

White Paper

Building Crop Resilience in the Face of Climate Change

September 2025





“If agriculture goes wrong, nothing else will have a chance to go right.”

Prof. M.S. Swaminathan

Founder, M.S. Swaminathan Research
Foundation (MSSRF)

Father of the Green Revolution in India



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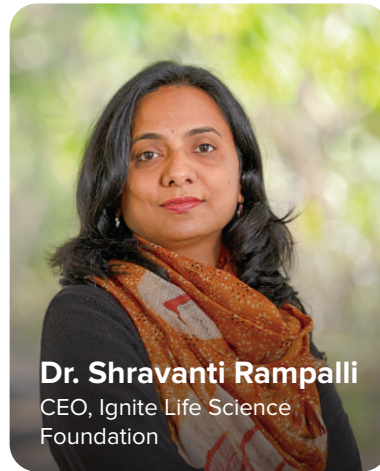
01 Preface

Ignite Life Science Foundation (Ignite) is a pioneering science philanthropy dedicated to fostering a vibrant and sustainable research ecosystem in India. Founded by a distinguished group of scientists and business leaders, our mission is to build the science ecosystem in India so that good science and scientists can flourish. We are committed to transforming India's scientific ecosystem by fostering world-class research, empowering scientists, and bridging critical funding gaps to drive innovation and discovery.

India has long been an agricultural powerhouse, with farming serving as the backbone of its economy. Today, the country stands among the world's leading producers and exporters of agricultural commodities. However, the sector faces increasing challenges due to climate change. Unpredictable weather patterns, unseasonal rains, and prolonged droughts are posing significant threats to crop yields, food security, and the livelihoods of farmers.

To address these complex challenges, India must adopt robust adaptation and mitigation strategies. These include the development of climate-resilient crop varieties, promotion of advanced agronomic practices, and widespread adoption of sustainable agricultural models. Central to these efforts is a strong investment in agricultural research and innovation. Over the years, Ignite has supported a range of life science initiatives, including several in the agriscience space. One of the ways we do this is through conducting **Special Academic Research Cooperatives (SpARCs)** meetings to generate new ideas at the forefront of science that require interdisciplinary brainstorming and collaboration.

To deepen our impact, Ignite has partnered with ITC Ltd., an organization equally dedicated to advancing agricultural growth and contributing to nation-building. ITC has spearheaded a large-scale **Climate Smart Agriculture Program**, spanning 31 lakh acres, to derisk farmers. This has been accomplished using a holistic approach with interventions that include access to irrigation, soil & moisture conservation, climate resilient package of practices, on-farm & off-farm diversification, and institutional linkages. ITC strongly believes in



Dr. Shravanti Rampalli
CEO, Ignite Life Science
Foundation

collaboration to strengthen Indian agriculture and the role of cutting-edge research, and is hence, partnering with Ignite. As part of this collaboration, the **AgriScience SpARCs meeting** was convened, bringing together a diverse group of stakeholders from academia, industry, greenhouse gas research, progressive farming, and other related domains. This multidisciplinary exchange was designed to identify a way forward for climate-resilient and sustainable agriculture in India.

We are pleased to share the outcome of this effort in the form of a **White Paper**, that captures:

- Key challenges confronting Indian agriculture in the face of climate change and food insecurity.
- Meeting outcomes, including practical adaptation and mitigation strategies.
- Additional actionable recommendations proposed by participants to strengthen future efforts.

We extend our heartfelt thanks to all participants for their dedication, and especially to our facilitators, **Dr. Ajay Kohli**, and **Dr. K.K. Narayanan**, for their leadership in making the AgriScience SpARCs meeting a success. We are deeply grateful to ITC Ltd. represented by **Mr. S. Sivakumar**, Group Head, Agri & IT Businesses, and **Mr. L. Prabhakar**, Executive Vice President and Head, Social Investments, ITC Ltd., for their unwavering support and commitment to this mission.

Our agriscience community members who participated in the SpARC, have contributed significantly to preparing this document with their inputs and insights.

We hope you find this document valuable. We would welcome your comments and look forward to your continued engagement in building a climate-resilient and sustainable agricultural future for India.

02

Executive
Summary

Indian agriculture is navigating a turbulent era under increasingly erratic weather patterns shaped by the progressively unfolding climate change, which also leads to growing ecological stress and socio-economic vulnerabilities. Unseasonal rains, drought and temperature variations affect the quantity of the crops produced and contaminated soil, air, and water status affect the quality of the crops' nutritional value. These compounded risks

threaten not just farm livelihoods, but national food and nutritional security also. Responding to this urgent scenario, Ignite Life Science Foundation, in partnership with ITC Ltd., convened the **AgriScience SpARCs** meeting - a national dialogue that brought together leading researchers, policy experts, industry professionals, and grassroots stakeholders to uncover 'known unknowns' and 'unknown knowns' in this field, whilst understanding the known knowns residing in different pockets.

A science driven roadmap for indian agriculture

The aim was to deliberate on science-driven solutions and co-develop a roadmap for transitioning Indian agriculture from risk-prone dependency to resilient and sustainable growth. The white paper that follows distils the outcomes of this three-day deliberation, presenting a coherent strategy for climate-resilient agriculture rooted in rigorous research, practical innovation, and policy foresight.



In addition to abiotic challenges, the white paper also highlights the growing threat of **biotic stresses**, that are intensifying under the influence of shifting climatic baselines.

Challenges

Rising temperatures and erratic humidity have contributed to the proliferation of pests, viral diseases, and invasive species that jeopardize key food and cash crops. Discussions revealed critical gaps that need immediate attention: high greenhouse gas emissions from agriculture especially methane and nitrous oxide; degradation of soil and water resources; fragmented adoption of digital technologies; underutilization of proven breeding innovations; and regional disparities in climate impact and access to resources.

Opportunities

Alongside these challenges, the participants identified powerful opportunities. Technological solutions like CRISPR/Cas9 for genome editing, climate-resilient seeds, AI-powered advisory tools, and IoT-enabled precision agriculture emerged as scalable interventions. Equally important are ecosystem-level approaches including soil health restoration, carbon sequestration, crop diversification, and nutrition-sensitive farming practices.

Participants called for strengthening inter-sectoral collaboration and aligning scientific efforts with grassroots realities.

Policy & infrastructure Priorities

The paper advocates for fast-tracking regulatory pathways for genome-edited crops, upgrading Krishi Vigyan Kendras into climate-nutrition knowledge hubs, and incentivizing regenerative agriculture and private-sector participation. It emphasizes the urgent need for a National Agri-Climate Resilience Observatory and a centralized AI-ready agri-data infrastructure to improve forecasting, monitoring, and delivery of targeted support to farmers. There is the need for small-scale mechanization because not all digital technologies are suitable for small-scale farmers. There therefore, exists a significant gap in serving this community of farmers. This white paper is more than a record of discussions - it is a call to action. It underscores that India's agricultural

transformation must be deliberate, integrated, inclusive, and systemic. Moving beyond incremental adaptations, it urges a bold reimagination of the sector - grounded in transdisciplinary science, emerging technologies, scalable innovations, farmer-centered design, and policy integration. For funders and public stakeholders alike, the message is clear: investing in climate-resilient agriculture is investing in India's food and nutrition security, economic stability, and ecological future. Ignite Life Science Foundation and ITC Ltd. are committed to translating these recommendations into action and invite collaborative partnerships to drive meaningful change from lab to land.

03

Preamble: A global and national view

Climate change has become one of the most pressing threats to global food security. According to the World Meteorological Organization's (WMO) State of the Global Climate Report, the past decade has been the hottest on record.

In 2024, there was a 1.5°C rise in temperature above the pre-industrial times (1850 -1900) (**Fig 1**). It was the warmest year in the 175 years of monitoring.¹ According to the Intergovernmental Panel on Climate Change (IPCC), a 2°C rise will put one-third of global croplands at risk of severe drought. Similarly, heat stress will reduce livestock productivity by up to 25%.²

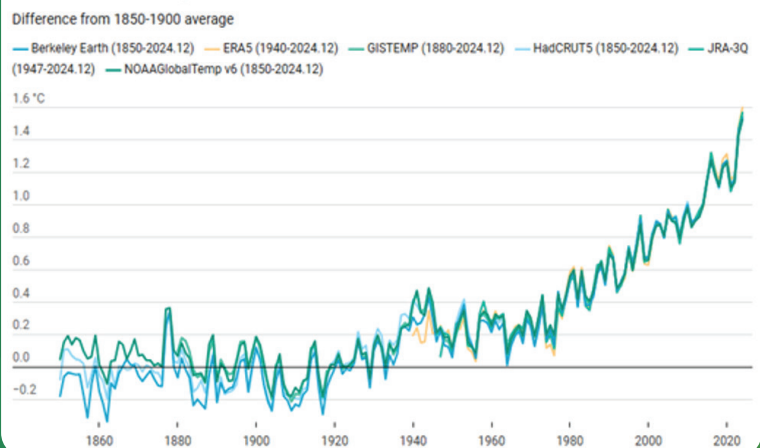
The increasing frequency and severity of heatwaves, droughts, floods, and storms reduce productivity. Climate-change driven seawater incursion and the

concomitant salinity ravage the productive deltas and the coastal agriculture. Such events have resulted in a documented reduction in agricultural yields.

The northwest regions of the United States experienced up to a 40% decrease in annual farm productivity due to extreme heat and crop sunburn. The expansion of drylands by approximately 4.3 million square kilometres worldwide has increased aridity in regions such as central Africa, adversely affecting agricultural productivity.³ Critically, the unpredictability of these events leaves little room for farmers and other value-chain actors, including policy experts, to mitigate the productivity and economic losses. This aspect damages food security and nutrition security more than most.

Figure 1: Annual global mean temperature anomalies are relative to a pre-industrial (1850 -1900) baseline from 1850 to 2024. The past decade has been the hottest on record, with 2024 reaching above 1.5°C.

Global mean temperature 1850-2024



¹ WMO press release, Climate change indicators reached record levels in 2024: WMO 19 March 2025

² IPCC AR6, Sixth Assessment Report on Climate Change.

³ USDA Climate Hubs, U.S. Department of Agriculture.

In 2024, India experienced extreme weather events in 322 days out of 366 days, surpassing the 318 days in 2023 and 314 days in 2022 of extreme weather events. This means that nearly 88 percent of the year saw extreme weather in one or more parts of the country, up from 87 percent in 2023 and 86 percent in 2022, highlighting a worsening trend.

The analysis is based on data from the interactive atlas on extreme weather events in India managed by the Delhi based think-tank Centre for Science and Environment (CSE) and Down To Earth (DTE). The extreme events recorded during the year include heat and cold waves, cyclones, lightning, heavy rain, floods, and landslides.

Indian agriculture has also been affected by climate change, with a reduction in crop yields impacting food security and the economy. Climatic changes such as rising temperatures, erratic monsoon events, and hailstorms, as well as extreme cold weather, make crops vulnerable across their phenological stage. Rising temperatures have shortened the

wheat-growing season in North India, leading to yield reductions of 10 -15% in some regions.

