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WORLD ECONOMIC FORUM

In collaboration with the Office of the Principal Scientific Adviser to the Government of India and BCG X

Future Farming in India
A Playbook for Scaling Artificial Intelligence in Agriculture

INSIGHT REPORT

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Foreword

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Agriculture is at a turning point.

In a world increasingly shaped by challenges such as unpredictable weather patterns, rising costs and resource scarcity, technological innovations are emerging as powerful tools to navigate these complexities. Among these, artificial intelligence (AI) stands out as a transformative force, capable of revolutionizing agricultural practices, enhancing productivity and ensuring sustainability.

India, home to more than 150 million farmers, holds a unique position in this transformation. Despite its rich agrarian heritage, Indian agriculture faces significant challenges. Low productivity, fragmented landholdings, limited financial access for smallholders and vulnerability to climate change hinder progress. These issues are further exacerbated by traditional farming methods, underscoring the urgent need for innovative solutions that address inefficiencies while building resilience.

This report, *Future Farming in India: A Playbook for Scaling Artificial Intelligence in Agriculture*, is designed to bridge the gap between aspiration and action, providing practical strategies for using AI to meet the needs of smallholder farmers in India and around the world. It builds on real-world examples and lessons learned from projects across India, where AI has helped farmers increase yields, reduce input costs and improve profits. These early successes demonstrate that AI can make a tangible difference – but only if implemented thoughtfully and at scale.

This playbook is the result of extensive consultations with policy-makers, researchers, industry leaders, agritech start-ups and farmers themselves.

It reflects a collective vision for harnessing AI to address systemic challenges in agriculture, guided by the principles of inclusivity, equity and sustainability.

It provides a structured roadmap for deploying AI solutions at scale, centred on three critical pillars: **enable**, **create** and **deliver**. The playbook demonstrates how robust digital infrastructure, inclusive policies and collaborative innovation ecosystems can accelerate AI adoption. It also highlights successful use cases, both global and local, showcasing AI's transformative potential when tailored to specific contexts.

The report aspires to be more than a toolkit. It aims to inspire and align governments, private enterprises and civil society in building an AI ecosystem that promotes a future in which farming is more productive, profitable and resilient.

The journey to scaling AI in agriculture is not without challenges, but it is also rich with opportunities. Whether you are a policy-maker, a start-up founder, an industry leader or a research scientist, as you engage with this playbook, you are encouraged to reflect on its insights and adapt its recommendations to your unique contexts.

The report's authors extend their deepest gratitude to all stakeholders whose expertise, vision and dedication have shaped this initiative. They hope this playbook serves as a beacon, guiding the global agricultural community towards a smarter, more sustainable future.

Executive summary

The agricultural sector is a cornerstone of India's economy, employing nearly 46% of the population and contributing 18% to the nation's gross domestic product (GDP).

Despite this, systemic challenges such as low productivity, fragmented landholdings, limited access to finance and the growing impacts of climate change continue to impede the sector's potential. Technology, particularly artificial intelligence (AI), presents an opportunity to address these challenges by enabling smarter, more efficient and more resilient agricultural practices.

AI has already shown promising results in Indian agriculture. Pilot projects have demonstrated significant improvements in yields, cost reductions and better market access for farmers. However, scaling these benefits to reach millions of smallholder farmers requires a structured approach that addresses adoption barriers and creates an enabling environment. This report, *Future Farming in India: A Playbook for Scaling Artificial Intelligence in Agriculture*, offers a roadmap for stakeholders to operationalize AI solutions at scale, making them accessible and impactful for farmers across India.

The need for an AI playbook

Effective deployment of AI for agriculture at scale faces significant obstacles, including fragmented infrastructure, limited access to high-quality data and affordability concerns for smallholder farmers. These challenges highlight the need for a clear and well-defined framework to guide the development of an AI ecosystem in agriculture. This playbook is designed to help policy-makers strategize and provide achievable insights and practical recommendations to scale the use of AI in agriculture.

The AI for agriculture playbook has four main purposes:

01

To offer an overview of potential AI use cases and applications in agriculture and how they can be operationalized

02

To present a structured framework based on three critical pillars – **enable**, **create** and **deliver** – with clear guidelines and actions for stakeholders

03

To provide a call to action that leads to a dynamic platform outlining the next steps

04

To align AI strategies with ongoing initiatives in India, such as the IndiaAI Mission (MeitY), Agri Stack and state-led AI programmes

While the playbook's primary audience is policy-makers, it is also designed to assist private-sector agribusinesses, agritech start-ups and development organizations in integrating AI into their strategies.

Methodology

To create a practical and context-sensitive playbook, the World Economic Forum, under the guidance of the AI for India 2030 Advisory Council, constituted a multistakeholder expert group. This group included agronomists, agricultural technologists, policy-makers and agribusiness leaders, ensuring a comprehensive range of perspectives.

The methodology for developing the playbook involved **three key steps**:

– **Design thinking-driven research** to identify innovative AI-based solutions for recurring agricultural challenges

– **Expert consultations** through in-depth interviews, to understand the primary challenges faced by smallholder farmers

– **Contextual analysis** to align AI solutions with the specific needs of Indian agriculture, factoring in constraints such as small landholdings, fragmented supply chains and climate variability

This **multistakeholder approach** provided a bottom-up perspective, integrating expert insights with the realities on the ground, resulting in a practical and achievable framework for building an AI-driven agricultural ecosystem.

Framework: principles and pillars

The **IMPACT AI framework** offers a structured approach to scaling AI in agriculture, aligning stakeholder efforts around three core pillars: **enable**, **create** and **deliver**. Guided by the principles of prioritizing public interest and safety, adopting risk-based regulation and building trust through transparent validation, the framework ensures inclusivity, sustainability and meaningful impact.

BOX 1 **Three-pillar framework for developing AI ecosystems in agriculture**

The **enable** pillar is anchored in the role of **governments** as primary stakeholders in establishing foundational systems for AI integration. Governments must develop clear strategies that reflect regional agricultural needs while fostering scalability and inclusivity. This involves crafting supportive policies to guide AI procurement, incentivize innovation and ensure data sharing across platforms. Central to this pillar is the creation of robust data infrastructure to aggregate and standardize agricultural data, enabling innovation and equitable access for all stakeholders.

The **create** pillar focuses on driving innovation, where **start-ups and innovators** play a key role. Collaboration is critical here, as these stakeholders must co-develop AI solutions with research institutions, using domain expertise to address real-world agricultural challenges. Validating solutions is equally important: pilots and controlled testing ensure AI applications are scalable, reliable and contextually relevant, laying the foundation for broader adoption.

The **deliver** pillar ensures that AI solutions reach the last mile, with **extension systems and farmer networks** as central actors. Strengthening these systems involves training extension workers to integrate AI tools into their advisory roles, ensuring farmers receive achievable insights. Additionally, establishing feedback loops enables ongoing refinement of AI solutions, making them adaptive to farmers' needs and challenges.

Together, these pillars provide a comprehensive roadmap for building an AI-driven agricultural ecosystem, transforming challenges into opportunities through collaboration and innovation.

Call to action

This playbook serves as a practical guide for stakeholders to collaboratively harness the transformative potential of AI in agriculture **Governments** must take the lead in creating enabling environments by forming multistakeholder expert groups, crafting AI strategies and establishing frameworks for governance, incentives and data sharing. **Start-ups and the AI industry** are key drivers of innovation, tasked with developing scalable AI solutions, validating them through sandboxes, and integrating products into accessible marketplaces. **Academia and research institutions** must support these efforts through applied research, mentoring and creating frameworks for ethical AI deployment.

By aligning these efforts, stakeholders can foster an inclusive and scalable AI ecosystem that empowers farmers, drives innovation and transforms agriculture into a resilient and sustainable sector. This is a call for coordinated action to ensure that AI's benefits reach every farmer and stakeholder, laying the groundwork for a smarter, more equitable future.

Telangana is committed to harnessing AI to empower our farmers and transform agriculture. The Future Farming Playbook emphasizes farmer-centric solutions backed by strong policies, affordable technology and robust data-sharing frameworks – paving the way for sustainable growth.

Jayesh Ranjan, Special Chief Secretary for Information Technology, Electronics & Communications (ITE&C), Government of Telangana

The Future Farming Playbook provides a strategic roadmap for leveraging AI to drive efficiency in agriculture. We see this as a game-changer – empowering farmers with smarter decisions, reduced risks and higher yields. This initiative marks a crucial step towards the future of farming.

Mohit Kapoor, Group Chief Technology Officer, Mahindra Group

Developed in collaboration with BCG X, the Future Farming Playbook will revolutionize agriculture – from soil to marketplace – making it more intelligent, adaptive and resilient. To realize this vision, we must foster an AI ecosystem that drives innovation, ensures accessibility and promotes responsible adoption across India's agricultural landscape.

Gaurav Jindal, Managing Director and Partner, BCG X

Introduction

AI promises to be a catalyst for transformation that will redefine industries and companies across the world.

The potential of AI in agriculture

The global AI market, valued at $136 billion in 2022, is projected to grow more than 13 times in just eight years, reaching $1.8 trillion by 2030.[1] In agriculture, as in other sectors, AI's growing use has started delivering results, including in emerging countries in the Global South. For instance, a recent pilot project in Telangana (Saagu Bagu),[2] conducted in collaboration with the World Economic Forum and the Government of Telangana, provided four AI-enabled applications to around 7,000 chilli-growing smallholder farmers.[3] After just one season, the farmers reported a 21% improvement in yields, an 11% increase in the unit prices their produce commanded and a 9% reduction in the fertilizers and pesticides they needed to use. Consequently, these farmers were able to significantly boost their net profits, earning an average of $800 more per acre per crop season – an impressive increase considering Indian farmers' average annual income is less than $1,500.[4] AI-based sowing advice has proven transformative in the Indian state of Andhra Pradesh, helping farmers boost yields by up to 30%. Similarly, AI-enabled pest-detection models have empowered around 3,000 farmers in the state to forecast and address pest infestations proactively.[5]

Global AI trends: A growing opportunity

$1.8 trillion

Expected global market size for AI by 2030

40%

Growth rate of AI markets in India between 2020 and 2025

1,500

Estimated number of agritech start-ups in India

$65 billion

Estimated value potential unlocked in India by investing in 15 foundational agricultural datasets

> AI creates opportunities for farmers to enhance their resilience, productivity and profitability.

