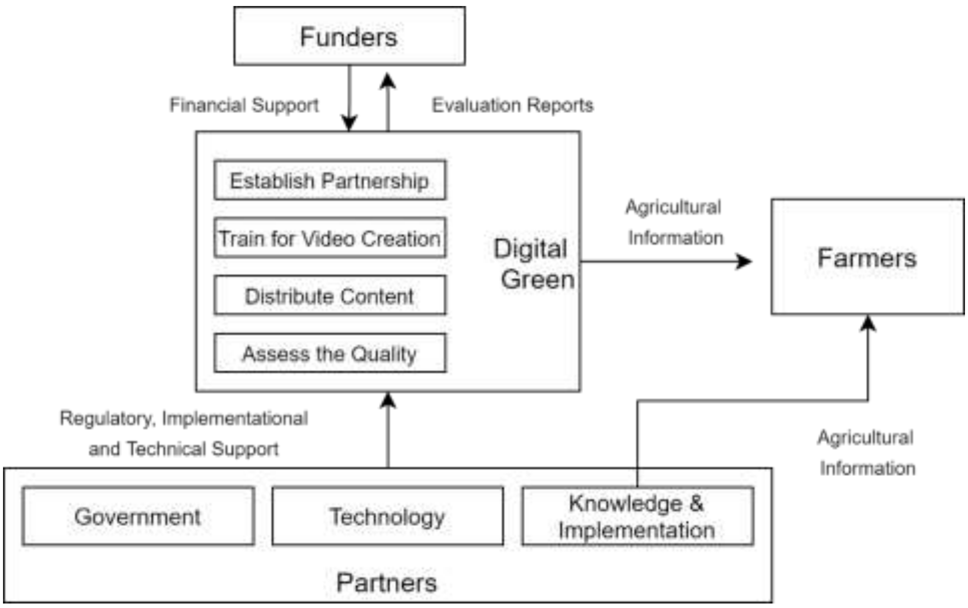
Exhibit 2: Digital Green's Key Constructs and Accomplishments



Source: Digital Green

[12] BIS Research. (2018, December 15). Compound annual growth rate (cagr) of precision farming worldwide between 2018 and 2025, by application [Graph]. In Statista. Retrieved June 08, 2021, from https://www.statista.com/statistics/958784/precision-farming-market-annual-growth-rate-by-application-worldwide/

Exhibit 3: Digital Green's Operating Model



Source: Prepared by Authors based on Digital Green Information

Exhibit 4: Digital Green's List of Partners

Funders	Government Partners		Knowledge + Implementation Partners		Technology Partners
	India	Ethiopia			
Alliance for a Green Revolution in Africa	Andhra Pradesh Department of Agriculture and Cooperation	Agricultural Transformation Agency	Arghyam	International Food Policy Research Institute	Awaaz.de
Bill & Melinda Gates Foundation	Bihar Rural Livelihoods Promotion Society (JEEViKA)	Amhara Regional Bureau of Agriculture & Natural Resources	CARE	International Maize and Wheat	CABI
David and Lucile Packard Foundation	Department of Agriculture and Farmers' Empowerment, Govt. of Odisha	Ethiopian Institute of Agricultural Research	Centre for Media Studies	Improvement Centre (CIMMYT)	tomorrownow.org
Fast Forward	Integrated Child Development Services	Ministry of Agriculture (Government of Ethiopia)	Centre for Youth and Social Development	JSI Research and Training Institute	eCom
Google.org	National Health Mission Assam	Oromia Regional Bureau of Agriculture & Natural Resources	CGIAR Platform for Big Data in Agriculture	London School of Hygiene & Tropical Medicine	Exotel