Erratic monsoons have intensified flooding in Eastern States, affecting rice production, while recurrent droughts in Maharashtra and Karnataka threaten fruit and pulse crops.⁴ In addition, unseasonal rain, hailstorms, and gusty winds have affected both food grains and horticultural crops like mango in North India, especially Uttar Pradesh.⁵ Severe hailstorms in Maharashtra have devastated crops across 18 lakh hectares, resulting in estimated losses of 10,000 crores. The damage has predominantly affected ready-to-harvest rabi crops and horticultural produce, including grapes, pomegranates, and mangoes.⁶

While there is clear evidence of an overall temperature warming trend and changing monsoon patterns, how these events play out across regions remains unpredictable, as local climatic variations make it difficult to generalize the impact, both nationally and globally.

Some parts of the world are more adversely affected, and this is a global challenge. However, the solutions must be locally adapted to different eco-geographies, hydrologies, economies, regulatory and policy frameworks. In addition, influenced by regional climatic conditions and regional crop physiology, climate change exerts diverse impacts on agriculture across the globe. These include:

01 Expansion of arable land in temperate regions.

02 Land loss in island nations and in coastal regions.

03 Differential responses of C3 (wheat, rice, etc.) and C4 (maize, sugarcane, etc.) plants which utilize different types of photosynthetic pathways.

⁴ THE DIPLOMAT: Rising Temperatures Threaten India's Wheat Production, June 21, 2024

⁵ The New Indian Express: Untimely rains, hailstorms damage 20 per cent of mango crop in country, says ICAR, March 31, 2023

⁶ The Indian Express: Hailstorm: Crop loss figure goes up to Rs 10,000 crore, 2024

04

Climate change and impact on agriculture

Part 1

1.1 Anthropogenic causes and their contribution to climate stress

Human activities have significantly accelerated climate change by increasing greenhouse gas (GHG) emissions and altering natural ecosystems. Burning fossil fuels, deforestation, transportation, industrial emissions, urbanization, and waste mismanagement have contributed to rising global temperatures, extreme weather patterns, and environmental degradation.

Today, greenhouse gas emissions can be traced back to five economic sectors - energy sector, agriculture, industrial processes, forestry, and waste and land-use

change. The energy sector accounts for the most significant amount of GHG emission (75.7%), followed by agriculture, being the second largest contributor (11.7%). The other main sectors include industrial processes (6.5%), waste and land-use change (3.4%), and forestry (2.7%). Agriculture-related activities result from emissions from livestock, manure, paddy rice, and crop-burning activities.⁷

In India, intensified farming methods, deforestation, excessive fertilizer use, and fossil fuel dependency are key anthropogenic factors contributing to climate change and environmental degradation. Synthetic fertilizers, especially nitrogen-based compounds, are the reason behind the emissions of N_2O , a gas with nearly 300 times the global warming potential (GWP) of CO_2 . The Haber-Bosch process for synthesizing ammonia (NH_3) from atmospheric nitrogen (N_2) and hydrogen (H_2) derived from natural gas is itself an energy-intensive and high CO_2 and CH_4 emission process.⁸

In agriculture, livestock and fisheries contribute 31%, crop production 27%, land use 24%, and supply chains 18% of emissions to make up 100%. Disaggregating the

three major GHGs, agricultural emissions are made up of 15% CO_2 , 35% N_2O , and 50% CH_4 . It is important to note two critical points. First, 35% of agricultural N_2O emissions make up nearly 67-70% of total N_2O emissions (**Table 1**). Agriculture creates both direct and indirect emissions. Direct emissions come from fertilized agricultural soils and livestock manure (42%), while indirect emissions come from runoff and leaching of fertilizers (25%).⁹ It is a far more potent GHG with 300x GWP (Global Warming Potential) and a 120-year half-life in the atmosphere.

Yet, most research is concentrated on CH_4 emission reduction. Why? The answer lies in the second point below.

⁷ Where Do Emissions Come From? 4 Charts Explain Greenhouse Gas Emissions by Sector. WORLD RESOURCES INSTITUTE, Dec 5, 2024

⁸ Haber-Bosch process, Britannica, Mar 2 2025

⁹ Main Sources of nitrous oxide. What's your Impact?

www.whatsyourimpact.com/greenhouse-gases/nitrous-oxide-emissions

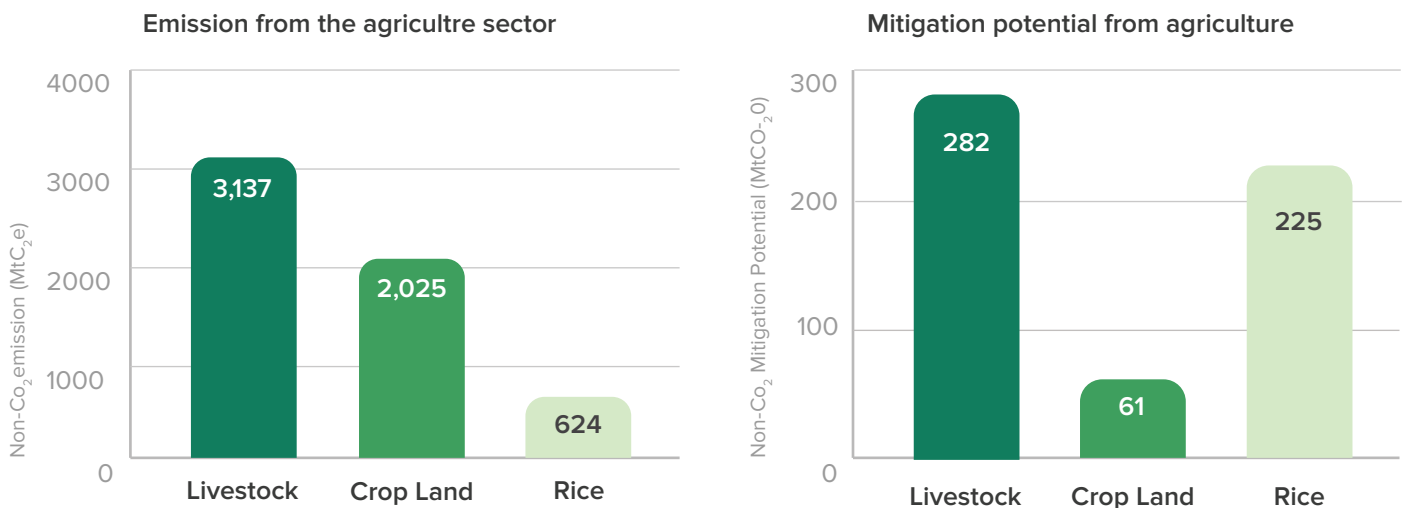
Table 1. Key Sources of N₂O Emissions

Sector	Percent Contribution	Main Sources
Agriculture	67-70%	Fertilizers, manure, soil management, crop residues.
Energy	12-15%	Fossil fuel & biomass combustion, industrial energy use.
Industry	5-7%	Nitric acid & adipic acid production (for fertilizers & nylon).
Waste	5-7%	Wastewater treatment, landfills, human sewage.
Other (Forestry; Land Use)	3-5%	Biomass burning, soil disturbances, deforestation.

Note:

The percentages may not add up to 100% due to independent rounding in the report.

Secondly, the emission reduction potential of CH₄ is maximum from paddy fields (**Fig 2**). Paddy contributes ~ 624 MtCO₂e (metric tons of carbon dioxide equivalent) emissions annually, and nearly 35% of that can be mitigated. However, livestock emits 3,137 MtCO₂e annually, but only 8% of it can be mitigated. Cropland mitigation potential is also low at 3%. Notably, the half-life of CH₄ in the atmosphere is 12 years compared to order of millennia for CO₂ and 120 years for N₂O. Reduction in CH₄ will therefore have a quicker mitigation effect than CO₂ or N₂O.¹⁰

**Figure 2: Emission reduction potential of livestock, cropland, and paddy fields¹¹**

While such numbers make a strong case for concentrating on research time and funding in CH₄ emission reduction, they make an equally strong point for devising means of reducing N₂O emissions, because delay in doing so will lead to the continuation of more harmful and more stable emissions.⁶

¹⁰ Unravelling the Origins of a Potent Greenhouse Gas, National Environmental Satellite Data, and Information Service, July 25, 2023

1.1.1 Way forward: Anthropogenic causes and their contribution to climate stress

Recent literature highlights the urgent need for multi-faceted strategies to mitigate anthropogenic greenhouse gas (GHG) emissions, particularly from agriculture and energy-intensive industries.¹² While methane (CH₄) reduction has been prioritized due to its short atmospheric lifetime and high mitigation potential in paddy fields, the long-term impact of nitrous oxide (N₂O) emissions, accounting for nearly 70% of total N₂O from agriculture, demands greater attention.

Precision agriculture & fertilizer optimization:

Research must pivot towards reducing synthetic nitrogen fertilizer dependency through biofertilizers, **slow-release nitrogen formulations**, and **enhanced-efficiency fertilizers** (EEFs).¹³ Integrating remote sensing and AI-driven soil nutrient analysis can optimize application rates, reducing excess N₂O emissions.

Methane & nitrous oxide co-reduction strategies:

Combining CH₄ and N₂O reduction approaches can yield synergistic benefits. Water-saving techniques like **Alternate Wetting and Drying** (AWD) and **Direct Seeding of Rice (DSR)** in paddy fields not only lower CH₄ emissions, but can also influence soil nitrogen dynamics, reducing N₂O flux.¹⁴ However, inherent limitations have not yet been addressed, such as the preponderance of weeds in DSR, and the physical limitations of small land-holding or financial restraints, that can be a hindrance to scaling.

Decarbonizing the Haber-Bosch process:

Hydrogen production via electrolysis using renewable energy instead of natural gas can lower CO₂ and CH₄ emissions from ammonia synthesis.¹⁵ Developing circular economy models for nitrogen recycling in agriculture will further reduce reliance on synthetic fertilizers.



The above-mentioned modalities and practices are implemented based on current climatic conditions, available water, soil health, and other resources. However, given changing climatic patterns worldwide, these processes must be continuously evaluated in future requirements.

¹¹ U. S. Environmental Protection Agency (EPA) report, 2019

¹² IPCC, 2023; Smith et al., 2022

¹³ Zhang et al., 2020

¹⁴ Linquist et al., 2018

¹⁵ Rouwenhorst et al., 2021

1.2 Regional disparities in climate change impact on agriculture

Climate-change exerts diverse impacts on agriculture across the globe, influenced by regional climatic conditions and crop physiology.