By delivering data-driven predictions and augmenting traditional farming, AI creates opportunities for farmers to enhance their resilience, productivity and profitability. For instance, precision agricultural solutions address farmers' resource constraints by offering best practices to maximize output with optimized input. Similarly, predictive analytics reduce climate vulnerability by providing weather forecasts and helping to manage pest infestations before they scale. Furthermore, AI-enabled market intelligence systems help alleviate the economic pressures faced by farmers, such as rising input costs or fluctuating market prices, by bridging information gaps and providing timely, data-driven insights for better decision-making. Additionally, at a macro level, AI has the potential to curb emissions from the agricultural sector by optimizing resource use to allow economies to reach their net-zero goals, while also enhancing agricultural GDP.

In the Indian context, use cases for AI in agriculture can help address systemic challenges in agriculture such as lower productivity in certain crops compared to global averages, restricted finance for smallholder farmers, increasing soil-degradation and high pre- and post-harvest losses. If implemented at scale, AI could be a critical tool to boost the agricultural sector's contribution to GDP, which is currently at 18% while employing close to 46% of the country's population.[6]

While the AI-driven transformation of agriculture may have begun, deploying technology at scale is not easy. Its use is still limited in agriculture: according to experts, fewer than 20% of Indian farmers use digital technologies, which are a superset of AI-enabled solutions. There are several reasons for this low rate of adoption. For instance, the low income of Indian farmers (around $1,500 annually)[7] restricts both their ability and willingness to pay for AI solutions. Without financing support, technology interventions are perceived to be an added burden, given the already increasing cost of cultivation. Additionally, close to 85% of India's 150 million farmers are smallholders and the Indian farmer's average landholding is just 1.08 hectares (about 2.67 acres). With such small landholdings, which are often fragmented, the cost of delivering AI solutions in rural settings increases tremendously. This pivots solution providers to focus primarily on larger farmers or businesses. On the supply side, the development and use of AI solutions relies on the collection of large volumes of data, often in real time, which needs investment in infrastructure and resources, and this drives up the cost of AI development. This indirectly increases the cost of services, further affecting their affordability. Additionally, there are very limited institutional mechanisms for validating technology before it is deployed, increasing the perceived risk of adoption.

The need for an AI playbook

> This playbook intends to be the first step in supporting policy-makers in strategizing approaches to scale the use of AI in their jurisdictions.

AI's potential to tackle agriculture's complex challenges combined with the many obstacles in deploying the technology together underscore the need for a clear and well-defined framework to develop an AI ecosystem for agriculture. This playbook intends to be the first step in supporting policy-makers in strategizing approaches to scale the use of AI in their jurisdictions.

This AI for agriculture playbook has three purposes:

1. To provide an overview of potential AI use cases for agriculture that can be operationalized
2. To illustrate a structured framework on the critical pillars (enable, create and deliver) with clear actions and guidelines for stakeholders
3. To lead the way to a call for action and provide a dynamic platform to explore what's next

The playbook's primary target audience is policy-makers, but it will help other stakeholders as well. Among them are the private-sector agribusinesses that serve farmers; agritech start-ups that develop AI-based solutions for agriculture; and development organizations designing technology programmes for farmers and extension systems.

Importantly, this playbook has been carefully designed to complement the many AI-related initiatives already under way in India including IndiaAI Mission[8] undertaken by MeitY (Ministry of Electronics and IT), Ministry of Agriculture's Agri Stack[9] and Vistaar[10] and AI initiatives (e.g. Telangana AI Mission[11] and Karnataka's AI COEs[12]) and pilots set up by various state governments.

Methodology

To explore how AI can provide solutions for farmers' recurring problems, a multistakeholder expert group (see Appendix 1) was constituted by the World Economic Forum under the guidance of the AI for India 2030 Advisory Council (see Appendix 2). The group used design thinking-driven research and conducted in-depth interviews with around 20 experts in India, including farmers, agronomists, agricultural technologists, policy-makers and agribusiness leaders, who offered a wide range of insightful perspectives. These interviews allowed the group to revisit the major problems that Indian farmers, particularly small farmers, face nowadays. Next, group members studied how AI could address those specific challenges, keeping in mind Indian agriculture's unique characteristics. By grounding analysis in the first-hand experiences and well-reasoned opinions of experts, the group was able to develop a detailed, bottom-up understanding of AI's potential to transform agriculture.

Challenges in Indian agriculture: The need for AI enablement

$1,500

Average annual income of farming households in India

52%

Proportion of farmers in India who are in debt

30%

Proportion of India's land that is degraded

10–40%

Expected decrease in key crop yields in India by 2080 due to climate change

1 Understanding stakeholders' AI aspirations at first hand

This section explores first-hand insights from key stakeholders on AI's role in agriculture, its challenges and its transformative potential.

The interviews conducted for this report offered valuable insights into the challenges currently faced by farmers and highlighted potential AI applications to address them. Before examining specific use cases, it is crucial to understand the perspectives of five key stakeholder groups – start-ups and the tech industry; the agribusiness industry; farmers and farmer cooperatives; government policy leaders; and academia – regarding AI in agriculture. These opinions, captured through multiple stakeholder interviews, have been edited and synthesized to present a cohesive perspective.

This perspective will serve as a guide to help stakeholders design and develop an AI ecosystem tailored to the unique needs of agriculture.

Start-ups and the tech industry

Farmers want to watch YouTube, not use Google. They often don't like to read

Farmers interact with technology differently from urban users. They're more likely to watch YouTube than search on Google, which makes voice-based technology far more effective in reaching them. User-friendly designs and patient capital are needed for AI to take root in agriculture. If AI solutions were designed with simple visual and voice-driven interfaces, farmers could start using them without needing much digital literacy.

Fear of missing out prevents farmers from realizing their full potential

Indian farmers are often reluctant to trust AI because it goes against traditional practices or what neighbouring farmers are doing. This creates a fear of missing out on tried-and-tested methods, making it hard to adopt innovative technologies. The result is poor coordination, especially during harvest season, when oversupply drives down prices. If AI could prove its value through small-scale demonstrations on farms and show results, it would help overcome farmers' hesitation.

Agribusiness industry

Farmers' lack of access to quality data leads to limited global market access for their produce

In India, the focus is largely on quantity, driven by minimum support prices, rather than on quality that meets global standards. Farmers prioritize producing government-backed crops that guarantee sales regardless of quality, which makes it difficult for us to source the high-quality produce needed for international markets. If only AI could connect local farmers to global demand for high-quality produce, it would transform agriculture in India.

When farmers cut out intermediaries, they also shrink the value they can realize

In India, farmers rely on intermediaries to handle crucial tasks such as pricing and grading, which adds value to products. While replacing intermediaries might seem beneficial, it could reduce the value farmers capture as they typically lack the resources to handle these additional responsibilities. If AI could provide real-time market data and pricing insights directly to farmers, it would allow them to negotiate better with intermediaries while maintaining the intermediaries' offers.

Farmers and farmer cooperatives

Farm producer organizations (FPOs) exist in India, but farm sector leaders are unaware of their potential

> We have (set up) farmer producer groups, but we still don't fully understand how AI can help us. We're missing out on opportunities that could improve efficiency and income for small farmers. If AI could show us how to use data to better manage our resources, negotiate prices and understand market trends, our FPOs would become a lot more efficient, making a bigger difference.

Farmers need curated wisdom, not clutter from the internet

> Today, even if farmers go online looking for advice, they are almost immediately inundated with 20–30 different information sources, from YouTube videos to apps from big companies. There is anxiety around which of these sources to trust. Even if they can get over this anxiety and pick a source, they are further restricted by the generic nature of the advice they are going to receive – these platforms can speak in general terms, but farmers need advice that accounts for local circumstances.

Goverment policy leaders

Yesterday's successes outweigh tomorrow's forecasts for India's farmers

> Farmers tend to make reactive decisions, often choosing crops based on past successes rather than future forecasts. This approach overlooks crucial factors such as soil health, water availability and market supply variations, leading to inconsistent results and missed opportunities for maximizing profits. If AI could provide forward-looking, data-driven insights, it would shift farmers from reactive to proactive decision-making.

Farmers can time sowing, but they can't time their demand for labour

> Farmers know the best times to sow their crops, but labour availability remains a major obstacle. With more people migrating to cities, rural areas are facing severe labour shortages, and farmers have little visibility of available labour beyond their own villages or districts. If AI could match farmers with the available labour across regions, it would be a game changer.

Academia

Fields of data abound, but the incompatibility of data sources limits their use

If AI could help digitize and standardize our historical agricultural data, it would unlock immense opportunities. Tools such as Gen AI and image recognition could digitalize our archives, while synthetic datasets could bridge the gaps between incompatible data sources. By creating a unified format for agricultural data, AI could provide more accurate predictions and personalized recommendations, enhancing the value of our research for farmers across India.

Agriculture R&D keeps leaping forward in India, but farmers only fall back

The research we conduct in universities could greatly benefit farmers, but there's often a significant lag in getting that knowledge to the field. Despite efforts, the time it takes to share our discoveries means farmers miss out on timely solutions and innovations. If AI could bridge the gap between research labs and the field, we could ensure that farmers access the latest scientific advances much faster. A Gen AI-powered system could simplify and disseminate research findings in real time, translating complex data into achievable advice for farmers.

2 Exploring promising AI applications for agriculture

AI applications in agriculture are being piloted and adopted globally, transforming farming practices in developed and developing nations.

2.1 Potential use cases

The World Economic Forum's AI4AI Framework has identified close to 30 use cases spanning all three stages of the agriculture value chain: **intelligent crop planning, smart farming and farm-to-fork solutions**. These use cases highlight the diverse ways in which AI can optimize agricultural productivity, sustainability and market connectivity.

The report's authors analysed these use cases and rigorously tested their feasibility in the Indian context through expert consultations. This process shortlisted several promising AI use cases for agriculture, four of which are described in detail in this section to illustrate their process flows and key enablers.

The analysis also identifies the foundational datasets required for each use case and outlines a roadmap for operationalizing these AI applications by 2030.

It is important to note that the use cases presented here are indicative; any effort to prioritize use cases must be tailored to specific needs and localized context.