Funders	**Government Partners**		**Knowledge + Implementation Partners**		**Technology Partners**
Hewlett Packard Enterprise Foundation	National Health Mission Chhattisgarh	Oromia Forest and Wildlife Enterprise	Dalberg	Mahila Kisan Sashaktikaran Pariyojana	Google
Mulago Foundation	National Health Mission Jharkhand	Oromia Environment, Forest and Climate Change Authority	Ekjut	One Acre Fund	Haptik
PepsiCo	National Health Mission Uttarakhand	Oromia Regional Bureau of Finance and Economic Cooperation	Environment and Coffee Forest Forum	Precision Agriculture for Development	Microsoft Research
UK Foreign, Commonwealth &	National Rural Livelihoods Mission Odisha Livelihood Mission	SNNPR Regional Bureau of Agriculture & Natural Resources	Global Forum for Rural Advisory Services	Societal Platform	MIT
Development Office	State Nutrition Mission Jharkhand	Tigray Regional Bureau of Agriculture & Rural Development	IDEO.org	University of London / SOAS	Navana Tech
United States Agency for International Development	State Rural Livelihood Mission Chhattisgarh		IDInsight	Voluntary Association for Rural Reconstruction and Appropriate Technology	One Mobile Projector Per Trainer
		Kenya			OnionDev (Gramvaani)
Walmart Foundation	**Rwanda**	Kenya Agricultural and Livestock Research Organization			OpenTEAM
Winrock International	Ministry of Agriculture and Animal Resources	Kenya Plant Health Inspection Services			
World Bank	Rwanda Agriculture and Animal Resources Development Board	Makueni County Government			

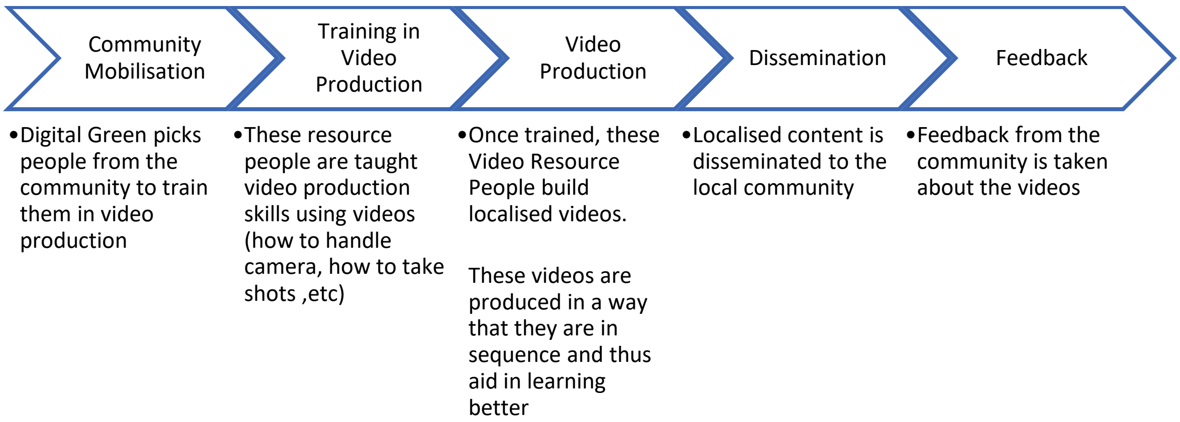
Source: Digital Green

Exhibit 5: Digital Green's Growth over the Years

	2018	2019	2020	2021E	2022E
Employees (FTE)	129	103	114	114	122
Farmers Reached (Annual)	621,181	1,572,374	1,368,242	1,293,000	1,629,000
Share of farmers adopting more than one practice	33%	34%	45%	48%	49%
Extension agents using Digital Green tools	14,472	17,000	21,123	9,000	32,000
Received health/nutrition advice (cumulative)	195,578	467,736	714,053	714,053	750,000
Cost per farmer reached (USD)	16.5	5.8	5.9	5.8	5.1
Cost per adopting farmer (USD)	49.8	31.1	17.7	25.5	20.6
Total Income (USD)	5,215	6,900	9,205	9,211	8,500
Total Expenses (USD)	10,244	9,192	8,071	7,511	8,300