Expansion of arable land in temperate regions:

In higher-latitude temperate zones, rising temperatures may extend growing seasons and potentially increase arable land availability. Warmer conditions can make previously unsuitable areas viable for cultivation, enhancing agricultural productivity. For example, cultivation of horticulture crops such as apple, pomegranate, grapes, guava are now inclined towards expanded land in various regions of India, previously known to be unsuitable due to extreme weather conditions. However, this expansion may be moderated by factors such as soil quality and water availability.¹⁶

Land loss in island nations and in coastal regions:

Island nations and low-lying coastal areas face significant risks due to climate-change induced rise in sea-levels. Coastal erosion poses implications for spice cultivation, particularly affecting crops like black pepper, cardamom and turmeric.¹⁷ Encroaching seas can lead to the loss of fertile agricultural lands, increased soil salinity, and displacement of farming communities, thereby threatening local food security. For example, increased flooding and salinity intrusion in the Ganges Delta has reduced the rice-growing capacity in Bangladesh.¹⁸

Differential responses of C3 and C4 Plants:

Plant species exhibit varied responses to climate change based on their photosynthetic pathways. C3 plants, which include staples like wheat and rice, may experience enhanced photosynthesis and growth under elevated atmospheric CO₂ levels. However, higher temperatures and limiting CO₂ conditions lead to photorespiration that results in less productivity in C3 plants. In addition, their lower water-use efficiency makes them more susceptible to drought conditions.

In contrast, C4 plants such as maize and sugarcane possess higher water-use efficiency and are better adapted to high-temperature environments, potentially giving them a competitive advantage in warmer climates. These varied impacts underscore the necessity for region-specific adaptation strategies to mitigate the adverse effects of climate change on global agriculture.¹⁹

¹⁶ Dar, M.H., Zaidi, N.W., Waza, S.A. et al. No yield penalty under favourable conditions, paving the way for successful adoption of flood tolerant rice. *Sci Rep* 8, 9245 (2018).

¹⁷ Sunshine Shift: Impact of climate change on India's spice production, 2024

¹⁸ Lucy M. Brichenno, Saline intrusion in the Ganges-Brahmaputra-Meghna megadelta, *Estuarine, Coastal and Shelf Science*, 2021

¹⁹ Hongchang Cui, Challenges and Approaches to Crop Improvement Through C3-to-C4 Engineering, *Sec. Plant Development and EvoDevo* (2021)

“Over the years since independence, innovations in crop and animal husbandry have propelled the country from a ‘ship-to-mouth’ existence to a food surplus nation.”

Dr. K.K. Narayanan

Member, Scientific Advisory Board,
Ignite Life Science Foundation

1.2.1 Way forward: Regional disparities in climate change impact on agriculture

As climate change is a reality, there is an immediate call for action to develop alternate pathways of working with competing countries and with competing crops for the accessibility to their resources, infrastructure, and market. By a coordinated approach towards crop cultivation based on climatic conditions in partner countries, better food and nutrition security can be achieved. This will enable India and other nations to be prepared for the futuristic food demands of growing populations. To increase the accessibility of the Indian crop market in competing countries, India needs to focus on improving agriculture and trade infrastructure, embracing technology, and international policies to foster collaborations.

Specifically, India needs to make significant investments in research and development a priority, strengthen rural infrastructure, modernize storage and warehousing, and embrace precision agriculture. In addition, by developing region-specific climate-resilient crops and by ensuring sustainable water and soil management, by integrating scientific advancements and policy interventions, global agriculture can enhance resilience, ensure food security, nutrition security and mitigate the adverse effects of climate change on farming communities.



1.3 Status of agricultural production: Global and national

Agricultural production is experiencing substantial changes due to globalization. Over the past three decades, agricultural systems have shifted from local relationships to a globalized network, linking distant production and consumption sites. This shift has altered trade patterns and the international division of agricultural labour. Major agritech firms and diversified food producers now dominate the production and consumption of agricultural products, controlling every part of the supply chain from seeds to retail. In developing areas, agricultural MNCs and local enterprises link smallholder farmers to global markets, offering vital access to capital, technology, and expertise. This linkage is essential for boosting agricultural productivity and enhancing export potential.²⁰

Global incidents like the COVID-19 pandemic, severe weather events, and the Russia-Ukraine conflict have revealed shortcomings in global agricultural production, in supply chains and in governance. Geopolitical tensions, especially the Russia-Ukraine conflict, have worsened food security worldwide. Together, Ukraine and Russia account for production of 34.1% of global **wheat**, 26.8% of **barley**, 17.4% of **corn**, and 72.7% of **sunflower oil** exports (**Fig 3**). Interruptions in these supplies have led to increased food shortages,

inflation, and trade limitations. These issues disproportionately impact low-income nations, exacerbating food insecurity. Developing countries in Asia, Africa, and Latin America depend on multinational companies for capital, technology, and market access. This reliance raises concerns about monopolistic practices and undermines independent agricultural development. In contrast, advanced agribusinesses in North America and Europe dominate the market through vertically integrated supply chains.¹⁴

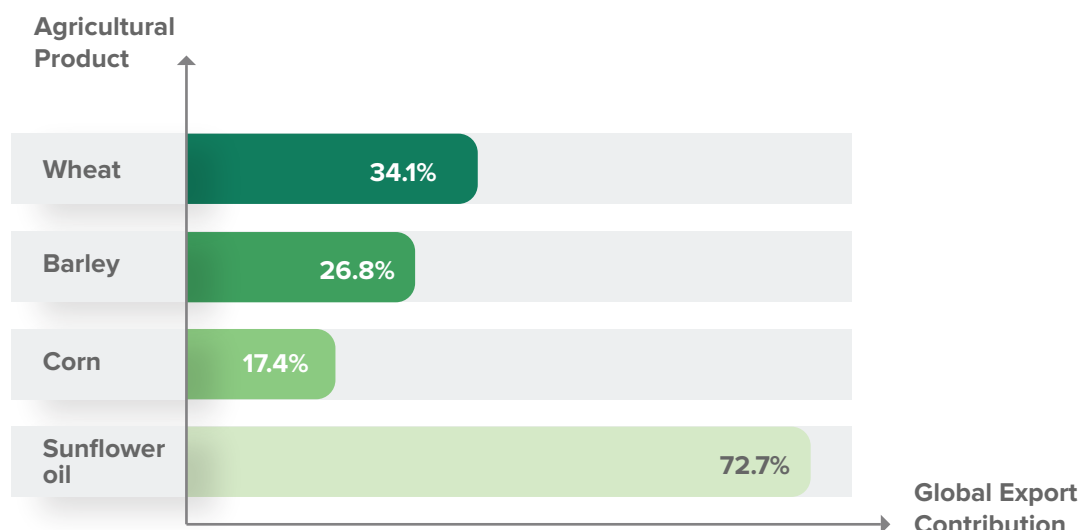


Figure 3: Agriculture production of various crops and export by regions of Ukraine and Russia

²⁰ Xinyu Yang & Weidong Liu. Agricultural Production Networks and Upgrading from a Global–Local Perspective: A Review, 2022



Indian agriculture remains a cornerstone of the economy, with diverse regional contributions across food grains, oilseeds, and horticulture. **Uttar Pradesh** leads in **wheat production** (33.95 million tonnes), **sugarcane production** (177.43 million tonnes), and production of total food grains (56.11 million tonnes).

West Bengal dominates rice production (16.76 million tonnes), while **Madhya Pradesh** ranks high in **wheat** production (22.42 million tonnes) and **maize** production (4.57 million tonnes). **Rajasthan** and **Gujarat** are key players in **oilseeds** and **cotton**, respectively. According to recent project on 'Adaptation of Indian Agriculture to Climate Change', implemented by Indian Agricultural Research Institute (IARI), New Delhi, an Info Crop simulation model assessed impact of climate change (MIROC and PRECIS scenarios) on **rice, wheat, mustard** and **potato** crops.

Climate change is projected to decrease the wheat yield in the range of 8-24% by 2050. Future temperatures may constrain higher productivity of irrigated rice in Punjab, Haryana and Rajasthan. In case of **mustard**, though yield may improve in Punjab and Haryana, in Uttar Pradesh, Bihar and Assam, it is projected to **reduce up to 6%**. The **potato** yields are projected to decline by ~6% by 2050 and by ~11% by 2080.²¹ As per the Tea Board of India, production of the world-famous **Assam tea**, known for its rich aroma and unmatched flavour, has **dropped from 6.9 million**

kilos (2022) to 5.6 million kilos in 2024, the lowest in recent times as reported and published in Hindustan Times Jammu, April 2025.

Rising temperatures have led to a significant decline in **saffron** production, plummeting from 8 metric tonnes in 2010-2011 to 2.6 metric tonnes in 2023-2024. In response, farmers in **Kashmir** are now cultivating saffron indoors, utilizing optimal nutrient conditions.

Crop losses due to extreme weather events are estimated to result in losses of around 0.25% of India's GDP. This economic strain can further exacerbate the challenges faced by farmers, leading to a cycle of low productivity and financial distress.²²

This shift emphasizes a move toward sustainable practices that are crucial for long-term resilience. There is a need to better equip ourselves with modern tools, rather than the conventional practices, that rely on natural rainfall, small landholdings, minimal mechanization, dependency on manual labour, and the use of chemical fertilizers. Investment in affordable tech like solar pumps, mobile-based integrated advisory apps, and drip irrigation methods are viable solutions. By moving away from conventional farming and adopting speedy, tech-driven methods, Indian agriculture can thrive in the face of climate challenges, while securing a prosperous future for farmers.²³

²¹ Climate Change and Agriculture in India, A Thematic Report of National Mission on Strategic Knowledge for Climate Change (NMSKCC) under the National Action Plan on Climate Change (NAPCC).

²² Pritha Datta et al, Climate change and Indian agriculture: A systematic review of farmers' perception, adaptation, and transformation, 2022, Environmental Challenges

²³ Sekhar et al., 2024. "Exploring Traditional Agricultural Techniques Integrated with Modern Farming for a Sustainable Future: A Review". Journal of Scientific Research and Reports 30 (3):185-98.

1.3.1 Way forward: Status of agricultural production

Considering the challenges of agricultural production, an organizational framework is needed to understand global agricultural production networks. Improving agricultural production requires an integrated and collaborative approach that addresses various economic, social, and environmental dimensions, with sustainability as a key component. There is a need to establish better regulatory and governance systems to prevent resource exploitation and ensure fair agricultural production practices. This is

particularly crucial for smallholders in developing regions. It is also critical to assess and differentiate facts from projections. Indian agriculture is known to be operational largely through small-scale farms. However, in many cases, land owned by multiple family members is operated as a single large unit for obvious efficiency reasons. At the national level, policy aspects may get skewed by such differences in documentary vs operational farm levels.