FIGURE 1 **Use cases identified using the World Economic Forum's AI4AI report**

	Intelligent crop planning	Smart farming	Farm-to-fork
Frameworks	Macro crop-planning models Micro crop-planning models	Smart F-a-a-S Integrated nutrient management Crop health management	Market intelligence Quality and traceability Logistics
Use cases/pilots	Varietal advice Extension planning Credit planning Macro irrigation planning Policy/incentive planning Inputs planning Sowing windows, sowing potential, sowing progress	Mechanization of farms Smart micro-irrigation SHC – rapid soil analysis Pest prediction Hyperlocal weather advice Smart insurance Yield prediction Crop input advisory and e-marketplace	Quality and traceability Supply-chain optimization Fintech, Electronic National Agriculture Market (eNWR) Warehousing supply cold chain Market linkage demand and price prediction

Notes: See *Artificial Intelligence for Agriculture Innovation*

FIGURE 2 **Four use cases detailed in the playbook**

Macro crop planning

Solutions that allow government stakeholders and private-sector enterprises to recommend crops based on historic data, climate risks and global market trends.

Rapid soil-health analysis

Solutions that provide a quick assessment of soil-health parameters, enabling farmers to choose which crops to grow, and aiding nutrient processes during the production phases.

AI-enabled pest prediction/control

Solutions that enable farmers and other stakeholders to forecast pest attacks in advance and manage ongoing pest attacks efficiently.

Smart marketplaces

Solutions that connect farmers and traders through e-marketplaces while digitizing quality and quantity assaying, eliminating information asymmetry.

2.1.1 AI-enabled crop planning

The context

In India, crop planning is typically reactive and driven by last season's prices at an individual farm level, often resulting in cycles of gluts and shortages. This reactive approach contributes to price volatility, which increases the risks associated with agricultural investments.

In contrast, AI-enabled crop planning uses a wide range of farm and non-farm data – such as soil health, weather patterns, historical prices and food import/export trends – to recommend optimal crops for farmers in various regions. This data-driven strategy aligns production with market demand, minimizing price fluctuations and mitigating the risks of overproduction and underproduction.

FIGURE 3 **A shift from reactive to AI-enabled crop planning**

CASE STUDY 1

Price volatility in India

There have been several times when the oversupply of tomatoes and onions has led to price volatility in India. For instance, tomato prices in the wholesale market surged over 300% between June and July 2023 from $0.35 per kilogram to more than $1.29 per kilogram.[13] In contrast, onion prices experienced a 32% drop in December 2023[14] due to early harvesting and oversupply, which was further exacerbated by unseasonal rainfall. These fluctuations are driven by supply gluts during harvest periods, leading to distress selling and scarcity in lean months, which forces prices higher. Similar supply gluts can potentially be addressed through AI-enabled predictive crop planning.

Enabling datasets

Several datasets are needed for macro crop planning, as depicted below.

FIGURE 4 **Enabling datasets required for macro crop planning**

Crop-suitability data based on agroclimatic zones

Creation of national database of crops suitable for different agroclimatic zones, if possible with granularity to district level.

Global and local pricing data zones

Includes data (historic and current) on the market prices of different crops in different geographical areas and export markets to identify crops that may be most lucrative to grow.

Market glut and shortage data

Includes data on past market gluts and shortages to correlate with other datasets in order to forecast such imbalances and reduce pricing risk.

Strategic crop data

Includes data on strategic crops for different state governments and national governments. For instance, could include crops that are prioritized for import substitution.

Land records and farm demographic data

Includes farm-level data on land records, farm income (projections or estimates) and cropping patterns to understand the suitability of a farmer planting recommended crops.

Climate and weather data

Includes climate forecast for cropping season, such as details about rainfall, precipitation, humidity, sunlight, temperature and wind at the district level.

Indicative roadmap for operationalizing macro crop-planning models

AI-enabled macro crop planning is a novel concept, especially in India, so a staggered approach should be followed while deploying the use case. Crop planning should be based initially on models that draw on crop-suitability data followed by adding additional layers of market intelligence data and climate-risk data.

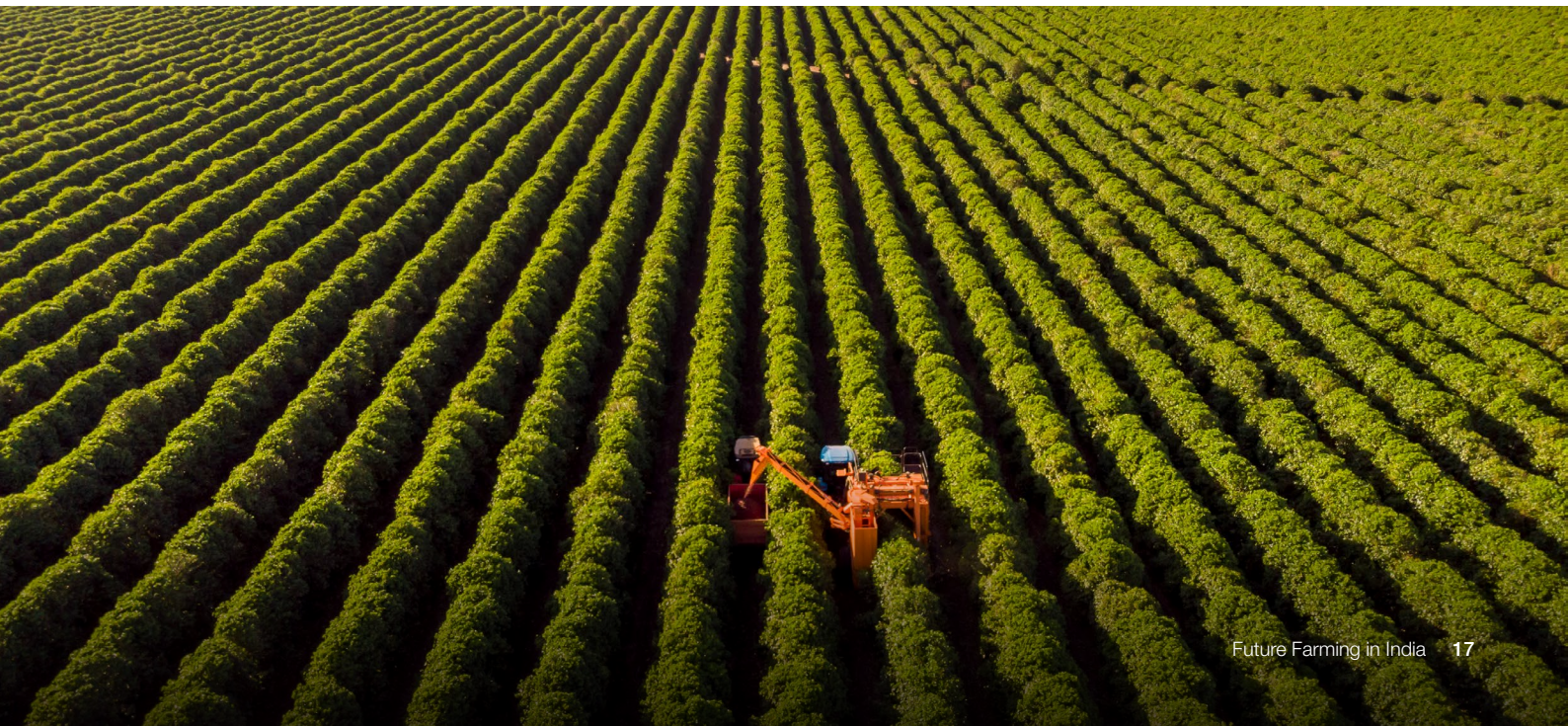


TABLE 1 | **Indicative roadmap for operationalizing AI-enabled crop planning**

	Outputs at end of step	Role of government	Other critical stakeholders
1 **Develop strategy and aggregate data** 	– Strategic plan – Documented data needs – Aggregated foundational datasets – Expert group – Pilot scope	– Lead strategy – Formulate expert group – Aggregate datasets – Finalize scope of pilots	– **Expert group:** advise on best practices – **Agricultural research institutions:** share existing datasets – **Agricorporates:** provide data on historic and demand/ procurement prices
2 **Develop AI crop-planning model** 	– Onboarded agency for developing AI model – Predictive models on crop recommendations based on viability/feasibility	– Onboard AI model developer – Set data privacy standards – Initiate sandbox for validation and governance	– **AI model-developer:** develop models – **Agricultural research institutions:** support testing of crop recommendation models through sandboxes and real-time data
3 **Generate regional crop plans** 	– Actionable crop recommendations at a regional level based on AI model	– Review regional crop plans through a federated structure, including local and national experts	– **Agricultural research institutions:** generate package of practices for recommended crops
4 **Deliver recommended crop plan** 	– Package of practices for recommended crops – Delivery plan for package of practices to farmers	– Train extension staff to deliver services – Design financial incentives for adoption	– **Agritechs, extension agents and FPOs:** disseminate recommendations and package of practices – **Agricorporates:** ensure availability of inputs
5 **Increase adoption and collect feedback** 	– Adoption by farmers – Feedback mechanism for continuous improvement of model	– Deliver extension through channels such as SMS, radio, extension staff and government institutes	– **AI model developers:** continuously improve model – **Agritechs, extension agents and FPOs:** support adoption within their network of farmers

2.1.2 AI-enabled rapid soil-health analysis

> As of 2021, 97.85 million hectares of land in India has been degraded,[15] a considerable proportion of which is agricultural land. The United Nations Food and Agriculture Organization warns that by 2050, 90% of the Earth's topsoil is likely to be at risk.[16]

The context

Soil health testing in India has become critical because of soil degradation[17] and the associated decline in yield. But traditionally, soil testing in India is time-consuming, requiring physical sampling and laboratory work. Additionally, India has only about 8,000 soil-testing labs to serve a farming population of approximately 150 million. It can be relatively expensive, too, so farmers often rely on

the blanket use of fertilizers, sometimes with the notion that **"more is good"**. In contrast, AI-enabled rapid soil analysis uses spectroscopy to study soil characteristics such as composition, nutrient availability, water retention capability and alkalinity. Rapid and on-site soil monitoring provides instant feedback on nutrient levels, moisture and soil acidity, helping to prevent the overuse of chemical inputs. Testing can also help optimize fertilizer use and provide crop rotation guidance to restore soil fertility.

Enabling datasets

The government must establish a centralized database that consolidates soil-health data from various sources and makes it accessible to researchers, policy-makers and digital start-ups aiming to develop AI-driven applications. Creating such foundational datasets will significantly accelerate the development and deployment of effective AI models in agriculture.

FIGURE 5 **Transforming soil-health analysis and management using AI**

Current scenario

Today, nearly 30% of India's soil is degraded, posing significant challenges to agricultural productivity.