Source: Digital Green

Exhibit 6: Digital Green Videos Creation Process Map



Source: Digital Green

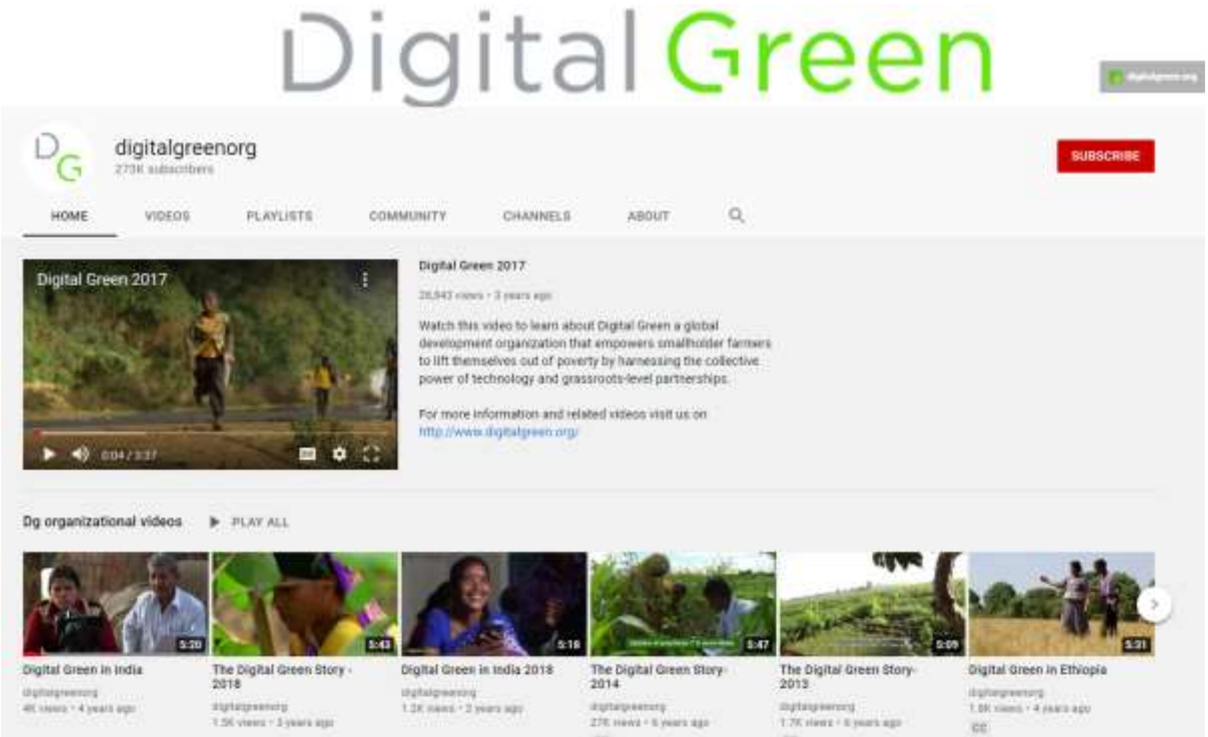
Exhibit 7: Video Creation

Source: Digital Green

Exhibit 8: Video Screening