1.4 Adaptation & mitigation strategies to Changing monsoon & soil patterns

With erratic monsoons and shifting soil dynamics posing growing challenges, Indian farmers are increasingly adopting climate-resilient agricultural strategies to sustain productivity. **Crop diversification**, particularly the shift toward millets, pulses, and short-duration crops, has gained momentum under the National Innovation on Climate Resilient Agriculture (NICRA) framework. ICAR-led studies highlight that replacing water-intensive crops like rice with drought-tolerant millets (sorghum, pearl millet) and pulses (chickpea, pigeon pea) has enhanced soil health and improved farm resilience against unpredictable rainfall.²⁴

C3 and C4 carbon fixation are two different pathways by which plants convert carbon dioxide (CO₂) from the atmosphere into organic compounds. Understanding C3 and C4 crop adaptations has further guided crop selection strategies. While C3 crops (wheat, rice) are more vulnerable to temperature fluctuations, C4 crops (maize, millets, sugarcane) exhibit greater efficiency in carbon fixation and water use under rising temperatures.²⁵ Additionally, the C4 pathway

allows crops like corn and sugarcane to be more productive, but the overall efficiency with which plants convert light energy into biomass is still relatively low for both C3 and C4 pathways. Advances in genome-wide deep-sequencing, gene discovery, and genome editing platforms have brought the possibility of engineering a C3 to C4 conversion closer than ever before. Bill & Melinda Gates Foundation (BMGF) is funding C4 pathway research for rice. C4 rice research, currently in its early phases, hopes to develop a new type of rice with improved photosynthesis capacity. Scientists have been using C4 pathway genes from maize, which can be integrated with the rice genome. The researchers have already identified crucial genes (PEPC, PPK, NADP-ME, and MDH) needed to assemble C4 photosynthesis in rice, have defined the basic elements required for functional C4 photosynthesis, and have successfully introduced 10 out of the 13 genes needed for C4 rice.²⁶ Therefore, there is great scope for improving and integrating complete C4 metabolism into the rice genome in the coming years.

²⁴ ICAR, National Innovation on Climate Resilient Agriculture (NICRA). NICRA Report.

²⁵ FAO, C3 and C4 Crop Adaptations in a Warming Climate. FAO Report.

²⁶ Pngeng Wa, Daniela Vlad, Jane A Langdale, Finding the genes to build C4 rice. Current Opinion in Plant



Soil quality

Soil salinization has severe effects on soil quality through changes in soil structure and chemistry, soil biology, crop productivity, and yield. Farmers are implementing organic soil amendments, including biofertilizers, green manure, and compost, to combat soil degradation and enhance fertility.

The Ministry of Agriculture & Farmers Welfare's 2023-24 report conveys the role of organic carbon enhancement techniques in reversing soil salinity and alkalinity, particularly in arid and semi-arid regions.²⁷ National Innovations in Climate Resilient Agriculture (NICRA) field trials indicate that vermicompost application has led to a 15-20% improvement in water retention capacity, thereby reducing crop failure risks. Carbon sequestration

strategies, such as conservation tillage and agroforestry, have demonstrated long-term benefits in improving soil health and reducing emissions from conventional agricultural practices.²⁸

A recent study led by Dr. Lewis Ziska published in Lancet Planetary Health identified that an increase in temperature, rising levels of CO₂, accompanied by contaminated soil and water is leading to changes in the soil chemistry promoting arsenic absorption into rice grains. As rice is a dietary staple in several parts of the world, these changes raise significant human health concerns. Going forward, strategies must be devised to breed plants for minimal arsenic uptake and for improved soil management in paddy fields.²⁹



²⁷ FAO, Soil Health and Climate Resilience Strategies.

²⁸ Paul, T., Banerjee, K., Patra, P.S., Nandi, K., & Roy, S. (2019). Soil Carbon Sequestration Through Farming

²⁹ Ziska LH et al., Impact of climate change on arsenic concentrations in paddy rice and the associated dietary health risks in Asia: an experimental and modelling study. Lancet Planet Health. 2025 Apr 16



Biotic stress

Climate change has significantly impacted agriculture in India, exacerbating pest infestations that threaten staple crops such as rice, wheat, maize, and cotton. Climate change also affects **pollinators** such as bees, butterflies, moths, beetles, bats, and birds. Temperature shifts can cause earlier flowering causing mismatches in bee activity, while heat stress can reduce bee fertility. Droughts and rains destroy habitats and reduce floral resources, and there may be abiotic stress-mediated shifts in altitude and latitude by the pollinators where the particular floral resources are lacking.³⁰ Temperature shifts can also increase bee disease causing parasites, and all of these changes affect agricultural production.

Rising temperatures, erratic rainfall patterns, and increased humidity create favourable conditions for pests, leading to substantial yield losses and economic hardships for farmers. For instance, the emergence of **black thrips** has caused significant damage to chilli crops in regions of Andhra Pradesh, Karnataka, and Tamil Nadu.³¹ They are diverse in their species, behaviours, and in the kind of damage they cause to crops. A small **green fly, Empoasca Onukii** has started taking a heavy toll on the tea industry of Darjeeling and Assam reported by Hindustan Times Jammu, April 2025. Some insects, such as aphids, whiteflies, and mites, are known to suck sap from plant tissues, causing wilting, stunted growth, and eventual death of plants if the infestation is severe. In seed spices such as cumin, coriander, fennel, and fenugreek, these infestations resulted in direct crop damage as well as the transmission of viral diseases that reduced both yield and quality.³²

Other pests like caterpillars and beetles consume plant tissues, leading to defoliation and reduced productivity. Some insects serve as vectors, carrying and transmitting diseases from one plant to another, multiplying the detrimental effects on the crops. The impact of insects and pests on crop yield and quality can be immense, necessitating effective pest management strategies.³³

Strategies for pest management involve traditional methods of pesticides and fungicides and modern methods involving genetic engineering, crop management, diversification, precision agriculture, and remote sensing methods. In India, regulating pesticides and biocontrol agents is critical to safeguarding human health and the environment. This responsibility is shared by several government bodies that oversee the production, registration, use, and disposal of these substances.³⁴



³⁰Philips BB et al., "Drought reduces floral resources for pollinators. Glob Chang Biol. 2018 Jul;24(7):3226-3235.

³¹CABI: Chilli Black Thrips Outbreak: Supporting Indian Farmers to Protect Crops Sustainably, December 2, 2024Springer.

³²Springer: Handbook of Spices in India: 75 Years of Research and Development by Amit Sharangi, SankarAcharya, and Suddhasuchi Das, 2024

³³Savary et al., 2019.

³⁴Modern Agriculture, Exploring current trends,2023

“We should encourage industries connected to farming, both those that work directly on the farm and those that handle the produce after it is harvested. These industries not only help grow the economy but also help shift workers away from low-paying farm jobs to better, more productive work.”

Dr. K.K. Narayanan

Member, Scientific Advisory Board,
Ignite Life Science Foundation

1.4.1 Way forward: Adaptation & mitigation strategies to Changing monsoon & soil patterns

To achieve ambitious mitigation targets, we need to smartly implement mitigation technologies and improve the structure of agri-food systems. As anthropogenic GHG emissions are responsible for one-third of all emissions, better irrigation practices to reduce CH₄ emissions from rice cultivation,

integrating C₄ metabolism into the crops using genome editing platforms, strategies to reverse soil salinity and alkalinity, strategies to breed plants for minimal arsenic uptake, including better pest management methods should be our current priorities.

1.5 Nutritional security in the face of climate change

Climate-related factors have not only led to reduced crop yields, but have also impacted the nutritional value of our crops. A key concern to us is that the world's human population is expected to reach 9.7 billion by 2050, and global food production will need to produce 40–54% more than the current need by

sustaining the nutritional content of the food we consume.³⁵ Increased CO₂ levels are expected to reduce the nutrient content of crops, particularly protein and important minerals, which could have significant consequences for human nutrition. Specifically,



Protein content

Many crops, especially C3 grains and tubers, are expected to experience a 7-15% reduction in protein content. This could lead to over 200 million people falling below the recommended protein intake thresholds.



Mineral content

Elevated CO₂ levels can lead to a 3-11% decrease in zinc and iron concentrations in cereal grains and legumes. This could result in 150-200 million people being at risk for zinc deficiency. Increased risk of iron deficiency and anaemia, particularly among children and women of child-bearing age in countries such as India, is already evident through several studies.



Other minerals

Reductions of 5-10% in the concentration of phosphorus, potassium, calcium, sulphur, magnesium, copper, and manganese have also been observed across various crops under high CO₂ conditions.

The nutrient reductions in crops due to increased CO₂ levels could significantly affect global food security in several ways, such as (1) Increased malnutrition, (2) Disproportionate impact on vulnerable populations, (3) Increased health risks, and (4) Potential economic impacts.³⁶

In addition to nutrient loss due to CO₂ levels, toxic food contaminants like arsenic threaten human health and global food security. A recent report by Ziska et al. showed that the climate change induced increase in arsenic levels in rice grains could significantly elevate the risk to various cancers, cardiovascular disease, neurodevelopmental disorders etc. in humans.²⁸ Together, these trends pose serious challenges to both food security and public health.³⁷

Rising temperatures and erratic weather patterns also stress livestock, aquaculture/pisciculture, affecting their productivity, altering the quality of milk and meat, fertility, and immunity. Meanwhile, the increased consumption of animal-derived products, especially from industrial livestock systems has been linked to rising risks of chronic diseases, antibiotic resistance, and environmental degradation.

³⁵ FAO, 2021

³⁶ Samuel S. Myers et al., Climate Change and Global Food Systems: Potential Impacts on Food Security and Undernutrition.(2017). Annual Rev Public health.

³⁷ Neus González, et al. (2020) Meat consumption: Which are the current global risks? A review of recent (2010–2020) evidences. Food Research International.

1.5.1 Way forward: Nutritional security in the face of climate change

Developing crop varieties that maintain higher nutrient levels even under elevated CO₂ conditions could help mitigate nutrient losses. Encouraging consumption of a wider variety of foods, including those less affected by CO₂-induced nutrient reductions, could help maintain overall nutrient intake. Biofortification and enhancing the nutrient content of crops through conventional breeding or genetic modification could offset some of the nutrient losses. Improved agricultural practices, such as optimizing soil health, fertilization, and irrigation, may help maintain nutrient levels in crops.

For populations at risk, providing targeted nutrient supplements could help address specific deficiencies. Finally, food fortification, which involves adding essential nutrients to staple foods during processing, could help compensate for nutrient losses in crops. While these strategies exist, it is crucial to note that as erratic temperature patterns continue, they will influence human metabolism and alter nutritional requirements. Consequently, it becomes essential to develop crop varieties that align with these evolving needs and design food systems capable of adapting to future climatic shifts.

1.6 Technological Innovations in the agriscience yield

With climate variability posing increasing challenges to food production, India is rapidly integrating smart agricultural technologies to enhance resilience, efficiency, and sustainability.

Climate-resilient seeds:

Research institutions such as ICAR and International Maize and Wheat Improvement Center (CIMMYT) are spearheading the development of climate-resilient seed varieties, including drought and heat tolerant hybrids of wheat, rice, and maize, designed to stabilize yields amid erratic weather conditions. ICAR's stress-tolerant rice variety, **DRR Dhan-57**, has demonstrated a 20–30% yield advantage over traditional counterparts under heat and drought stress. Flooding is one of the major constraints for rice production in rainfed lowlands, especially in the years and areas of high rainfall.

Incorporating the **Sub1 (Submergence1)** gene into high-yielding popular varieties has proven to be the most feasible approach to sustaining rice production in submergence-prone areas. The Sub1 gene was identified as a major contributor under short-term submergence. Hence, breeding programs used marker-assisted backcrossing to introgress the Sub1 gene into eight regionally preferred genotypes for flood-prone areas in different countries.¹²

CRISPR/Cas9 mediated technology:

Innovative genome editing technologies have been implemented for crop improvement and disease resistance to obtain desired features. Clustered Regular Interspaced Palindromic Repeats [(CRISPR)/Cas9 (CRISPR-related protein)] is a new advancement in gene editing technology.