Farmers struggle to know the exact nutrient needs of their soil. They often follow general soil-nutrient recommendations that ignore specific needs, leading to nutrient imbalances, environmental harm, higher cultivation costs and lower incomes.

The absence of incentives for sustainable soil management discourages farmers from adopting regenerative practices, leaving soil health to decline and threatening future food security.

AI-enabled rapid soil-health analysis

Vision 2030

India has significantly reduced agricultural soil degradation by supporting farmers' efforts to optimize the use of fertilizers and follow regenerative crop planning.

Farmers use a spectroscopic device for real-time soil analysis, receiving instant insights into nutrients, organic matter or contaminants. The analysis offers fertilization and crop-rotation plans, helping to lower costs, boost yields and raise income.

India has national soil dashboards with real-time soil data. This has been coupled with soil-health credits that reward farmers for replenishing soil health. These have significantly improved the resilience of food systems, while providing additional income to farmers.

FIGURE 6 **Enabling datasets required for rapid soil-health analysis**

Farm-level soil data

Includes farm-level data on soil profiles (e.g. composition, texture, microbial activity, pH level, organic carbon).

Historical soil degradation and erosion data

Includes data on changes in soil quality over time at a jurisdictional level.

Historic nutrition and water management data

Includes historic data on fertilizers and irrigation processes that have been used.

Best practices and advisory from research institutions

Includes recommendations on cultivation practices/ crop selection for different soil characteristics to generate advisory.

Indicative roadmap for operationalizing AI-enabled rapid soil analysis

Existing agritech companies have models for AI-enabled soil-health analysis. The government could use existing players through public–private partnerships (PPPs). Additionally, aggregation of individual soil assessment results into a regional dashboard could aid soil management policy.

TABLE 2 **Indicative roadmap for operationalizing AI-enabled rapid soil-health analysis**

	Outputs at end of step	Role of government	Other critical stakeholders
1 **Establish soil-health management plan and expert group** 	– Soil-health management strategy/plan – Soil-health data standards – Expert group	– Develop a plan for soil-health assessment – Formulate an expert group – Institutionalize soil-health data standards	– **Expert group:** advise the government on data requirements, data standards and soil-health assessment strategy/plan
2 **Engage partners for rapid soil-health assessment and strengthen models** 	– Identified agritechs for AI-rapid soil assessment – PPP business model – Accurate soil testing	– Onboard technology partners and agritech – Aggregate data for training soil assessment models – Set up technical sandboxes	– **AI model-developer:** support evaluation of agritechs for PPPs – **Agricultural research institutions:** participate in government tenders and expressions of interest (EOIs); work with agritechs to improve models using real-time data through sandboxes
3 **Improve deployment of AI-enabled rapid soil-testing kits** 	– Deployment plan for soil-testing kits – Package of practices for segments of soil health	– Integrate AI in existing soil-testing labs – Deploy village-level entrepreneurs to support soil testing – Incentivize purchase of kits	– **Agricultural research institutions:** produce package of practices – **Agritechs**: create innovative business models to improve adoption (rent, pay-as-you-go) – **Agritechs, extension agents and FPOs:** support soil testing at individual farm level and provide package of practices
4 **Integrate soil-testing data into a regional dashboard** 	– Regional dashboard for soil health with geocoordinates of previous soil tests	– Engage implementation partners – Develop regional dashboard for real-time soil-health analysis	– **Agritechs, extension agents and FPOs:** ensure geotagging of soil samples tested via them – **Dashboard developer:** aggregate farm-level soil-test data to develop regional dashboard
5 **Refine models and recommendations based on real-time data** 	– Refined models based on ground data – New low-cost technology such as remote sensing	– Track adoption of soil testing and create infrastructure for improving models – Improve approaches to soil testing based on remote sensing	– **Agricultural research institutions:** use regional soil-health dashboards to continuously improve package of practices on soil rehabilitation

2.1.3 AI-enabled pest prediction and control

Around

40%

of the global crop production equivalent or close to $220 billion[18] is lost to pests annually. In 2015, it was highlighted that India lost almost $36 billion[19] to pest attacks.

The context

AI-enabled pest prediction uses historic data on climate and soil characteristics, together with other farm-level data, to create early warnings about high-potential pest attacks. Furthermore, these applications provide farmers with real-time recommendations to manage pest infestations, such as pest identification, risk scores of different farm locations, integrated pest management (IPM) practices and vendors. Such pest-management systems are critical for reducing economic losses[20] from pest attacks and building the resilience of India's agricultural sectors.

FIGURE 7 **Harnessing AI for early pest detection and control**

Current scenario

Climate change has led to more frequent and severe pest infestations in Indian agriculture. Estimates suggest that India loses $36 billion to pests.

Farmers lack timely pest-detection tools, forcing overuse of pesticides. This increases costs, leads to high pesticide residues and often results in market rejections, affecting income.

Extension channels often provide generic advice for pest management. Most of this advice is shared post-infestation.

AI-enabled pest prediction and control

Vision 2030

Governments have used AI to develop both predictive and reactive models for pest management. Recommendations from these models are shared in a timely manner by means of extension agents, rapidly building resilience to pest attacks.

Farmers upload an image of an infested crop and get real-time recommendations on pest management. This reduces pesticide use and costs, and allows farmers to meet the maximum residue level (MRL) standards of global buyers to achieve premium prices.

Extension agents provide early warnings on potential infestations, enabling precautionary action, along with specific hyperlocal advisory in case of infestations.

CASE STUDY 2

National pest-surveillance models[21]

Launched in August 2024, India's National Pest Surveillance System (NPSS) is an AI-powered platform designed to enhance pest management for farmers. The system will enable farmers to connect with agricultural experts through their mobile phones. By uploading images of pests or affected crops, farmers receive tailored pest-control advice based on real-time data. The platform aims to reduce farmers' dependence on pesticide retailers, promote scientific pest-management practices, and prevent pesticide misuse, ensuring sustainable farming.

Enabling datasets

The following foundational datasets are critical to train AI models for pest detection and control.

FIGURE 8 **Enabling datasets required for pest prediction and control**

Farm-level coordinates and soil data

Includes farm-level data on coordinates and soil profiles (e.g. composition, texture, microbial activity, pH levels, organic carbon).

Climate and weather data

Includes data on (historic and current) rainfall and other forms of precipitation, humidity, sunlight, temperature and wind at district level.

Best practices and advisory

Includes knowledge on pest-management practices for potential pests in different crops.

Historic pest-attack data

Includes historic data on pest incidence in different locations with clear time signatures.

Pest biology, behaviour and images

Includes repository of data on pests, including behaviour, feeding patterns and images.

Indicative roadmap for operationalizing AI-enabled pest prediction and control

The following steps outline how AI-enabled pest prediction and control systems can be deployed.

While many technology companies currently provide reactive insights for pest control, there is significant potential to develop and train models for proactive early-warning systems, enabling timely interventions and minimizing crop losses.

TABLE 3 **Indicative roadmap for operationalizing AI-enabled pest prediction and control**

	Outputs at end of step	Role of government	Other critical stakeholders
1 **Establish pest-management plan and expert group** 	– Expert group – Pest-management strategy – List of priority crops for different regions – Shortlisted regions for pilots	– Formulate an expert group – Develop a plan, including high-priority value chains and regions	– **Expert group:** advise the government on pest-management strategy, priority crops/regions
2 **Aggregate historic data on pest attacks for priority crops** 	– Comprehensive datasets on pest images, pest patterns, environment and farming practices across priority crops/regions	– Facilitate data collection/ exchange – Consolidate historic data on pest attacks through nodal departments	– **Agricultural research institutions:** provide historic data on pest attacks and practices for pest management
3 **Empanel technology providers for developing pest-management advisory** 	– AI-driven system that can accurately predict pest outbreaks and improve models	– Empanel technology companies that have pest-management systems – Set up technical sandboxes to improve models	– **Agritechs:** participate in government tenders and expressions of interest (EOIs) – **Expert group:** evaluate agritechs for PPPs – **Agricultural research institutions:** improve models and provide recommendations
4 **Deliver pest-management advisory** 	– Pest-management practices integrated with AI models – Trained extension workers, recommendations to farmers	– Deliver pest-management recommendations on a timely basis through government extension channels	– **Agritechs, extension agents and FPOs:** deliver pest predictions and pest-management advisory
5 **Promote adoption and use aggregated data to develop early-warning system** 	– Region-wide deployment – Continuous monitoring and model refinement – Early-warning system for key pests	– Track adoption of pest-management systems and develop feedback loops for improving model strengths and accuracy – Develop early-warning system	– **Agricultural research institutions:** continuously engage in research and development (R&D) to develop effective pest-management approaches – **Agritechs:** ground truthing to develop accurate predictive models for early-warning systems

2.1.4 AI-enabled smart marketplaces

The context

AI-enabled smart marketplaces are digital platforms that use historic data to provide adaptive price forecasts to producers and aggregators. They are enabled by internet of things (IoT) hardware at aggregation points to accurately measure quantity/quality in seconds. Such marketplaces help farmers eliminate information gaps that create uncertainty about demand, supply and prices, which prevents them from selling to the most remunerative markets.

By directly connecting sellers with buyers, these marketplaces also reduce farmers' reliance on intermediaries. Moreover, when farmers need bridge financing to pay off creditors, meet household expenses and defray transport and warehousing costs, they can tap institutional finance providers through the platform. These marketplaces will also help buyers discover production volumes that meet their quality criteria with ease.

FIGURE 9 **Empowering farmers with AI-enabled smart marketplaces**

Current scenario

Policy-makers struggle to promote demand-driven production without reliable data on buyer requirements.

Without reliable price forecasts or buyer insights, many are forced into distress selling. They are also apprehensive about getting the right prices as quality/quantity assessments are cumbersome.

Financial institutions are hesitant to extend capital to producers and FPOs due to limited visibility on market trends, leading to a dearth of working capital.

Due to a lack of traceability systems, buyers focus on other countries for procurement, and farmers miss out on price premiums for following sustainable practices.

AI-enabled smart e-marketplaces

Vision 2030

Using historic buyer requirements for different crops, policy-makers launch incentives to promote demand-driven production that meets market interests.

Farmers receive market forecasts with lists of buyers, allowing them to harvest at the optimum time. There are no fears of misassessments in quality and quantity as they are measured through state-of-the-art AI-enabled assaying equipment that generates results in minutes.

The transparent mapping of market orders allows financial institutions to provide low-interest financing to cultivators as working capital.

