Policy Paper 50

Indian Agriculture to 2047

Reshaping Policies for Sustainable Development

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Citation: Pratap S Birthal, Shivendra K Srivastava, Raka Saxena, Samarth Godara, Prem Chand, Prabhat Kishore, Jaya Jumrani, Ankita Kandpal, Purushottam Sharma, and Devesh Kumar Pant. (2025). Indian Agriculture to 2047: Reshaping Policies for Sustainable Development. Policy Paper 50. ICAR-National Institute of Agricultural Economics and Policy Research, New Delhi.

Published
March 2025

Published by
Dr P S Birthal
Director
ICAR-National Institute of Agricultural Economics and Policy Research (NIAP)
New Delhi-110012

Pratap S Birthal, Shivendra K Srivastava, Raka Saxena, Prem Chand, Prabhat Kishore, Jaya Jumrani, Ankita Kandpal, Purushottam Sharma, and Devesh Kumar Pant are affiliated with the ICAR-National Institute of Agricultural Economics and Policy Research (NIAP), New Delhi. Samarth Godara is associated with the ICAR-Indian Agricultural Statistics Research Institute, New Delhi. The views presented in this paper are those of the authors and do not necessarily reflect the official policy or position of the institutions, they are affiliated.

Printed at
M/s Chandu Press, 469, Patparganj Industrial Estate, Delhi 110 092.

Foreword

Indian agriculture has reached the stage of unprecedented achievements, accompanied by unprecedented challenges. It has witnessed an all-time high growth of approximately 4% during the past decade ending 2023-24, which is likely to continue with the right set of technologies, policies and institutions. However, it is pertinent to examine the factors underlying these achievements and their associated costs to prepare a roadmap for sustainable growth of agriculture to achieve the national goals of food and nutrition security, and inclusive development. In some states, agricultural sector has emerged as the primary driver of economic growth. However, this occurred because of the intensive use of resources and prioritizing short-term gains over long-term sustainability in most cases. This is evidenced by the factors such as increased use of fertilizers to produce the same amount of output, declining groundwater levels, soil degradation, and environmental pollution.

This paper discusses achievements in Indian agriculture, while simultaneously highlighting the challenges associated with these. The beauty of this paper lies in its systematic compilation and presentation of the scattered data and evidence in a cohesive manner and their interpretations in light of emerging challenges and opportunities. It quantifies the role of various factors such as technology and prices in agricultural growth and highlights that the contribution of prices has surpassed significantly the contribution of technologies in the recent past. However, price-driven growth has several social and economic implications. The Working Group and Steering Committee on Agriculture for the Eleventh Five-Year Plan (2007-2012) highlighted that the growth driven by an increase in real prices is unsustainable in the long-run. Another implication is the divergence in the share of agricultural sector in the gross value added (GVA) at constant and current prices. Between 2011-12 and 2023-24, the share of the agricultural sector in the total GVA at constant prices (base year 2011-12) decreased by 22%, from 18.5% to 14.5%, whereas at current prices, it did not show any significant change, indicating that agricultural prices increased at a higher rate than the prices of non-agricultural commodities. This increase in prices was partially market-driven and predominantly influenced by the increase in the Minimum Support Prices (MSP) by the central government and bonuses given by several state governments over and above MSP. This prevented demand signals from guiding production decisions, resulting in distortions in cropping patterns and imbalances in the demand and supply of various commodities. Price intervention also resulted in significant market distortions, which have had an impact on agricultural trade, as maintaining artificially high prices through interventions restrict exports and favors imports. The third significant consequence of price-driven growth is the decrease in the competitiveness of domestic production, which also translates into an increase in inflation.

This policy paper shows that the production of commodities, such as rice and wheat, has increased at a rate exceeding domestic demand, resulting in an increase in their surplus. This necessitates an increase in exports to dispose of produce, and, pushing more exports requires improvement in the competitiveness. However, the sources of recent growth indicate that the real cost of production is not declining, and this disadvantage is further exacerbated by price distortions.

Maintaining 4% or higher growth in the agricultural sector requires primacy of technology and an increase in production efficiency. It also requires competitive prices that correspond to supply and demand dynamics. A significant challenge in balancing the role of price intervention and ensuring adequate returns for farmers is identifying the appropriate price intervention measures. India will have to rely on alternative options beyond MSP to ensure remunerative prices for farmers. Alternatives include implementing MSP payments without imposing them on the market dynamics through price deficiency payments, increasing the involvement of the private sector in marketing, developing efficient and integrated supply chains, and improved agricultural infrastructure.

For the long-term sustainability of agriculture, non-price factors must receive adequate attention and price interventions should avoid distorting markets. The country must promote the responsible use of land, water, and energy, and implement climate-smart techniques to achieve the overarching goal of net-zero emissions while ensuring welfare of farming communities.