CRISPR/Cas9 has proven a wonderful tool for revolutionizing plant breeding and developing various biotic and abiotic stress-tolerant crops. For example, by targeting the *SIPe1* gene associated with Tomato Yellow Leaf Curl Virus (TYLCV) susceptibility and the *SIM1* gene linked to powdery mildew susceptibility, investigators generated tomato lines with reduced viral accumulation and complete resistance to powdery mildew.³⁸

Precision agriculture:

Precision agriculture is also transforming farming practices, with AI-powered yield prediction models, satellite-driven soil moisture mapping, and innovative irrigation systems improving water-use efficiency by 25% in pilot projects across Punjab and Maharashtra.³⁹ Adopting **vertical farming and hydroponics** in urban and peri-urban areas is helping mitigate land constraints while reducing water usage by up to 90% without compromising productivity. Additionally, AI-driven algorithms can analyse vast amounts of data from satellite images, weather forecasts, and soil sensors, providing farmers with precise insights into crop health, soil conditions, and optimal planting times.



Innovative water management:

Water scarcity poses one of the most significant threats to global food security and agricultural sustainability. Innovative water management technologies are crucial for enhancing agricultural productivity and sustainability, particularly in regions like Bangladesh, India, and Ethiopia, where water resources are under significant stress. One of the approaches involves the **Alternate Wetting and Drying (AWD) technique**⁴⁰, primarily applied in rice cultivation. It involves the periodic drying and re-flooding of rice fields, allowing the soil to dry to a certain extent before re-irrigation. This method contrasts with the traditional practice of continuous flooding. In addition, it is crucial to optimise financial models for irrigation. In Bangladesh, diverse financial models have emerged to facilitate access to irrigation services among smallholder farmers, such as the **Individual Ownership Model, Water Renting Services, and Group Ownership Models**.

Robotics:

The advent of robotics and automation in agriculture heralds a new era in input and resource efficiency and labour optimization. These innovations, from smart irrigation sensors to autonomous tractors and drones to robotic harvesters and weeders, are streamlining operations, reducing the need for manual labour, and mitigating the risks associated with hazardous farming activities.

³⁸ Pramanik D, Shelake RM, Park J, Kim MJ, Hwang I, Park Y, Kim JY. CRISPR/Cas9-Mediated Generation of Pathogen-Resistant Tomato against Tomato Yellow Leaf Curl Virus and Powdery Mildew. *Int J Mol Sci*. 2021Feb

³⁹ USDA, Grain and Feed Annual Report: India 2024. USDA Report.

⁴⁰ Gonçalves JM, Nunes M, Ferreira S, Jordão A, Paixão J, Eugénio R, Russo A, Damásio H, Duarte IM, Bahcevandziev K. Alternate Wetting and Drying in the Center of Portugal: Effects on Water and Rice Productivity and Contribution to Development. *Sensors (Basel)*. 2022 May

1.7 Future and direction of agriculture

The future of agriculture lies at the intersection of sustainability, innovation, and resilience. Differentiating between climate change adaptation and mitigation helps understand the two pathways and their solutions towards resilient agriculture. However, robust solutions for resilient and sustainable agriculture will come from merging the two areas for the practical utility of synergistic tools, technologies, approaches, and innovations. There are many recent innovations in intensive farming practices, such as precision agriculture with drones and sensors, automation with robotics and autonomous systems, and soil-less farming techniques like vertical farming and aquaponics. These systems must account for and must balance the books on increasing yields vs energy inputs and GHG emissions involved in generating the materials to manufacture and use the system components of the modern approaches, including synthetic fertilizers and pesticides.

Some examples of early-stage innovations enabling resilience and sustainability are: first, **electro-agriculture**, which allows crops to grow without sunlight, soil, or large land areas. The method uses **solar-powered chemical reactions** to convert carbon dioxide into organic molecules that plants can utilize, enhancing photosynthesis and allowing growth in complete darkness. While still experimental, it could significantly reduce land use and carbon emissions by facilitating vertical farming in urban areas and challenging environments.

Second, **green ammonia fertilizers**, as opposed to fertilizers produced through fossil fuels, which contribute approximately 2% of global carbon emissions. Green ammonia production relies on using renewable energy to produce hydrogen through water electrolysis, which is then combined with nitrogen from the air via the **Haber-Bosch process**, resulting in a **carbon-free ammonia synthesis**. The Korean Energy Research Institute has showcased the innovations, and companies like TalusAg are developing localized green ammonia production systems to improve food security while reducing the environmental impact associated with conventional fertilizers.

Scaling such **'balanced' technologies** is one part of the equation, and continuously innovating for sustainable agricultural production is the other part. Sustainability must run through the value chain and not only in generating the produce from the field. Hence, workable solutions can be generated only through trans-disciplinary knowledge synthesis and collaborations. Agricultural innovations must be tailored to local, regional, and national needs. Unlike information & computer technologies, which are easily adopted, agricultural advancements from the West or Asia-Pacific often face challenges due to differences in size of landholdings, ecology, climate, soil conditions, policies, and regulations. Thus, localized solutions are essential.

Most importantly, innovators need to think about challenges from two perspectives: **first, how and what their area of expertise can provide in the name of solutions, and second, what limitations in other areas of expertise are creating roadblocks in their area in providing a substantive solution**. The barriers and silos of expertise and disciplines must be overcome for effective solutions. For example, a 7-8 year breeding cycle for cereals is not conducive to providing adapted and resilient cereal varieties

when climate change is worsening on an annual basis. Yet, the breeding cycle can be shortened to 2-3 years by collaborating with physiologists working on speed-breeding and with molecular biologists working with CRISPR tools for gene editing. Also, the genetic gain can be fast-tracked through genomic selection approaches. However, such gains can make a difference only **if translational aspects of success in the farmers' fields are built into the research proposals right from the beginning**.

“

“My primary concerns are whether the key stakeholders fully grasp the long-term consequences of climate change and if those with the resources are preparing adequately.”

Mr. S. Sivakumar

Group Head, Agri & IT Businesses,
ITC Ltd.

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Part 2

2.1 Background: Gaps and barriers in Indian agriculture research

The **Ignite-ITC Agriscience SpARCs** meeting convened agricultural scientists, policy experts, economists, industry leaders, and technologists to consider the urgent challenges of climate change and food security for Indian agriculture and Indian farmers. The focus was on taking Indian agriculture from a high-risk to a more resilient, secure and hopeful enterprise activity through a multi-faceted strategy of nurturing an ecosystem anchored in knowledge, science and research. Participants discussed issues around how personalized advisory systems, scientific innovations, accurate climate forecasting, digital technology, and farmer support mechanisms could collectively transform Indian

agriculture, benefitting millions of Indian farmers. The key goals were:

- Defining short, medium, and long-term research and innovation priorities.
- Moving ideas from land to lab and vice versa with a sense of urgency without compromising on fundamentals. The latter is important to understand why something works.
- Building inter-disciplinary as well as inter and intra-institutional collaboration that drives actionable outcomes.

Technologies/Solutions available but not used effectively because of:

1. Structural agricultural challenges:

Small and fragmented landholdings, low productivity, inadequate irrigation facilities, and the effects of climate change.

2. Adoption and implementation gaps due to aging farmers:

Factors like farmer's age, education level, experience, and access to credit - significantly influence technology adoption decisions.

3. Resource use efficiency concept not fully appreciated:

Excess water, fertilizers, chemicals used where easily available and affordable. For others, these are not available or affordable, and hence productivity is affected.

4. Extension services and support systems:

The traditional agricultural extension system has not fully adapted to offer hyper-localized services and support digital and precision agriculture adoption.

5. Economic and financial barriers:

The cost of adopting new technologies remains a major obstacle. Most Indian farmers operate small landholdings with limited financial resources.

6. Knowledge and education gaps:

Lack of conventional and/or digital technology training and lack of awareness programs and outreach activities.

7. Infrastructure and connectivity gaps:

Many rural areas still lack reliable physical and/or digital facilities including extension network to be able to use technologies optimally.

8. Data and interoperability issues:

No single technology can work wonders. There could be a need for other technological solutions to have a complete package, which may not be available now, and, even if multiple and complementary technologies are available, for them to work cohesively, data platforms and their interoperability are necessary.

9. Bottlenecks in the public-private research ecosystem:

This hampers the seamless transformation of laboratory innovations into translated field applications.

10. Policy issues:

These interconnected challenges require comprehensive policy interventions, infrastructure development, financial support mechanisms, and capacity-building programs to bridge the gaps between available agricultural technologies and their effective implementation by Indian farmers.

Barriers To Technology Adoption in Indian Agriculture

Policy Interventions

01

Extension Services Adaption

02

Data Interoperability Issues

03

Resource Use inefficiency

04

Research Ecosystem Bottlenecks

05

06

Aging Farmers

07

Structural challenges

08

Knowledge Gaps

09

Economic Barriers

10

Infrastructure Gaps

Technologies and solutions are unavailable, resulting in suboptimal approaches listed below:

Reducing the use of fertilizers and other chemicals:

Excessive fertilizers and chemicals are applied with the mistaken assumption that more is better, which contributes to financial, ecological, and climate issues.

Increasing productivity under variable local stress conditions:

The unique challenge of managing both droughts and floods, either in the same regions during different seasons, or during a season at various stages of the crop, but integrated technological solutions for this dual and unique challenge are still immature. Stress conditions are becoming extremely hyperlocal challenging even the digital technologies to predict reliably in a cost effective manner.

Maintaining or improving soil health:

Efforts for increased productivity rarely, if ever, consider soil health which is a major gap in yield potential.

Pest and disease epidemiology of climate change:

There is little understanding of changes in pest and disease frequencies and pest and disease strengths with climate change.

Small-scale mechanization:

Not all digital technologies are suitable for small-scale farmers, but in the rush to sound relevant and contemporary, efforts in small-scale mechanization are suffering.