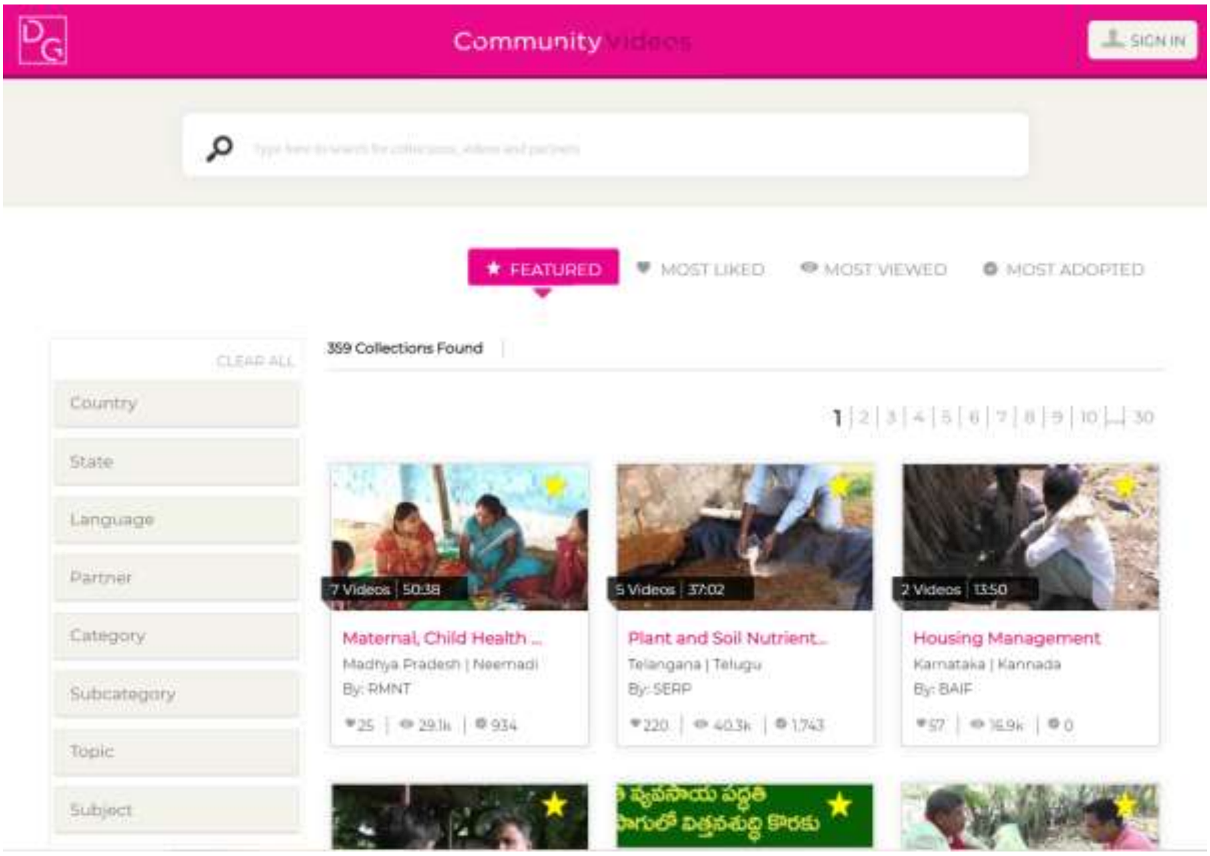
Source: Digital Green

Exhibit 9: YouTube Channel Screenshot



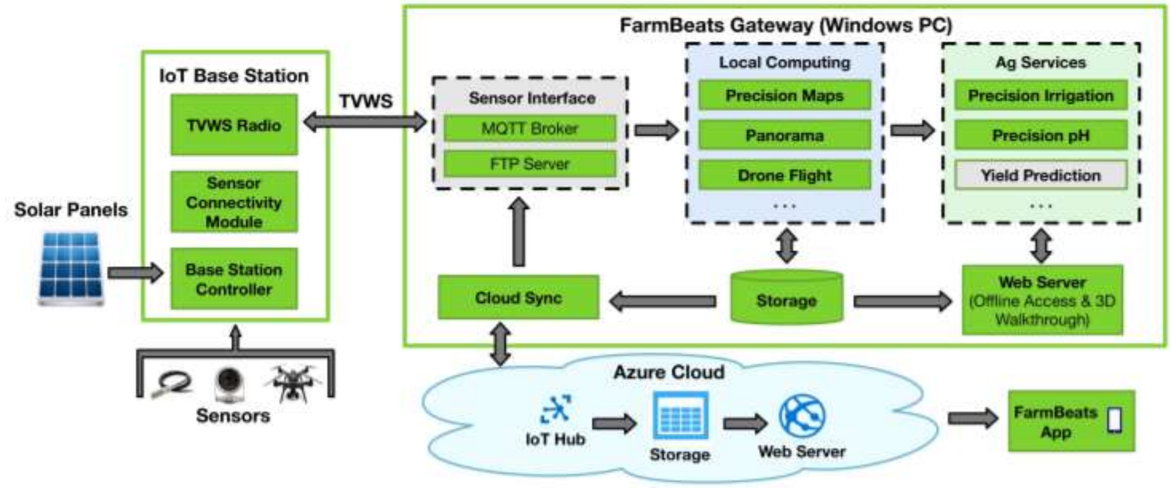
Source: digitalgreenorg, (n.d.). *Home*. https://www.youtube.com/user/digitalgreenorg/featured