Traceability systems allow the produce to be traced back to farmers, and buyers reward them with a premium for following sustainable agricultural practices.

CASE STUDY 3

AI-enabled quality assaying

Agnext's IoT hardware significantly improves the prices farmers receive by ensuring that produce is accurately assessed for quality, leading to better market prices. By using their AI-driven quality-assessment tools, farmers can secure higher prices for their crops compared to traditional methods where quality assessments are less reliable. In some cases, improved quality grading and traceability can result in increased premiums, especially when the produce meets sustainability standards.

Enabling datasets

The following foundational datasets are critical for developing smart marketplaces.

FIGURE 10 **Enabling datasets required for developing smart marketplaces**

Farm records and production data

Includes high-resolution images to identify farm boundaries, production patterns and expected yields.

Real-time and historic market data

Includes real-time statistics on market prices and arrivals for different crop varieties from commodity trades, along with historic prices across different markets.

Buyer preference data

Includes historic trends and expected quality requirements of different buyers (>60% of market size) for different crops.

Hyperlocal and weather data

Includes climate details such as rainfall and other forms of precipitation, humidity, sunlight, temperature and wind at the district level.

Geospatial and agricultural market data

Includes geospatial data on the network of agricultural markets by location and crop type. Also includes data on post-harvest infrastructure.

Indicative roadmap for operationalizing AI-enabled smart marketplaces

The graphic below outlines the essential steps for developing smart marketplaces. Existing e-markets in India, such as e-NAM, could use AI to provide price forecasts and efficiently match sellers with buyers. Additionally, physical market infrastructure (mandis) can be enhanced with AI-driven quality-assaying tools to ensure fair pricing and improve market transparency.

TABLE 4 **Indicative roadmap for operationalizing AI-enabled smart marketplaces**

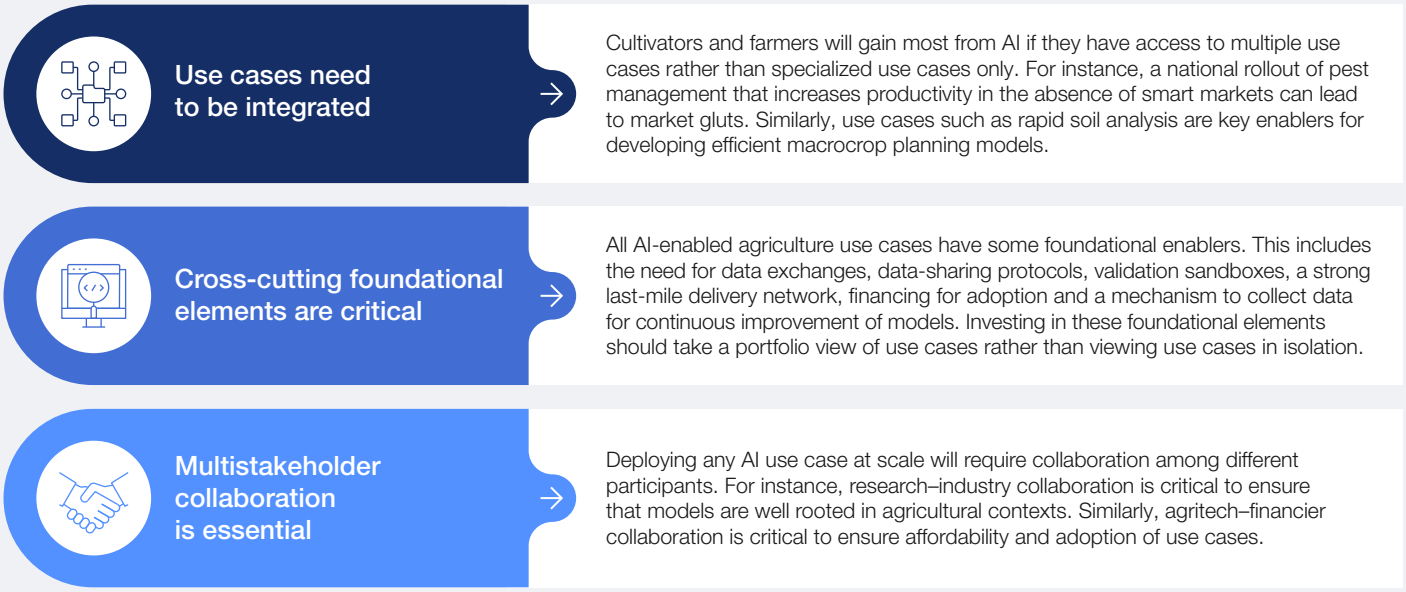
	Outputs at end of step	Role of government	Other critical stakeholders
1 **Strategic planning and market-mapping**	– Expert group – Smart marketplace strategy with priority regions and value chains – Mapping of markets in priority regions	– Formulate expert group – Develop a plan for smart marketplaces that prioritizes regions – Consolidate data on existing government post-harvest infrastructure and market prices	– **Expert group:** assess strategy, data needs, priority value chains/regions – **Agricultural research institutions:** supply information on existing market infrastructure in priority regions
2 **Develop AI model for price forecasting and buyer matchmaking**	– AI-driven models for prediction of market prices – AI-driven models for matching farmers/their collectives with potential buyers	– Onboard a technology company to develop AI models for price forecasts and buyer matchmaking – Integrate with existing markets such as e-NAM	– **AI-model developer:** develop price forecast and buyer matchmaking models and integrate with traceability systems – **Agricultural research institutions:** provide technical support to start-ups to enable them to enhance their models – **Agricorporates:** empanel in buyer/seller matchmaking pilots and provide historic data on demand, prices and volumes – **Extension agents and FPOs:** support quality adherence and aggregation of produce to meet buyer requirements and last-mile data collection
3 **Deploy e-market and national traceability system**	– E-market (either integrated with existing market or new) – National traceability system that maps products from farm to markets	– Develop an e-marketplace and integrate price forecasts and buyer matchmaking – Develop a national traceability system for priority crops – Train extension agents for collection of data for feeding traceability systems	
4 **Deploy quality-assaying infrastructure in priority aggregation points**	– AI-enabled quality-assaying systems across aggregation points or markets	– Provide incentives for deploying AI-enabled quality-assaying infrastructure in mandis and other aggregation points	– **Agritechs, extension agents and FPOs:** deploy quality-assaying hardware across aggregation points – **Agricorporates:** incentivize high-quality production through price premiums
5 **Incentivize demand-driven production**	– Incentive mechanisms to support farmers transition to demand-driven farming	– Develop incentives and working capital finance structures to support farmers in transitioning to demand-driven crop production	– **Agritechs, extensions:** ensure aggregation of produce – **Agricultural research institutions:** develop package of practices and customized recommendations – **Agricorporates:** invest in supply chains to ensure quality standards are met by producers

2.2 Lessons learned from AI use cases

Working with AI programmes for agriculture has highlighted critical lessons that foreground the need for a framework to develop AI ecosystems.

In light of these lessons, Section 3 describes a multistakeholder framework for scaling the use of AI for agriculture.

FIGURE 11 **Three key lessons learned from AI use cases in agriculture**



3 Framework for developing AI ecosystems

The AI landscape is evolving rapidly because of a sudden flurry of activity by the major players in the business such as governments, start-ups, digital giants, businesses and academia.

3.1 Introducing the IMPACT AI framework

“ There is a need to tread a middle path that will allow society to harvest AI’s benefits while preventing the downsides.

The world is experiencing an “AI rush”. AI is presumed to be a panacea for everything, leading to the belief that it is a universal solution. Left uncoordinated, development and deployment efforts, and the enthusiasm surging around AI, are likely to hurt, rather than benefit, society and eventually slow down the AI industry’s growth.

Attempts to regulate AI prematurely will thwart innovation, but a laissez-faire situation does not augur well, either. There is a need to tread a middle path that will allow society to harvest AI’s benefits while preventing the downsides.

The golden mean is a framework that harmonizes the major stakeholders’ interests as well as their concerns.

This report presents the Inclusive Multistakeholder Pathway for the Accelerated Convergence of AI Technologies (IMPACT AI) Framework.

Using the IMPACT AI framework will result in several benefits including:

1. It will accelerate both the speed-to-market and the speed-to-benefit. AI innovators and users will achieve results more quickly due to the synergies created by the framework.
2. It will establish a multistakeholder environment conducive to both competition and collaboration, with AI innovators cooperating with each other at the development stage while competing fiercely in the marketplace.
3. It will increase the demand for AI solutions, enabling the creation of markets where none currently exists. As a result, all AI players will get a larger piece of the fast-growing pie.
4. It will de-hype the AI market and rightsize expectations by demonstrating the real nature and size of AI’s benefits through use cases.
5. It will provide a mechanism to balance the demand for and the supply of AI applications.

3.2 Objectives of the framework

IMPACT AI will guide all stakeholders to unify their efforts to achieve a common goal: AI for all. It will spur those engaged to take action and play a positive role in AI’s development and deployment. It will also accelerate the responsible development and deployment of AI at scale.

3.3 Principles of the IMPACT AI framework

The success of the **IMPACT AI framework** depends on a set of guiding principles that bind all stakeholders in the AI ecosystem to ensure responsible development and deployment of AI technologies. The key principles are:

1. **Prioritizing public interest and safety:** Public welfare must take precedence in all AI-related decisions. The **do no harm** principle should guide design and development choices.

2. **Adopting a risk-based regulatory approach:** Regulations should be designed based on risk levels, with self-regulation as the standard except in sensitive areas where stricter oversight is required.

3. **Facilitating the AI ecosystem:** Governments will act as enablers by enacting supportive legislation, implementing policies, providing data access and ensuring a level playing field for all participants.

4. **Creating catalysts for AI adoption:** Governments will drive the adoption of AI by executing flagship projects in critical social sectors and implementing AI-powered social protection initiatives for public benefit.

Additionally, **a transparent, rigorous and effective testing and validation system** must be developed to establish trust and promote the growth of a credible AI marketplace.

3.4 Pillars of the framework

The IMPACT AI model is a multistakeholder initiative, with three distinguishable streams: enable, create and deliver.

Each will have a principal actor (the de facto leader) and one or more supporting actors. The three streams will run in parallel, although there are dependencies between them, as the following discussion shows.