Climate mitigation, carbon sequestration, and carbon credits:

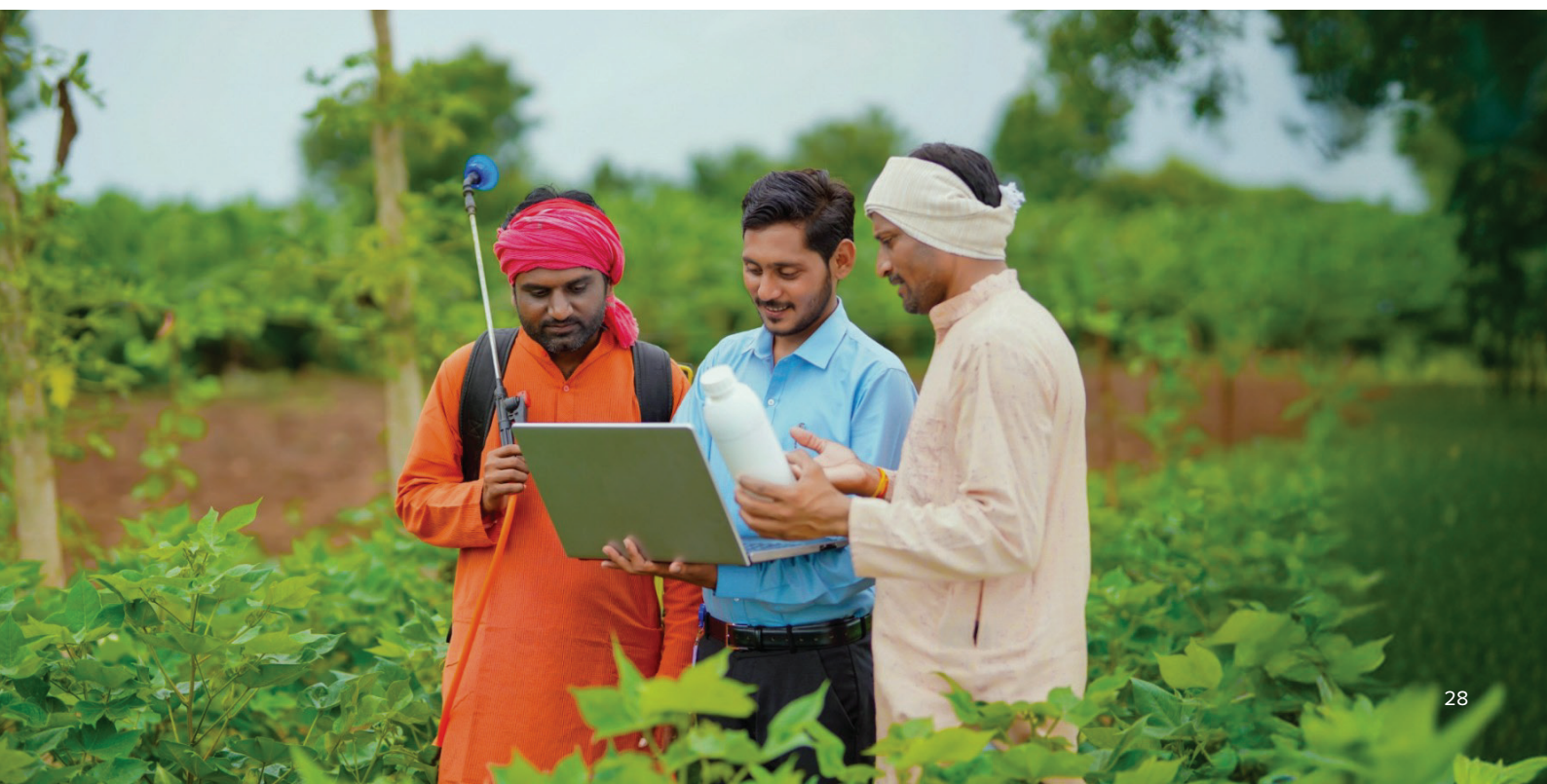
While a lot of debate is happening, there are neither platforms or adequate research on these topics, nor enough successful agri-projects at scale that have received carbon credits.

Post-harvest and value chain integration:

Despite widespread appreciation of the extent of post-harvest losses, solutions are not easily forthcoming, which derails any efforts for value chain integration.

Going for “jugaad” fixes:

There is a growing tendency to prioritize short-term, easy solutions which often lack rigorous scientific validation, in place of more permanent, deep science discovery to translation approaches.



2.2 Suggestions from the participants

Following are the inputs drawn by the proactive engagement of participants and contributions to the responses shared with Ignite and ITC, post the meeting.

Structural and organizational level issues:

- Clarify current research gaps within ICAR and similar institutions: ICAR's institutes, such as the Central Institute of Agricultural Engineering (CIAE) and IIRR have advanced labs, phenomics facilities, and seed banks. However, access is largely restricted to internal scientists rather than being open to State Agricultural Universities or external research groups. There is a much-needed mandate for the sharing of protocols and access to publications, which is poorly utilized. For example, **ICAR's** open repository, "**KRISHI**," hosts publications and data across over 110 institutes, but implementation is uneven. Many State Agricultural Universities and institutes still do not actively deposit lab data, field trial datasets, or unpublished reports, thereby limiting shared use and transparency.

Platform for information and resource sharing:

Establish a unified digital platform for real-time sharing of research infrastructure, datasets, and best practices across ICAR institutes and agricultural universities to enable collaborative research, avoid duplication, and accelerate field-level innovation in climate-resilient and nutrition-sensitive agriculture.

- Leverage datasets from platforms like ITCMAARS for AI model training.
- Develop cost-effective speed breeding facilities and protocols for under-represented crops.
- Learn from international experiences (e.g., IRRI's stress-resilient rice programs).

Research level issues:

- Promote biodegradable sensors to monitor environmental stress.
- Sensor-based Stress Detection: Use IoT and AI for real-time crop stress diagnostics.
- Improve understanding of lodging in wheat, especially root lodging over stem lodging.
- Initiate fruit breeding programs with faster innovation cycles.
- Integrate field agronomy with microbial research. Ensure practical application of microbial consortia for stress management.
- Combine genetic and agronomic interventions. For example, design flood-tolerant solutions by pairing traits (e.g., root aerenchyma) with land configuration.
- Enhance phosphorus mineralization through tailored microbial consortia.

Finance and scaling level issues:

- Harmonize financial assistance and insurance bodies and their operations.
- Use PPP models for Genomic and Systems Biology-mediated discoveries and fast-track the scaling of the innovative germplasm to the farmers.

2.3 Ideas emergent from the discussions

2.3.1 Climate change adaptation and mitigation

Monsoon variability, erratic rainfall, cloud bursts, thunderstorms, glacial melt, extreme and erratic weather (both heat and cold), groundwater depletion, land degradation, and shifting arable zones are the major risks from climate change. These are increasing at a rapid pace. Climate change is multidimensional, affecting weather predictability, crop productivity, and multiple simultaneous stresses like drought, heat, flood, salinity and pathogens. Bridging the gap between experimental and farm outcomes is critical. While crop breeding efforts concentrating on stress tolerance could be seen as ‘adaptation’ approaches, the frequency and strength of weather events warrants **‘systems approaches’ rather than single trait-based breeding approaches.**



Climate Change Adaptation

Breeding innovations:

- Move beyond Quantitative Trait Locus (QTL) identification to actual deployment in breeding programs.
- Adopt precision and speed breeding methods to accelerate varietal development.
- Integrate genomic selection to prioritize physiological traits to improve both resilience and nutrition.

Genome editing, metabolic engineering and synthetic biology:

- Exemplify and improve CRISPR-based tools to facilitate licensing and deployment barriers.
- Target traits like tolerance to physiological impacts of climate change such as stomatal responses, vapor-pressure deficit tolerance, heat-tolerant enzymes (e.g. Rubisco activase), and improved starch synthesis for future-proofing crops.

Resource use efficiency:

- Focus on water, nitrogen, phosphorus, and solar radiation use efficiency in breeding and agronomy.
- Photosynthesis at lower radiation.

Advanced Tools & sensors:

- Incorporate AI/ML tools for predicting stress response and improving agronomic decisions.
- Use digital Tools and AI such as satellite data, and climate models for forecasting, monitoring, and advisory services.

Perennial Crops:

- Expand focus from seasonal and cereal crops to perennials like fruit trees (mango, apples, etc.) to ensure diversity in diet and nutrition under climate change.

Nutri-cereals:

- These were highlighted for their stress memory, water-use efficiency, and nutritional potential. Their study can inform future designs for engineering climate resilience in mainstream cereals like rice and wheat. However, challenges remain in enhancing their palatability and consumer appeal.



Climate change mitigation

Climate-smart irrigation:

- Promote practices like AWD and aerobic rice with incentive mechanisms.
- Develop low-cost IoT sensors for resources like water, nitrogen for application.

Soil carbon sequestration:

- Enhance soil health through conservation agriculture and carbon credits-linked practices.

Standardize Measurement, Reporting and Verification (MRV) tools for strengthening carbon markets:

- Modernize carbon credit systems with blockchain for transparency.
- Develop India-specific standards for MRV (Monitoring, Reporting, Verification).

Agroforestry redesign:

- Replace unsustainable species with multi-functional systems optimized for carbon and biodiversity.

“Considering the inter-sectionalities and inter-dependencies, there is a need for a holistic and integrated approach to address the problems instead of the current siloed approach.”

Mr. L. Prabhakar

Executive Vice President and
Head, Social Investments,
ITC Ltd.

Fodder crops:

- Breed and make available higher-quality fodder to reduce livestock methane emissions.

Reduction of methane emission:

- Soil microbiome studies for oxygenation of methane.
- Develop / find rice plants with reduced methane emissions.

2.3.2 Adapting to biotic and abiotic stresses

Real-world farming involves simultaneous stresses - drought, heat, salinity, pathogens, etc. - that are rarely isolated. The need for resilient systems demands a shift from single-stress models to integrated solutions.



Emerging strategies and Research directions

Multi-stress high-throughput phenotyping:

There is a need to develop technologies that simulate combined field stresses, with an emphasis on real-world performance, rather than on lab-controlled conditions. In addition, one should use genomic selection early in the breeding cycle to reduce cost and improve efficiency in screening for multiple traits like biotic and abiotic stress tolerance.

Root traits as game changers:

- Focus on root architecture and plasticity to improve drought resilience, nutrient uptake, and anchorage (especially for lodging tolerance).
- Increase the use of tools and platforms like X-ray CT scanning that provide non-destructive insights.

Microbial consortia & soil health:

- Shift from inventorying microbes to understanding functional dynamics for stress mitigation.
- Identify individual or consortia of microbes that are widely beneficial rather than just location-specific.

Photosynthesis optimization:

- Explore C4/CAM pathway engineering, tissue-specific expression, and photo-respiratory bypass systems in crops like rice and wheat.
- Redesign RuBisCo (Ribulose-1,5-bisphosphate carboxylase / oxygenase) for altered / reduced affinity to oxygen.

Stress priming & epigenetics:

- Leverage stress memory in millets / cereals and explore epigenetic priming for crops exposed to recurrent stress.
- Use cereal grafting technology for epigenetic signals of tolerance / resistance.

Standardized metrics for measuring resilience:

- Resilience Index (yield stability under stress).
- Physiological Buffering Capacity and Time to Recovery (extent of stress tolerated in time to symptoms and time to normalcy under no stress).



2.3.3 Diversified and resilient farming systems

Multiple cropping systems:

Encourage growing multiple crops (e.g., rice + pulses) to enhance biodiversity, reduce risk, and stabilize income.

Multiple trait-based vegetable models:

Select crop varieties with high yield, pest resistance, and nutritional quality to improve sustainability and profitability.

Buffer agronomy:

Complement buffer physiology with adaptive agronomic strategies to address extreme climate variability.

Indoor aquaponics or aeroponics-based vertical farming.