Exhibit 10: Video Library Screenshot



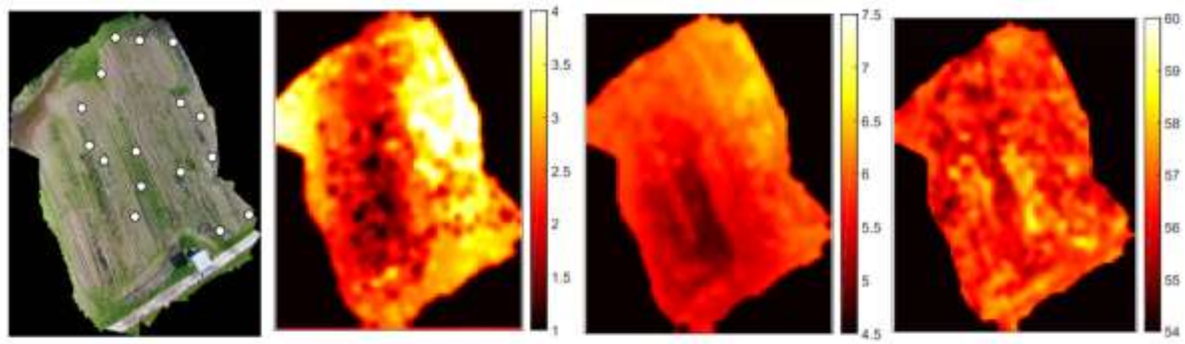
Source: Digital Green. (n.d.). *Community videos*. https://solutions.digitalgreen.org/videos/library

Exhibit 11: FarmBeats System Overview



Source: Vasisht, D., Kapetanovic, Z., Won, J., Jin, X., Chandra, R., Sinha, S., Sudarshan, M., & Stratman, S. (2017). Farmbeats: An IoT platform for data-driven agriculture. In 14th {USENIX} Symposium on Networked Systems Design and Implementation ({NSDI} 17) (pp. 515-529)

Exhibit 12: FarmBeats Precision Maps



(a) Orthomosaic (b) Moisture Map (c) pH Map (d) Temperature Map

Source: Vasisht, D., Kapetanovic, Z., Won, J., Jin, X., Chandra, R., Sinha, S., Sudarshan, M., & Stratman, S. (2017). Farmbeats: An IoT platform for data-driven agriculture. FarmBeats: An IoT platform for data-driven agriculture. https://www.microsoft.com/en-us/research/wp-content/uploads/2017/03/FarmBeats-webpage-1.pdf

Exhibit 13: Agricultural Revolutions in India

Name of the Revolution	Period	Related Products	Father/Associated Person
Green	1966-67	Food Grains	Norman Borlong; M.S. Swaminathan; William Goud (UK)
Pink	1970s	Onion / Prawn	Durgesh Patel
White	1970 - 96	Milk	Verghese Kurien
Blue	1973 - 02	Fish	Dr. Arun Krishnan
Red	1980s	Meat / Tomato	Vishal Tiwari
Yellow	1986 - 90	Oilseed	
Brown	-	Leather / Cocoa / Non-Conventional products	Hiralal Chaudri
Golden	1991 – 03	Fruits / Honey / Horticulture Development	Nirpakh Tutaj
Protein	2014 – 20	Agriculture (Higher Production)	Coined by Narendra Modi
Evergreen	2017 – 22	Overall Production of Agriculture	M.S. Swaminathan

Source: Monica. (2021, August 10). List of major agricultural revolution in India. https://www.kopykitab.com/blog/agricultural-revolution-india/