FIGURE 12 | **Three-pillared IMPACT AI framework for developing AI ecosystems in agriculture**

Create

AI products, models, solutions

AI industry/start-ups

- Develop innovative AI products, models and solutions
- AI solution certification and validation prior to scaling
- Collaborate with academia
- Support pilots and showcases
- Cooperate to develop markets, specifications and standards

Governments

- Provide access to data
- Establish AI sandbox
- Provide computational power on subsidy
- Offer collaboration platforms

Enable

Accelerated evolution of AI ecosystem

Governments

Formulate

- AI strategy for the country, state and skills programme
- Enabling digital public infrastructure for AI (data exchanges and data-sharing policy frameworks)
- Enabling policies for procurement
- AI regulations to establish guardrails

Establish market access

- AI for public good (e.g. health, education, social protection)

Academia

Research

- Standards
- Policy

- AI upskilling and reskilling
- Mentor start-ups, platforms and accelerators

Deliver

AI services and integration

Last-mile ecosystem + AI industry start-ups

- Empowering front-line extension systems
- Feedback loops for strengthening AI
- AI marketplace and digital gateway
- Conform to regulations, self-regulate and co-develop risk-assessment framework

Governments

- Create awarness
- Establish consumer forum

Consumers

- Assess user experience
- Give feedback

Principal actor Sub-actor

Pillar 1

Enable

The **enable** stream forms the fertile soil for AI to grow, flourish and bear fruits. It creates an environment conducive to the innovation of AI solutions and their deployment at scale – whether at national or state scale. While a few other enablers exist, the model identifies the major ones.

FIGURE 13 **Enable pillar of the IMPACT AI framework**

> The enable stream forms the fertile soil for AI to grow, flourish and bear fruits.

Develop a strategy

Governments – federal and provincial – can best begin their AI journey by developing an AI strategy appropriate for the promotion of responsible AI. The strategy should reflect the way AI is used given the needs, resources and capabilities of that geographical area. Examples are the AI strategies of Singapore,[22] the UK[23] and Canada,[24] and the UP Digital Agriculture policy.[25]

Deploy contextual policies

The strategy must be closely followed by a set of clear and achievable policies, including those relating to procurement of AI solutions by public agencies, financial incentives and responsible data-sharing by public agencies. Without these policies there is uncertainty and indecision.

1. **Enabling procurement policies and market access:** Developing clear guidelines for the procurement of AI solutions by government agencies can streamline the adoption process. AI Procurement in a Box guidelines on government AI procurement (published by the World Economic Forum) provide guidance for public-sector agencies on procuring AI solutions.

2. **Financial incentives:** Offering financial incentives and support to farmers through cooperatives can encourage the adoption of AI technologies. Implementing the digital payment solution e-RUPI[26] can provide farmers with vouchers specifically earmarked for procuring AI services validated by AI sandboxes. Examples include the National Health Authority (NHA) using prepaid e-vouchers for healthcare. The Saagu Baagu 2.0 project in Telangana provides farmer cooperatives with financial support to implement AI solutions.

3. **Robust digital public infrastructure and data-sharing policies:** This is foundational for the integration and scaling of AI solutions in agriculture. Centralizing agriculture-related data on a secure and accessible platform provides a backbone for all stakeholders in the AI ecosystem.

    a. **Data platforms and exchanges:** Aggregating agriculture-related data (landholding crop data, soil health, weather patterns, market prices and more) will enable AI developers to create more precise and reliable models, reducing data silos. The Agri Stack[27] initiative from the government of India and the Agricultural Data Exchange (ADeX)[28] from the government of Telangana are examples.

    b. **Data-sharing policies:** DEPA (Data Empowerment and Protection Architecture)[29] and the Telangana ADMF (Agricultural Data Management Framework)[30] – drafted in collaboration with the World Economic Forum – are public–private efforts designed for data protection and to ensure data empowerment by facilitating smooth and secure data flow, enabling AI.

Promote responsible AI

Governments do well to initiate discussion on developing a "progressive" regulation on AI to balance the positive and negative externalities of AI solutions. MeiTY, India has launched an initiative to build tools and frameworks[31] to promote the ethical development and deployment of AI across different sectors.

Pillar 2

Create

> This stream is where innovation happens.

The leader of this stream is the **start-up, technology and innovator community**. The AI start-ups go through the typical cycles of funding and development, but with a difference under the IMPACT model. They perform activities to achieve convergence and to create a win–win situation for all. For instance, they cooperate with the potential consumers – governments, business and industry – to develop ideas that can solve real-world problems in a unique way. They also collaborate to develop open specifications, open standards and implementation models. Collectively, they strive to create new markets in which everyone will have a share. They also receive mentoring on domain issues from academics, and benefit from the results of their research, which can be applied to society.

Co-innovate for AI products with academia and research

India, with more than 97 Indian Council of Agriculture Research institutes[32] and 53 agricultural universities across the country, offers the largest national agricultural research system in the world. Such research institutions have great potential to be catalysts for collaboration with start-ups and industry in the development of open-source AI models for the agricultural sector. AgHub Telangana,[33] the UK's Agri-Tech Catalyst[34] and the Netherlands' Wageningen University are examples, supporting partnerships between start-ups and researchers.

Sandboxes for certification and validation

AI sandboxes establish a transparent and efficient platform for validation and certification of AI solutions from three perspectives: governance; domain applicability of agriculture; and technology. Telangana's agritech sandbox framework is an excellent example for adoption. In addition, the Reserve Bank of India (RBI) and the NHA regulatory sandboxes for fintech and the healthcare sector respectively are good examples for validating AI solutions in a controlled setting.

Pilots and showcases

Establishing a network of demonstration farms in diverse agricultural zones is essential for AI solutions in real-world environments, allowing developers to refine technologies based on practical feedback and build trust for adoption. The World Economic Forum's Saagu Baagu[35] project in Telangana showcases tangible benefits of AI tools at scale. In addition, Mahindra Agri has established a network of more than 6,000 demonstration farms to provide insights into the performance of AI solutions in different environments.

Collaboration platforms

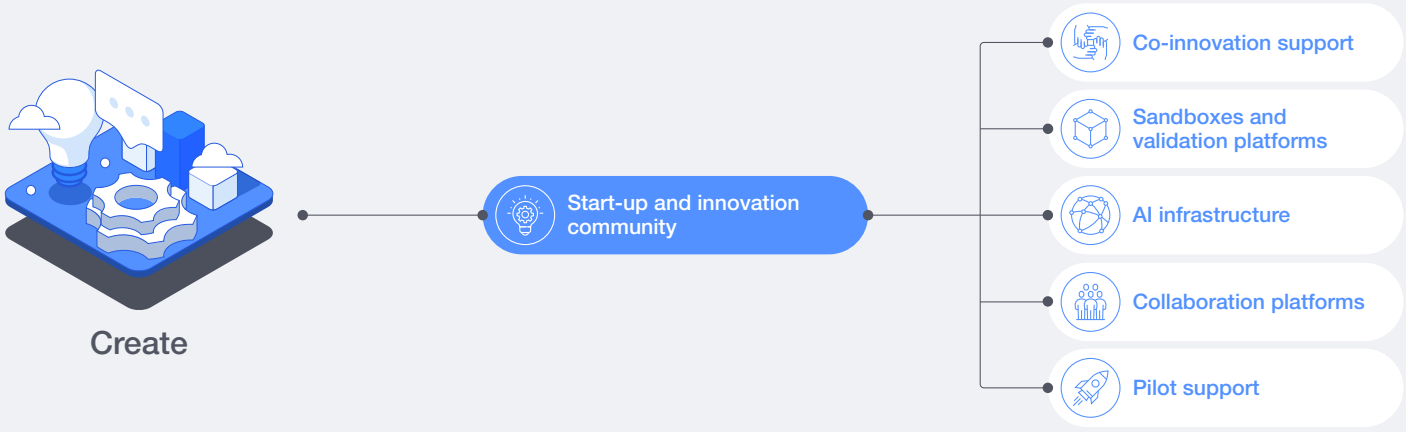
Collaboration platforms can be hotbeds of innovation by bringing together stakeholders to promote creativity and problem-solving. Y Combinator,[36] the Israel Innovation Authority,[37] T-Hub (Telangana)[38] and the K-Tech (Karnataka)[39] hub have successfully nurtured start-ups by providing seed funding and mentorship.

AI infrastructure

The IndiaAI Mission is enabling a scalable AI computing ecosystem with more than 10,000 graphic processing units (GPUs) through public–private partnerships to meet the demands of India's growing AI start-ups and research community and AI marketplace. It will offer AI as a service and pre-trained models, serving as a central hub for essential AI resources.

Once all these elements are in place, they will cumulatively bridge the gap between innovation and applications, which will accelerate the development and deployment of AI-driven solutions for agriculture.

FIGURE 14 **Create pillar of the IMPACT AI framework**



Pillar 3

Deliver

The **deliver** stream ensures that the benefits of AI reach the last mile – securely, efficiently and inclusively. The AI industry, start-up community and the last-mile delivery ecosystem are the principal stakeholders in this activity. It is service delivery with a difference. The special value envisaged through the IMPACT AI Model is outlined below.

FIGURE 15 **Deliver pillar of the IMPACT AI framework**

> This stream ensures the benefits of AI reach all stakeholders.

Empower front-line extension systems

Working at the back end, AI empowers front-line workers to be more productive and effective in their interactions with the end beneficiaries of programmes and services. Enhancing AI capacity among 200,000 agricultural extension officers[40] supporting 700,000 villages is essential and pivotal to integrate AI solutions into broader agricultural best practices.

Additionally, platforms such as Kisan call centres[41] and the VISTAAR[42] portal serve as vital touchpoints for farmers seeking advice. Integrating AI into these platforms can enhance the quality and timeliness of information provided, enabling farmers to make data-driven decisions.