2.3.4 Precision phenotyping and stress tolerance

Stomatal Dynamics:

Adjusting stomatal function to improve drought tolerance and water use efficiency.

High-throughput Screening:

Use AI, sensors, and imaging to non-destructively assess traits for abiotic/biotic stress tolerance, including insights from extremophile plants and CAM/C3 switching.

Root Traits Engineering:

Improve traits like root angle, hair density, and nodulation. Use technologies like Laser Ablation Tomography and non-destructive root phenotyping.

Aerenchyma Formation in Cotton:

Boost cotton's flooding tolerance by promoting internal oxygen transport via root aerenchyma; integrate genetic and agronomic strategies.

Transcription Factor Regulation:

Target upstream regulators (e.g., Sub1 gene) to develop multi-stress-tolerant crop varieties.

“We need large-scale implementation programmes that translate existing agricultural research into on-ground action with farmers at the center.”

Dr. Soumya Swaminathan

Chairperson, M. S. Swaminathan Research Foundation (MSSRF)
Member, Scientific Advisory Board, Ignite Life Science Foundation

2.3.5 Strengthen breeding for conservation agriculture

Dynamic phenotyping platforms:

Develop mobile and in-situ phenotyping tools integrated with IoT and satellite data to assess conservation agriculture traits (e.g., root depth, stubble retention tolerance).

Carbon-use efficiency:

Focus breeding on increased photosynthate allocation to roots for soil carbon.

Pre-breeding with landraces adapted to low-input systems:

These could offer unexplored traits relevant for conservation practices (e.g., drought escape, weed competitiveness).

Long-term trait-environment interaction studies:

A reappraisal of agro-climatic zones and set up trials across multiple agro-ecologies to understand how conservation traits interact with environmental variability and climate stress.

Non breeding approaches for crop improvement:

Cereals that were till now recalcitrant to grafting are now becoming amenable, especially rice where examples have been provided for successful grafting. Even **inter-species grafting** is being attempted. Other vegetative means, such as tissue culture approaches should be mainstreamed to reduce time to generate new varieties.

2.3.6 Nutrition and Innovation

Nutritional GIS Mapping:

Integrate crop nutrition data with region-specific health deficiency maps to guide location-specific breeding and interventions.

Behavioural economics in dietary shifts:

Research on nudging consumer behaviour (pricing, presentation, social cues) to adopt nutritious food choices.

Food formulation innovations:

Collaborate with the food industry to integrate bio-fortified grains and vegetables into value-added products (e.g., millet-based noodles, ready-to-eat pulses).

Urban kitchen garden policy:

Institutionalize support for vertical/rooftop gardening in urban areas to supplement access to fresh vegetables and microgreens. FPOs can be encouraged to put up climate-controlled vegetable production clusters, supported by land allocation (even barren) near urban areas as also subsidized electricity.

Diet–microbiome–crop linkages:

Encourage research on how different crops affect gut microbiota and long-term nutritional health — this can inform breeding for functional foods.

2.3.7 Additional Challenges and Implementation Issues

Precision policy tools:

Develop regional policy dashboards that identify where incentives (e.g., MSP, subsidies, water policies) misalign with nutrition and climate goals.

Farmer-led innovation platforms:

Institutionalize participatory innovation platforms (like Living Labs) where farmers, scientists, and start-ups co-design context-specific technologies.

'Seed-to-Stomach' certification ecosystem:

Establish third-party certification for traceability, nutrient retention, and climate resilience from seed through consumption.

Localized extension models:

Empower Gram Panchayats with AI-powered advisory tools tailored to local crops, soils, and socio-economic profiles, especially for smallholders and women farmers.

R&D for bio-inputs:

Increase investments in microbial consortia and bio-stimulants that can support nutrient uptake in degraded soils without synthetic inputs.

“Adaptation and mitigation strategies must ultimately be judged by whether they improve farmers’ income, food security, and public health, not just by yields or emission reductions.”

Dr. Ajay Kohli

Member, Scientific Advisory Board,
Ignite Life Science Foundation

2.3.8 Future Research and Policy Priorities

To build a resilient and climate-smart agricultural future, research and policy must align around key priorities such as predictive breeding, microbiome-based solutions, and region-specific agronomic strategies. Emphasis should also be placed on conservation agriculture traits, carbon-use efficiency, and leveraging digital tools for real-time data and monitoring.

Genetic and biological Innovations:

- Predictive breeding for resilience traits (drought, heat, nutrient-use efficiency).
- Balancing grain yield with nutritional quality (e.g., zinc content, chalkiness in rice).
- CAM/C3 hybrid pathways as promising stress-adaptation strategies.

Holobiome and livestock Emissions:

- Develop plant-microbiome-based solutions for nitrogen efficiency and methane reduction.
- Standardize livestock emissions data for mitigation and carbon market inclusion.

Data and infrastructure Needs:

- Create integrated region-specific agronomic recommendations.
- Improve soil monitoring through expanded remote sensing.
- Establish centralized databases and digital infrastructure for GHG and livestock data.

2.3.9 Recommended national-level initiatives

India Genebank 2.0:

Expand beyond conservation to active phenotyping and use of indigenous varieties in climate-nutrition breeding programs. Utilization of germplasm diversity is essential. Characterization of the germplasm for climate resilient specific traits relevant to the target crops of interest also needs to be undertaken.

Digital Public Good:

This should include a tool-kit with actionable intelligence for different land/climate contexts and crops that stratifies such 'known knowns' to be used by field/extension resources that can facilitate adoption by farmers. It should capture all 'known knowns' and be validated through standardised protocols.

Public science communication strategy:

Launch a multi-language, multimedia campaign to raise public awareness about nutritious crops, similar to ISRO's model for science outreach.

Pan-India school meal innovation program:

Link local agriculture with school nutrition by redesigning menus (breakfast and mid-day meals) to include seasonal, nutritious, and locally grown crops as a balanced diet.

Inter-ministerial agri-health convergence:

Mandate coordinated programming between the Ministries of Agriculture, Allied Ministries like Animal Husbandry and Fisheries, Irrigation, Health, Education, Finance and Women & Child Development under a one national secretariat.

National climate & nutrition scorecard:

Annual ranking of Districts/States based on combined metrics of climate resilience, nutrition indicators, and policy action.

2.3.10 Policy Recommendations

Supporting traditional and gender-targeted seed systems:

Establish women-friendly seed networks and input services, positioning **women as seed custodians and decision-makers**. Evidence from IRRI shows that community-based women's groups substantially increase access to quality seed, enhance the dissemination of improved varieties, and build resilience through local seed saving. Scaling this approach nationally could shift informal seed systems from fragility to self-sufficiency. However, continued neglect of gender-informed extension and systemic bias could stall progress. Similarly, the traditional sources of seeds and information could be promoted in a similar gender supportive manner, whereby nutritional and cultural aspects of certain types of seeds and crops could be protected.

Pollution-food-health nexus policies:

Launch dedicated research and policy dialogue connecting water, soil, biodiversity and air pollution to food safety and nutrition outcomes. Without this, contamination hotspots may persist, undermining public health even as agricultural production expands.

Regenerative agriculture incentives:

There is a need to integrate agro forestry, cover crops (crops grown for protection and enrichment of soil), and practices like **Zero Budget Natural Farming** into mainstream programs. India's agro-forestry policy and **Sub-Mission on Agroforestry (SMAF)** have seen agro-forestry expand to just ~8–9% of land, far from its potential for carbon sink formation and ecosystem restoration. Proper incentives could trigger a major transition, but fragmentation, regulatory hurdles, and lack of awareness remain bottlenecks.

“Farmers do not get the benefit of what has been discovered in the lab, and the regulatory process delays this further, where technology does not reach the farmers. These need to be addressed for a farmer centric approach for the benefit of the society.”

Ravichandran Vanchinathan
Global Farmer Network

Reform Krishi Vigyan Kendras (KVKs) into 'Climate-Nutrition Knowledge Hubs':

Upgrade Krishi Vigyan Kendras to provide holistic support including health, nutrition, climate adaptation, and market access. Reconfigure Krishi Vigyan Kendras to deliver integrated advisory services linking farm techniques, nutrition, climate adaptation, and market access. Given that over 700 KVKs exist, this pivot promises enormous reach, but inadequate staffing, underinvestment and rigid mandates may limit operational transformation. Status quo cannot be allowed to continue in the coming times.

Fiscal reforms for sustainability:

Pilot on tax incentives could be provided to firms and FPOs investing in climate-resilient, nutrition-sensitive agriculture. If designed well, this policy could attract more private investment into sustainable agriculture and encourage practices that protect the environment. A new Accelerator Fund could be set up for FPOs which have demonstrated good progress and are ready for scaling up to the next stage – such fund could be utilized for promoting climate-smart technologies, including digital across the crop lifecycle. However, existing subsidy systems and slow government processes might make it difficult to implement these changes quickly.

Reform the public-public and public-private interfaces:

Streamline interfaces between institutions, from discovery to dissemination, especially in genome editing, seed systems, and biologicals. This is necessary to remove the lingering operational bottlenecks that stand in the way of a seamless transition from discovery to translation to the dissemination of scientific solutions.

Mission for climate adaptation in agriculture:

This can be set up to catalyze collaboration between Weather Forecasting Agencies, Agri Research Institutions and Value Chain Players to develop

adaptation tool-kits and disseminate to farmers. To strengthen Climate Smart Agriculture, with the proposed Agri Stack as the foundation layer, two more layers could be added as part of ‘Climate Stack’ under the **Agri Digital Public Infrastructure (DPI)**.

- **Agri DPI Layer 2:** Weather forecasts for micro-regions can include decadal (using the models developed under CMIP6 for IPCC or such other for long term), as well as short-term seasonal forecasts, which could be undertaken by IMD.
- **Agri DPI Layer 3:** ICAR can use the decadal forecasts to guide varietal research under National Agriculture Research System (NARS) and develop agronomy practice tool-kits based on the yield & quality implications of different weather parameters (temperature, precipitation, wind etc) at each phenological stage of all the crops.

Value chain players can then create farmer-centric services using the above three layers, and customize them based on short-term weather forecasts. These players can be businesses, not-for-profits, farmer collectives and government agencies. Such collaborations can be formally facilitated by specially created agencies like “**National / State Climate Adaptation Councils**”.





“In a country like India with 15 agro-climatic zones and 72 sub-zones, there can be no federated solutions to combating climate change.”

Dr. Ajay Kohli

Member, Scientific Advisory Board,
Ignite Life Science Foundation



05

Conclusion

The Ignite-ITC AgriScience SpARCs meeting marked a significant step forward in fostering collaborative dialogue on known-knowns and known-unknowns and solution-oriented thinking around the urgent challenges facing Indian agriculture. By bringing together diverse expertise and lived experiences from cutting-edge researchers to grassroots practitioners, we were able to surface both the complexities and the opportunities that lie ahead.

The dialogue underscored that Indian agriculture is at a tipping point. Incremental improvements will no longer suffice. Instead, what is required is a shift - from reactive adaptation to proactive resilience-building, grounded in science, collaboration, and inclusivity. Participants collectively emphasized the need for short, medium, and long-term strategies that link research and real-world applications, supported by a robust ecosystem of data, policy, and technology.