Exhibit 14: Indian Agriculture

Key Indicators

- Country Area - 328,725.9; Land Area - 297,319; Agricultural Area - 179,674; Forest Area - 71,094.4 ; Ranks 2nd in Arable land
- Ranks 2nd in Total Population and 1st in Rural Population; Nearly 60% population dependent on farming;
- Operational land holdings: Marginal - 68.45%; Small - 17.62%; Others - 13.93%

Agricultural Characteristics

- Prominence of labour intensive subsistence farming on small land holdings with high dependence on uncontrollable factors - such as rainfall
- Farming Seasons - Kharif (July-October); Rabi (October - March); Zaid (Throughout the year)
- Diversity - 127 agro-climatic regions supporting 3000 different crops and one million varieties; 130 million farmers in the country, speaking roughly 800 languages
- Gross Challenges
  - Land fragmentation; Weak supply chain; Inadequate access; Increasing divides; Youth Retention

Source: * - DFI Volume 11
http://www.fao.org/india/fao-in-india/india-at-a-glance/en/
https://farmer.gov.in/imagedefault/DFI/DFI%20Volume%2011.pdf
Compiled by authors based on publicly available data

Exhibit 15: Farmer Profiles

Farmer 1: A young and educated progressive farmer from Bihar state. He used many paid and free mobile applications. He used applications to buy fertilisers, monitor plant health through satellite imagery, digital payments, etc. He had also subscribed to certain YouTube channels that he found most appropriate. He used soil sensors for moisture, humidity, etc, and got information on his phone.

Farmer 2: A middle-aged progressive farmer from Bharuch district of Gujarat state. He had been engaged in agriculture since 1997. He practiced farming on 30 acres of self-owned farm and 50 acres of the rental farm. He grew watermelon, sugarcane, banana, papaya, cotton, soyabean, *chana*, jowar, wheat.

Farmer 3: A middle-aged progressive woman farmer from Surat district of Gujarat state. She believed in and did natural farming, not organic farming. She prepared and used cow dung as fertilisers and did not apply chemical-based fertilisers or pesticides. She did not find any difference in yield as compared to chemical-based fertilisers. She did not use sensors or web portals at all. She believed the traditional approach to be better than modern.

Exhibit 15: India's Internet Profile[13]

Internet Access	
Internet Penetration Rate	
2017	34.40%
2018	38.02%
2019	48.48%
2020	50%
Type of Mobile Network	
2G	4%
3G	13%
4G	85%
WiFi	6%
By Frequency	
Everyday	65%
4-6 days a week	4%
1-3 days a week	11%
Once a week	7%
< once a week	13%

Internet Users	
Number (Millions)	
2017	422.2
2018	493.96
2019	636.73
2020	696.77
Share by Age Group	
12-15	14%
16-19	18%
20-29	35%
30-39	19%
40-49	9%
50+	6%
Share by Gender & Region	
Females	33%
Males	67%
Urban-Females	38%
Urban-Males	62%
Rural-Females	28%
Rural-Males	72%

Internet Activities	
Share of Mobile Data Traffic, by content in 2018	
Video Streaming	80%
Browsing	14%
Social Media	12%
Others	10%
Leading Social Media Sites in April 2020	
	Market Share by Page Traffic
Facebook	86.04%
Instagram	4.84%
YouTube	3.26%
Pinterest	3.00%
Twitter	2.57%
Time Spent on Internet on Sundays/holidays	
Less than 15 minutes	19%
15-30 minutes	29%
31 minutes to 1 hour	18%
More than 1 hour	31%
Can't say/Don't know	11%

Source: Statista

[13] Keelery, S. (2021, August 2). Internet Usage in India. Statista. https://www.statista.com/topics/2157/internet-usage-in-india/

Exhibit 16: World's Internet Profile

Percentage of households with computer and Internet access at home, 2019[14]

	Internet Access		Computer Access	
	Urban	**Rural**	**Urban**	**Rural**
World	72.00%	37.00%	63.00%	25.00%
Developed	87.00%	81.00%	84.00%	66.00%
Developing	65.00%	28.00%	54.00%	17.00%
Least Developed Countries (LDCs)	25.00%	10.00%	17.00%	3.00%
Land Locked Developing Countries (LLDCs)	46.00%	14.00%	37.00%	8.00%