Deploy an AI marketplace gateway

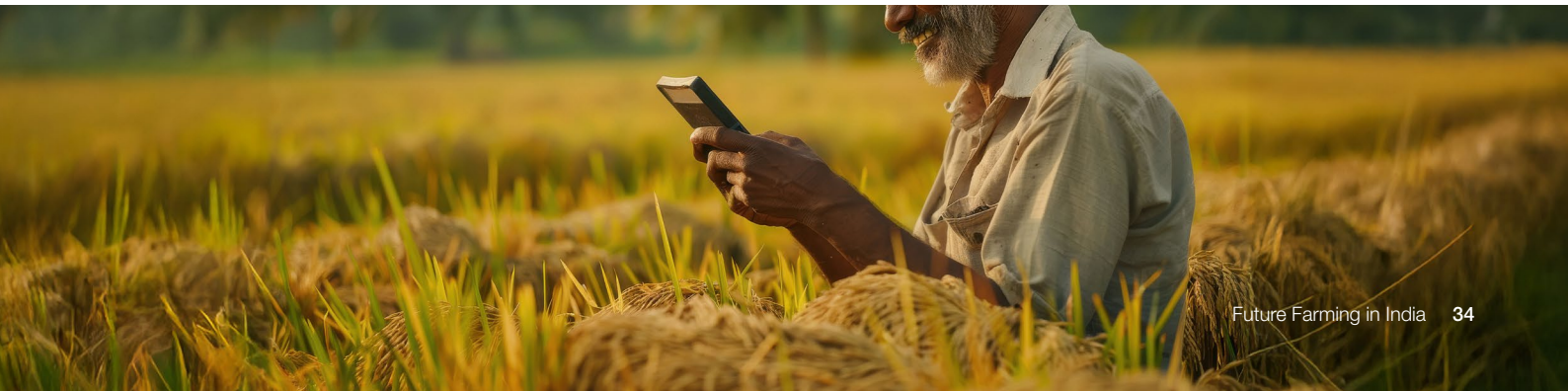
Integrating agriculture data platforms (such as Agri-Stack and ADeX) with digital e-commerce platforms such as the Open Network for Digital Commerce (ONDC)[43] can offer an AI marketplace gateway and streamline access to AI services for farmers. This platform can provide extension systems and farmers with trusted access to a variety of AI services and use cases, including fintech solutions, insurance products, advice, pest-detection tools, yield-prediction models and price forecasts. By offering a single point of access, it simplifies the user experience and encourages adoption.

Establish robust feedback loops

Incorporating feedback loops is crucial for the continuous improvement of AI solutions. Recognizing that AI requires a phygital (physical and digital) approach, it is important to combine digital tools with on-the-ground interventions. Collecting georeferenced crop images after AI advisory implementation allows for the refinement of AI models based on real-world outcomes. This data will help in validating the effectiveness of AI recommendations and adjusting algorithms to local conditions.

Raise awareness at the grassroots

Transforming initiatives such as the Agri-Clinics and Agri-Business Centres (ACABC)[44] scheme with AI enablement can further empower agripreneurs to offer advanced services to farmers. Incorporating AI technologies into their operations will enhance advisory services, diagnostics and precision farming techniques.



4 Conclusion and call to action

This playbook is intended to serve as a practical guide and as an instrument that various stakeholders can use to unlock transformative benefits.

Stakeholders – government, start-ups and academia – have roles in several parts of the AI value chain.

Stakeholders have roles in several parts of the AI value chain. The top five actions expected of the three major stakeholders – governments, AI industry/ start-ups and academia – are outlined below.

For governments

1. Establish a multistakeholder expert group to guide the development of policies and to structure technology governance.
2. Formulate an AI strategy that can shape the growth of the AI ecosystem through a system of incentives, projects and programmes.
3. Establish a legal and technology environment conducive to promoting the use of AI and governing it to safeguard societal and individual interests. The initiatives recommended in this regard are:
    a. Introduce AI procurement and financial incentives
    b. Enable agriculture digital public infrastructure and policies for agriculture data-sharing
    c. Establish AI sandboxes for validation and co-innovation in partnership with research institutions
4. Implement a portfolio of pilot projects for learning and building trust.
5. Undertake a public awareness campaign to empower farmers and cooperatives and enable them to assert their rights. Establish a consumer forum to receive and address grievances.

For start-ups and the AI Industry

1. Collaborate with government through a multistakeholder environment to co-develop AI strategy, policies, the procurement framework and the risk management framework and standards.
2. Develop AI models, products and solutions for domestic and global markets.
3. Collaborate with AI sandboxes for validation and co-innovation of solutions.
4. Strengthen the AI marketplace ecosystem by integrating with access platforms such as ONDC, agriculture data exchanges and Agri-Stack.
5. Offer AI-enabled products and services to farmers, cooperatives and extension systems through the AI marketplace.

For academia and research bodies

1. Conduct applied research in association with industry (with a focus on AI ethics, governance, standards and interoperability) and develop case studies for agriculture.
2. Mentor and co-innovate with start-ups, using their domain knowledge.
3. Partner with start-ups for validation of AI solutions from a domain and technology perspective.
4. Develop a workforce ready for the AI age, equipped for innovation and responsible deployment.
5. Design an AI evaluation framework, maturity models and impact-evaluation methods.

5 Next steps – models and templates

This AI playbook has outlined a framework for promoting the evolution of an AI ecosystem for the agricultural sector.

Several recommendations constitute a **call to action**. The next steps by the main actors necessarily require formal documentation and approvals at various levels. A good practice for action-oriented playbooks is to provide a set of models and templates that tend to trigger immediate action by the key stakeholders. Distilling the foregoing discussion, the following model documents and templates are presented to be developed in a multistakeholder environment and made available to the larger community.

TABLE 5 **Model artefacts and templates to promote the development of an AI ecosystem**

Model artefacts	
1	Model AI strategy (national/state)
2	Model terms of reference for a multistakeholder expert group
3	Model request for proposal for AI procurement
Templates and frameworks	
1	Reference architecture of AI sandbox
2	Framework for providing access to agriculture data for AI
3	Criteria for testing and validation of AI agriculture solutions
4	Checklist of governance, risk and compliance for industry and start-ups
5	Dynamic compendium of AI use cases for agriculture

Appendix 1: The Agriculture Expert Group

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Appendix 2: AI for India 2030 Advisory Council

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Appendix 3: The stakeholders matrix

Developing and deploying AI-based applications in Indian agriculture hinges on the collaborative efforts of all stakeholders.

Each has a unique role to play. By aligning these, it is possible to foster an environment in which AI technologies are developed, deployed and scaled to meet the needs of the agricultural sector. The interplay between stakeholders will create a dynamic ecosystem in which innovation, policy and application converge to transform agriculture through AI.

TABLE 6 **Stakeholder roles and value in AI integration for agriculture**

Stakeholder	Role	AI value sought
Individual farmers	Adopt AI-based solutions for productivity, sustainability and market access	Enhanced yields, better market access and reduced input costs
Farmer producer organizations (FPOs)	Aggregate demand, facilitate adoption of AI tools and provide market access	Improved incomes, collective bargaining power, data-driven decisions, efficient market linkages, increased transparency and optimized quality control
Agriculture extension officers	Train farmers, deliver AI-enabled advice, monitor crop health and provide precision farming inputs	Increased effectiveness of advice, real-time insights and better yield predictions
Village-level entrepreneurs (VLEs)	Act as intermediaries for AI tools delivery, gather data and provide financial services	Empowered last-mile delivery, real-time feedback loops, enhanced data collection
Common service centres (CSCs)	Provide farmers with access to AI advice, digital finance and marketplace tools	Financial inclusion, improved access to advisory and digital platforms
Agri input companies	Supply AI-integrated seeds, fertilizers and machinery; predict demand using AI tools	Precision input use, better forecasting and market expansion
Start-ups and innovators	Develop platforms for AI-based advice, fintech, yield prediction and marketplaces	Scalable AI solutions, market leadership and profitability through innovation
Tech providers	Offer AI platforms, cloud infrastructure and data integration services	Innovation, market expansion and efficiency through digital platforms
Banks and fintech companies	Provide AI-driven credit scoring, loans and insurance products	Improved risk management, financial returns and increased access to financial markets
Food companies	Use AI to optimize supply chains, ensure product quality and predict demand	Efficient logistics, enhanced product quality and demand fulfilment
Government bodies	Develop AI policies, provide infrastructure and financial support and promote adoption	Food security, improved farmer incomes and sustainable agricultural practices
Universities and research centres	Conduct AI research, develop innovative models and train future technologists	Knowledge creation, academic reputation and impactful solutions

Appendix 4: A repository of AI use cases in agriculture

TABLE 7 **AI use cases in agriculture**

Crop monitoring and management			
Use case	**Description**	**High-level flowchart of AI value delivery**	**Start-up examples**
Satellite-based crop monitoring	AI analyses satellite images to monitor crop health and growth patterns and detect issues such as drought stress or nutrient deficiencies. This helps farmers make timely decisions to improve yields and manage resources efficiently.	– Satellites capture images of fields – AI analyses images for crop health indicators – AI identifies areas needing attention – Farmers receive easy-to-understand reports – Farmers adjust practices accordingly	SatSure (India): Case study Planet Labs: Agriculture case studies
Crop variety selection	AI helps farmers select the best crop varieties for their fields by analysing soil type, climate and historical yield data, leading to better yields and resilience to pests and diseases.	– Soil, climate and yield data are gathered – AI evaluates suitable crop varieties – Farmers receive suggestions on the best varieties to plant – Farmers choose varieties based on advice – Improved yields and crop resilience	SatSure (India): Case study AgroStar (India): Successful applications
Drone-based field analysis	Drones equipped with cameras capture detailed images of crops. AI processes these images to detect pests, diseases or water stress early, enabling precise interventions and reducing crop losses.	– Drones fly over fields capturing images – AI analyses images for issues – AI pinpoints problem areas – Maps highlighting issues are sent to farmers – Targeted treatments are applied where needed	DJI Agriculture: Solutions
Weather forecasting for farming	AI models predict weather patterns to help farmers plan planting, irrigation and harvesting schedules. Accurate forecasts reduce risks associated with adverse weather conditions.	– Collect historical weather data and information on current conditions – AI analyses data to predict weather – Provides localized weather forecasts – Farmers receive weather advisories – Farmers plan activities accordingly	IBM's The Weather Company: Case study Skymet (India): Case study

TABLE 7 | **AI use cases in agriculture** (continued)

Advisory services and knowledge dissemination

Use case	Description	High-level flowchart of AI value delivery	Start-up examples
AI chatbots for farmer advice	AI-powered chatbots provide farmers with instant answers to agricultural queries in local languages, offering advice on best practices, crop management and problem-solving.	– Farmers ask questions via app or SMS – AI understands the query using natural language processing – AI accesses agricultural information database – Answers provided in simple language – Farmers receive timely advice	Awaaz De (India): case study Microsoft AI for Agriculture: Case study
Decision support systems	AI systems integrate various data sources to provide farmers with personalized recommendations on crop planning, input usage and market opportunities, enhancing decision-making.	– Data on weather, soil and markets gathered – AI processes data to generate insights – Personalized advice provided to farmers – Farmers make informed decisions – Improved farm productivity and profitability	Kisan Network (India): Case study Cropin (India): Case study