A recurring theme across the discussions was the gap between innovation and implementation, where existing technologies remain underutilized, and novel solutions are still in early development or lack the infrastructure for scale-up. These barriers must be addressed urgently through well-coordinated public-private partnerships, policy reforms, and investments in last-mile delivery systems that reach the most vulnerable farmers.

Crucially, the meeting helped prioritize actionable areas for intervention, from genome editing and precision phenotyping to nutrient-sensitive agriculture and gender-inclusive seed systems.

The meeting called for a paradigm shift in Indian agriculture - from reactive adaptation to proactive resilience building by integrating cutting-edge science, policy, and farmer-centric design. The way forward lies in funding the focused multi-disciplinary research and ensuring last-mile delivery of climate-smart innovations. As the first steps, the list of targeted approaches above was discussed within the **Ignite Scientific Advisory Board** for actionable items based on immediate priorities or criticality for future scenarios to come up with action to be taken as

- Evolve / Create science based, transparent and predictable regulations for GM / genome edited crops.
- Enable farmer adoption through subsidies, digital FPO networks, and behavioral incentives.
- Build a national agri-data platform for AI-driven advisory systems.
- Establish a National Agri-Climate Resilience Observatory to evaluate and steer interventions.
- Prioritize private-public software partnerships for scalable breeding tools (e.g., Phenome Networks).
- Encourage speed breeding in fruit crops, where India lags in varietal innovation.

It also spotlighted the need for institutional transformation, from reforming extension models and research-sharing platforms to integrating health, nutrition, and climate goals within agricultural planning.

This meeting is not an end, but a starting point - a foundational effort to shape an agricultural future that is not only climate-resilient and technologically empowered, but also nutritionally secure, economically inclusive, and ecologically sustainable.

We hope this document sparks further collaboration and inspires stakeholders across sectors to join hands in driving sustainable agricultural transformation. Ignite Life Science Foundation and ITC Ltd. remain committed to catalyzing this transformation by supporting cutting-edge science, enabling cross-sectoral partnerships, and ensuring that innovation reaches every field and farmer. The journey ahead is challenging - but with collective commitment and shared vision, it is undoubtedly achievable.



“We must move beyond disciplinary boundaries and form multidisciplinary teams, from scientists to stakeholders, to generate knowledge and technologies that solve real-world problems.”

Prof. Ramaswamy Subramanian

Director, Bindley Bioscience Center,
Purdue University
Chairperson, Scientific Advisory Board,
Ignite Life Science Foundation

06 Acknowledgements

We begin by extending our heartfelt gratitude to the farmers of our nation whose tireless work forms the backbone of our food and nutrition security. Their dedication sustains not just our plates, but our entire society.

To all our agriscience community members who took the time and effort to travel and contribute over three focused days at the SpARCs meeting, thank you. Your willingness to engage, reflect, and collaborate was central to identifying challenges and shaping new ideas to address them.

A sincere thank you to our partner ITC, represented by Mr. S. Sivakumar Group Head, Agri & IT Businesses, ITC Ltd. and Mr. L. Prabhakar Executive Vice President and Head, Social Investments, ITC Ltd., for the steadfast support and shared commitment to advancing agriculture in meaningful ways.

We are deeply grateful to our key facilitators, Dr. Ajay Kohli, Dr. K.K. Narayanan, and Dr. Ram Subramanian, members of the Ignite Scientific Advisory Board, for their valuable guidance, encouragement, and for constantly inspiring the community to think innovatively and act with purpose.

We also thank the Ignite Project Management Team, Andrea and Ambika for their behind-the-scenes dedication and continued engagement with ITC to keep this mission moving forward.

Lastly, we're grateful to everyone who contributed directly or indirectly to this initiative. This white paper is a reflection of your collective wisdom, energy, and belief in creating impact for society at large.



“With more than a quarter of the global workforce relying on agriculture as the primary source of livelihood, and many of them poor, it’s agriscience that can raise their incomes through innovation.”

Mr. S. Sivakumar

Founder, M.S. Group Head, Agri & IT Businesses,
ITC Ltd.



07

Agriscience community members

Name	Organization
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Ms. Ramona Parsani	Ignite Life Science Foundation



08 Glossary

01

AI (Artificial Intelligence)

A branch of computer science that uses algorithms and data to enable machines to mimic human decision-making and learning. In agriculture, AI is used for yield prediction, pest monitoring, and advisory systems.

02

Agro-forestry

An integrated land-use system that combines agriculture and tree cultivation, aiming to improve biodiversity, productivity, and sustainability.

03

Aerenchyma

Plant tissue containing large air spaces, which facilitates internal oxygen transport, especially in crops like rice and cotton under flooded conditions.

04

AWD (Alternate Wetting and Drying)

An irrigation technique used in rice farming to reduce water use and methane emissions by periodically allowing the field to dry before re-irrigation.

05

Anthropogenic

Originating from human activity, often used in the context of climate change contributions such as greenhouse gas emissions from agriculture and industry.

06

Biofortification

Breeding crops to increase their nutritional value (e.g., higher iron, zinc, or vitamin A content) through conventional or molecular techniques.

07

Carbon Credits

Tradable permits representing the right to emit a specific amount of carbon dioxide. In agriculture, credits can be earned by adopting climate-smart practices.

08

Carbon Sequestration

The long-term storage of carbon in soil, plants, or geological formations, used as a strategy to mitigate climate change.

09

C3 and C4 Plants

Two types of photosynthetic pathways in plants. C3 plants (e.g., rice, wheat) are less efficient under high temperatures, while C4 plants (e.g., maize, sugarcane) perform better in hot, dry climates.

10

CAM Plants (Crassulacean Acid Metabolism)

A photosynthetic adaptation seen in desert plants (e.g., pineapple, cacti) that allows them to conserve water by fixing carbon dioxide at night.

11

CRISPR/Cas9

A genome-editing tool that allows for precise modifications in DNA. Used in agriculture for developing stress-tolerant and disease-resistant crop varieties.

12

CSA (Climate-Smart Agriculture)

An approach to agriculture that sustainably increases resource efficiency and productivity, enhances resilience, and reduces greenhouse gas emissions.

13

DPI (Digital Public Infrastructure)

This refers to the foundational digital systems that enable secure, inclusive, and scalable delivery of public and private services.

14

DSR (Direct seeding of rice)

It is a rice cultivation method where seeds are sown directly into the field (dry or wet soil) instead of the traditional method of growing seedlings in a nursery and then transplanting them into puddled fields.

15

Epigenetics

Heritable changes in gene expression that do not involve changes to the underlying DNA sequence. Used in stress memory and priming strategies for crops.

16

FPO (Farmer Producer Organisation)

A collective of farmers organized as a business entity to enhance bargaining power, market access, and adoption of technology.

17

GHG (Greenhouse Gases)

A set of technologies (e.g., CRISPR) that allow scientists to change an organism's DNA with high precision.

18

Genome Editing

A set of technologies (e.g., CRISPR) that allow scientists to change an organism's DNA with high precision.

19

Genomic Selection

A breeding approach that uses genome-wide markers to predict the performance of plants or animals, accelerating varietal development.

20

GIS (Geographic Information System)

A framework for gathering, managing, and analyzing spatial and geographic data, used in agriculture for precision mapping and nutrition tracking.

21

ICAR (Indian Council of Agricultural Research)

India's apex body for agricultural research and education, under the Ministry of Agriculture.

22

IMD (India Meteorological Department)

It is the national agency for weather and climate services in India, functioning under the Ministry of Earth Sciences (MoES).

23

IoT (Internet of Things)

A network of connected devices (e.g., sensors, drones) used to collect and exchange data. In agriculture, IoT supports precision farming.

24

ITCMAARS

ITC (Metamarket for Advanced Agriculture and Rural Services) is a crop-agnostic full stack Agritech platform coupled with a 'phygital' ecosystem. It empowers the farming community by delivering AI/ML enabled personalized and dynamic advisory services, climate-smart technologies as well as hyperlocal offerings, including market linkages, agri inputs and credit enablement.

25

KVKs (Krishi Vigyan Kendras)

Agricultural extension centres in India that provide farm-level technology dissemination and training to farmers.

26

MNC (Multinational Company)

It refers to a company that is headquartered in one country but operates in multiple other countries through subsidiaries, branches, or joint ventures.

27

MRV (Monitoring, Reporting, and Verification)

A framework used to measure the effectiveness of climate-related actions, particularly in the carbon market context.

28

N₂O (Nitrous Oxide)

A potent greenhouse gas primarily released from agricultural activities like fertilizer use. It has 300 times the global warming potential of CO₂.

29

NICRA (National Innovations in Climate Resilient Agriculture)

A flagship ICAR initiative focused on developing and promoting technologies to make agriculture resilient to climate change.

30

Nutri-cereals

Also known as millets; these are climate-resilient, nutrient-rich grains (e.g., pearl millet, finger millet) important for food and nutritional security.

31

Participatory Innovation Platforms (e.g., Living Labs)

Collaborative spaces where farmers, researchers, and innovators co-design agricultural solutions tailored to local needs.

32

Phenotyping

The process of assessing observable traits of plants (e.g., drought resistance, yield). Precision phenotyping uses sensors, imaging, and AI tools.

33

PPP (Public–Private Partnership)

A collaborative arrangement between government agencies and private companies to fund, design, and implement development projects.

34

QTL (Quantitative Trait Loci)

Genomic regions that are associated with complex traits such as yield or drought tolerance. Used as markers in plant breeding.

35

Rubisco (Ribulose-1,5-bisphosphate carboxylase/oxygenase)

Rubisco (Ribulose-1,5-bisphosphate carboxylase/oxygenase)

36

SAUs (State Agricultural Universities)

Autonomous institutions in India focused on agricultural education and research at the state level.

37

Speed Breeding

A technique to accelerate plant growth and reduce breeding cycles using controlled lighting and temperature conditions.

38

Sub1 Gene

A gene introduced into rice varieties to enhance tolerance to submergence due to flooding. A key component of flood-resilient rice breeding programs.

39

Synthetic Biology

An interdisciplinary field that applies engineering principles to biology to design and build new biological functions or systems.

40

ZBNF (Zero Budget Natural Farming)

A farming method that relies on natural inputs without synthetic chemicals or fertilizers, aimed at reducing input costs and improving sustainability.



“Curiosity must meet collaboration: only then can science tackle the challenges of our time. And, at Ignite we will endorse such initiatives.”

Prof. Ramaswamy Subramanian

Director, Bindley Bioscience Center,
Purdue University
Chairperson, Scientific Advisory Board,
Ignite Life Science Foundation

This White Paper is based on discussions, presentations, and exchanges of ideas during the Special Academic Research Cooperatives (SpARCs) held from April 27th to 29th, 2025, at Hyderabad. The contents reflect the collective opinions and perspectives of participants, synthesized with desk research, and also views of experts from Ignite Life Science Foundation. Readers are advised and encouraged to consider the White Paper as a reference document and do further study/research where necessary before taking any decisions.



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