Percentage of individuals using Internet, 2019

	Total	Female	Male	Youth
World	51.40%	48.30%	55.20%	69.00%
Developed	86.70%	85.60%	87.80%	87.00%
Developing	44.40%	40.40%	48.90%	44.00%
Least Developed Countries (LDCs)	19.50%	14.70%	27.60%	19.00%
Land Locked Developing Countries (LLDCs)	27.40%	21.30%	33.50%	27.00%
Small Island Developing States (SIDS)	52.40%	53.10%	51.70%	52.00%

Internet Subscribers Around The World, 2019

	Fixed Telephone	Fixed Broadband	Mobile Cellular	Mobile Broadband
World	12.10	14.90	108.00	83.00
Developed	35.60	33.60	128.90	121.70
Developing	7.40	11.20	103.80	75.20
Least Developed Countries (LDCs)	0.80	1.60	74.90	33.10
Land Locked Developing Countries (LLDCs)				

Mobile Coverage by Type of Network and Development, 2019

	LTE or Higher	3G	2G
World	81.80	11.40	3.20
Developed	92.90	5.00	0.90
Developing	79.60	12.70	3.70
Least Developed Countries (LDCs)	40.00	38.80	9.90
Land Locked Developing Countries (LLDCs)			

Source : International Telecommunication Union

[14] International Telecommunication Union. (2020). *Measuring digital development: Facts and figures 2020*. https://www.itu.int/en/ITU-D/Statistics/Documents/facts/FactsFigures2020.pdf

References

Department of Agriculture, Cooperation and Farmers' Welfare. (2017a). *Empowering the farmers through extension and knowledge dissemination* (Government Report No. 11; Report of the committee on doubling farmers' income). Ministry of Agriculture & Farmers' Welfare. https://agricoop.gov.in/sites/default/files/DFI%20Volume%2011.pdf

Department of Agriculture, Cooperation and Farmers' Welfare. (2017b). *March of agriculture since independence and growth trends* (Government Report No. 1; Report of the committee on doubling farmers' income). Ministry of Agriculture & Farmers' Welfare. https://agricoop.gov.in/sites/default/files/DFI%20Volume%201.pdf

Directorate of Economics & Statistics. (2019). *Agricultural Statistics at a Glance 2019*. https://eands.dacnet.nic.in/PDF/At%20a%20Glance%202019%20Eng.pdf

Gandhi, R., Veeraraghavan, R., Toyama, K., & Ramprasad, V. (2007). *Digital green: Participatory video for agricultural extension*. 1–10.

ITU, & FAO. (2020). *Status of Digital Agriculture in 18 countries of Europe and Central Asia* (p. 102). International Telecommunication Union. http://www.fao.org/3/ca9578en/CA9578EN.pdf

Niti Ayog. (2018). *National Strategy for Artificial Intelligence*. Niti Ayog. http://niti.gov.in/sites/default/files/2019-01/NationalStrategy-for-AI-Discussion-Paper.pdf

Trendov, N. M., Varas, S., & Zeng, M. (2019). *Digital technologies in agriculture and rural areas – Status report* (p. 152). Food and Agriculture Organization of the United Nations. http://www.fao.org/3/ca4985en/ca4985en.pdf

Van Dijk, J. A. (1999). The one-dimensional network society of Manuel Castells. *New Media & Society*, *1*(1), 127–138.

Van Dijk, J., & Hacker, K. (2003). The digital divide as a complex and dynamic phenomenon. *The Information Society*, *19*(4), 315–326.

Vasisht, D., Kapetanovic, Z., Won, J., Jin, X., Chandra, R., Sinha, S., Kapoor, A., Sudarshan, M., & Stratman, S. (2017). *Farmbeats: An IoT platform for data-driven agriculture*. 515–529.

Venkatesh, V., Sykes, T. A., Rai, A., & Setia, P. (2019). Governance and ICT4D Initiative Success: A Longitudinal Field Study of Ten Villages in Rural India. *MIS Quarterly*, *43*(4).