Precision agriculture

Use case	Description	High-level flowchart of AI value delivery	Start-up examples
Variable rate application (VRA)	AI systems analyse field data to determine the precise number of inputs (such as seeds, fertilizers and pesticides) needed in different parts of the field. This optimizes input usage, reduces waste and enhances crop yields.	– Field data gathered via sensors and maps – AI determines input needs per area – AI generates a prescription map showing input requirements – Machinery applies inputs precisely – Improved yields and resource efficiency	John Deere: Technology for precision agriculture Trimble Agriculture: Solutions
Precision irrigation management	AI analyses weather forecasts, soil moisture data and cropwater needs to optimize irrigation schedules. This ensures that crops receive the right amount of water at the right time, conserving water and improving plant health.	– Soil-moisture sensors and weather data collected – AI calculates irrigation needs – Optimal watering times are set – Irrigation systems water crops accordingly – Continuous adjustments are made based on new data	Netafim Precision Agriculture Fasal (India): Case studies
Automated farm machinery	AI-powered tractors and equipment perform tasks such as planting, weeding and harvesting with high precision, reducing labour costs and increasing efficiency.	– AI plans farming tasks – Autonomous machinery carries out tasks – Machines gather data as they work – AI refines operations based on data – Efficient farm operations with reduced labour needs	CNH Industrial: Case study

TABLE 7 | **AI use cases in agriculture** (continued)

Pest and disease control

Use case	Description	High-level flowchart of AI value delivery	Start-up examples
Early pest and disease detection	AI models analyse images of crops to detect early signs of pests or diseases, enabling timely intervention and reducing crop damage.	– Images captured via smartphones or drones – AI identifies signs of pests/diseases – Specific issues are diagnosed – Notifications with treatment advice are sent to farmers – Farmers apply remedies	Plantix (Germany/India): Case study TartanSense (India): Case study
Predictive pest modelling	AI predicts pest outbreaks by analysing weather data, crop conditions and historical pest patterns, helping farmers implement preventive measures.	– Weather, crop and pest data collected – AI identifies risk factors – Potential outbreaks are forecast – Warnings and preventive advice sent to farmers – Farmers take action to reduce risks	Climate Corporation (USA): Case study Wadhwani AI-cotton crop: Case study
Integrated pest management (IPM)	AI assists in developing IPM strategies by analysing data on pest life cycles, natural predators and environmental conditions to minimize chemical pesticide use.	– Data on pests and environment gathered – AI assesses best IPM strategies – Farmers receive guidance on biological controls and minimal pesticide use – Farmers apply recommended practices – AI continues to assess effectiveness and adjusts advice	Bayer Crop Science: Case study BioCrop (India)

Soil and nutrient management

Use case	Description	High-level flowchart of AI value delivery	Start-up examples
Soil health monitoring with sensors	Sensors placed in the soil collect data on moisture, nutrients and pH levels. AI analyses this data to provide recommendations on irrigation and fertilization, helping farmers maintain optimal soil conditions for crop growth.	– Soil sensors gather data – AI assesses soil health – AI suggests irrigation and fertilization – Advice is sent to farmers – Farmers adjust practices based on recommendations	CropX (Israel) FarmBee (India): EM3 Agri Services
Soil nutrient mapping	AI creates detailed maps of soil nutrient levels using sensor data and remote sensing, allowing for precise fertilizer application and improved soil health.	– Soil samples and sensor data collected – AI analyses nutrient levels – Detailed nutrient maps are created – Farmers receive guidance on fertilizer application – Precise fertilizer use enhances soil health and crop yields	Krishi Tantra (India): Case study
AI-based soil testing	AI algorithms analyse soil images and data to provide instant soil-testing results through mobile apps, reducing the need for laboratory tests and enabling quick decision making.	– Farmers capture soil images via app – AI assesses soil properties – Soil test results are provided on the app – Advice on soil-improvement measures is given – Farmers implement suggestions promptly	Agrocares (Netherlands) SoilCares: Case study

TABLE 7 | **AI use cases in agriculture** (continued)

Post-harvest management

Use case	Description	High-level flowchart of AI value delivery	Start-up examples
AI-based quality assessment	AI systems assess the quality of harvested produce using image recognition, sorting them based on size, colour and defects, which improves market value and reduces waste.	– Images of produce are captured – AI evaluates quality attributes – Produce is sorted into categories – Proper packaging based on quality grades – Higher market value and reduced waste	Intello Labs (India) AgNext (India)
Storage condition monitoring	AI monitors storage conditions such as temperature and humidity to prevent spoilage of stored grains and produce, extending shelf life and ensuring food safety.	– Sensors monitor storage conditions – AI detects deviations from optimal conditions – Notifications sent if issues detected – Adjustments made to storage environment – Reduced spoilage and maintained quality	Ecozen Solutions (India) GrainSense
Demand forecasting	AI predicts consumer demand for various crops, helping farmers and suppliers adjust production and inventory levels accordingly, reducing waste and optimizing profits.	– Market trends and historical sales data gathered – AI forecasts future demand for crops – Farmers and suppliers adjust production plans – Supply-chain logistics are aligned with demand – Reduced overproduction and waste, with optimized profits	Udaan (India)
Route optimization for transportation	AI optimizes transportation routes for delivering agricultural produce, reducing fuel costs, delivery times and carbon emissions.	– Data on destinations, traffic and road conditions collected – AI calculates optimal routes – Drivers follow AI-recommended routes – AI adjusts routes in real time if needed – Efficient deliveries and cost savings	Locus.sh (India) BlackBuck (India): Case study

Market access and price forecasting

Use case	Description	High-level flowchart of AI value delivery	Start-up examples
Price-forecasting models	AI analyses market trends, supply and demand and historical prices to forecast future commodity prices, helping farmers decide when to sell their produce to maximize profits.	– Market data and historical prices gathered – AI predicts price movements – Farmers receive price forecasts – Farmers plan sales accordingly – Improved income through better market timing	AgriBazaar (India) Commodities Control (India): Case study
Digital marketplaces	AI-powered platforms connect farmers directly with buyers, reducing intermediaries. The platforms match supply with demand efficiently, ensuring fair prices for farmers and fresh produce for consumers.	– Farmers and buyers join the platform – Farmers list produce availability – AI matches farmers with buyers – Secure payments and logistics are arranged – Fair pricing and efficient market access achieved	DeHaat (India): Case study eNAM (India): Success stories

TABLE 7 | **AI use cases in agriculture** (continued)

Agricultural finance and insurance			
Use case	**Description**	**High-level flowchart of AI value delivery**	**Start-up examples**
AI-based credit scoring	AI assesses the creditworthiness of farmers by analysing data such as crop history, landholding size and market trends, enabling financial institutions to offer loans to farmers lacking traditional credit histories.	– Farmers' data on crops, land, etc. collected – AI evaluates credit risk – Credit score assigned to each farmer – Banks offer loans based on scores – Increased access to finance for farmers	Samunnati (India): Case study Jaikisan (India)
Parametric insurance solutions	AI models predict weather events and crop risks, enabling insurance companies to offer parametric insurance products. Payouts are automatically triggered based on predefined events such as drought or flood, providing quick financial relief to farmers.	– Weather and crop data monitored – AI evaluates risk probabilities – Farmers buy insurance policies – AI tracks events in real time – Payouts are triggered automatically if events occur – Quick financial relief for farmers	SatSure (India) Cropin (India): Case study

Appendix 5: An assessment of critical datasets for AI in agriculture

Reliable datasets are essential to develop AI-based tools for yield forecasting, pest control and supply-chain optimization.

The report team evaluated datasets for availability, useability and quality, taking on board insights from the United Nations Food and Agriculture Organization, India Meteorological Department (IMD), Copernicus and Agri-Stack. This process enabled the team to identify the 15 most critical datasets and the key gaps in granularity, real-time availability and interoperability. Closing these gaps will strengthen India's agricultural data ecosystem, ensuring AI adoption that is aligned with global agriculture's best practices. This assessment was guided by an earlier McKinsey–National Association of Software and Services Companies (NASSCOM) report, and targets AI start-ups and government leaders who can unlock AI's potential in agriculture.

TABLE 8 **Fifteen critical datasets for AI in agriculture**

Names of dataset	Dataset descriptions
Digital land records registry*	Digital land records* registry that establishes titling of collateral and has legal validity with various departments (revenue, survey, etc.)
Crop calendar and yields***	Crop-cutting experiment data, data on actual yields for crop varieties per area harvest, crop weather calendars of major crops, cropping area under the Regulated Farming Initiative* (Agri-Stack*)
Soil health**	Agronomic details such as soil type and fertility, including nutrient availability (macro, micro, secondary) and moisture content, for each farm, fertilizer subsidy data
Satellite imagery**	High-resolution images to identify farm boundaries, crop distribution, yield, etc.
Real-time mandi data***	Includes real-time statistics on market prices and arrivals for different crop varieties from commodity trades, along with historic price data across various markets
Agriculture market network***	Agriculture market network by location, crop type
Import, export volume details***	Import and export volumes for crop varieties by month and location
Historical purchase prices for crops***	Historical daily purchase prices for crops by location, market type and level (e.g. farmer, intermediary, etc.)
Production and consumption data***	Production and consumption volumes for crop varieties by month and location

TABLE 8 **Fifteen critical datasets for AI in agriculture** (Continued)

Names	Dataset descriptions
Weather data**	Climate details including rainfall, precipitation, humidity, sunlight, temperature, wind, etc. at the district level
Irrigation maps**	High-resolution irrigated area mapping to identify areas under irrigation, moisture levels in topsoil, root zone, etc.
Storage network details***	Storage network details such as crop varieties stored, maximum capacity, average use and safety buffer
Warehouse details***	Warehouse details including geolocations, facilities such as cold storage, capacity constraints, tariffs, operating and handling costs and fixed costs
Commodity profile data***	Profile including standards for defects based on crop varieties and usage, shelf life, trade constraints, purchase limits and timing of production
Defect and pest images***	Annotated high-resolution images of pests and diseases of different crop varieties for AI-based grading, diagnosis and defect identification

Note: * indicates data that will be available via Agristack. ** Indicates data that will be available through Krishi Decision Support System. *** Indicates data that could be facilitated through an agriculture data exchange such as ADeX

Source: World Economic Forum. (2021). *Artificial Intelligence for Agriculture Innovation*. https://www3.weforum.org/docs/WEF_Artificial_Intelligence_for_Agriculture_Innovation_2021.pdf.

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