This paper advocates a shift in the business-as-usual approach toward an adaptive policy framework that encompasses technologies, market forces, infrastructure, and institutions to address interconnected challenges for a sustainable future for agriculture. I congratulate the authors for this valuable and timely contribution on the current state of Indian agriculture and clearly articulating the set of policies which may serve as a crucial reference point for future discussions and initiatives aimed at transforming agriculture into a more resilient, efficient, and sustainable sector of Indian economy.

Ramesh Chand
Member
NITI Aayog

Preface

India's agri-food system has undergone significant transformation over the past six decades, with changes occurring both upstream in production and downstream in distribution and consumption. As the country looks to the future, these changes are expected to continue. The ambitious goal of achieving the status of a developed nation by 2047, the centennial year of its independence, will impact the transformation of the agri-food system. While this transformation may offer opportunities for growth, it is accompanied by multiple challenges, including climate change, water scarcity, land degradation, fragmentation of landholdings, and limited access to markets and finance. Addressing these challenges will be crucial to ensure that the ongoing transformation of the agri-food system supports the progress towards achieving the status of a developed nation.

This paper synthesizes scattered data and empirical evidence to provide a comprehensive analysis of the existing and potential challenges and opportunities in the agri-food system transformation. By elucidating both challenges and prospects, it provides a balanced perspective on the current state of affairs and potential pathways for fostering a more resilient, efficient, inclusive, and sustainable agri-food system. It advocates for an adaptive policy framework, developed through comprehensive consultation with diverse stakeholders, capable of responding to emerging challenges and opportunities. We hope that the insights provided here will be useful for policymakers and other stakeholders.

This paper has been built upon the issues raised by the first author in his presidential address at the annual conference of the Agricultural Economics Research Association (India) held on December 11-13, 2024 at Indira Gandhi Krishi Vishwavidyalaya, Raipur (Chhattisgarh). The authors thank the conference participants for their comments and suggestions. In addition, several professionals have provided their valuable comments on an earlier draft of this manuscript. The authors express their sincere gratitude to all of them for their inputs. Particularly noteworthy are the contributions of Prof Ramesh Chand, Member, NITI Aayog, Dr P K Joshi, former Director (South Asia), International Food Policy Research Institute, and Dr Devesh Roy, Senior Research Fellow, International Food Policy Research Institute, whose expertise in agri-food policy has enriched the paper's perspective. The authors are deeply appreciative of their time and effort in reviewing and offering suggestions that helped us in bringing the manuscript in its present form.

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Executive Summary

Over the past six decades, advancements in agricultural research, coupled with the investments in irrigation, rural infrastructure, and electrification; the development of institutions and innovations for the delivery of technologies, information, and financial services; and the provision of financial incentives in the form of input subsidies and minimum support prices (MSP) for key crops have transformed India from a food-insecure to a food-surplus nation. Beyond ensuring food security, this transformation has enhanced the country's capacity to mitigate risks to food security arising from extreme changes in climate and global supply chain disruptions. Furthermore, this enabled India to emerge as a significant supplier of various agricultural commodities to international markets, thereby contributing to global food security.

Nonetheless, India's agri-food system is at a crossroads, confronting both challenges and opportunities. By the 100th year of its independence in 2047, India aims to attain the status of a developed nation. Progressing towards this goal would necessitate an economic growth rate of approximately 8% per annum, implying a significant increase in purchasing power. By this time, of the projected 1.6 billion population, approximately half may reside in urban areas. Thus, the need to produce more and diverse foods remains as urgent as ever. By 2047, the aggregate food demand is projected to exceed twice the current demand, whereas the demand for nutrient-rich foods, including horticultural and animal products, is expected to increase 3-4 times. However, to meet the growing food demand, the agri-food production system will face numerous interconnected challenges spanning biotic, abiotic, and structural dimensions.

At the same time, the agricultural sector is expected to experience significant structural transformations. By 2047, its contribution to the national income may decrease to 8% from the current 18%. However, the sector will remain important from the perspective of employment, engaging 29% of the total workforce, 17 percentage points less than at present. Concurrently, the average landholding size is expected to decrease significantly to 0.6 hectares from approximately one hectare now. Nonetheless, in response to these changes, to maintain and improve their livelihoods, farmers would increasingly diversify their production portfolios towards less land-intensive activities such as animal husbandry and fisheries. Projections indicate an increase in the contribution of livestock to the gross value of agricultural output to 39% from the current 31%, and of fisheries to 10% from 7%. The fast-growing demand for milk, meat, eggs, and fish compared to staple cereals signals this structural transformation in the agricultural sector.

Furthermore, agricultural land is expected to decrease from 180 million hectares in 2022-23 to 176 million hectares by 2047. The net cropped area shrinks marginally, prompting farmers to practice multiple cropping on the same piece of land. Hence, the cropping intensity is likely to increase to 170% from the current 156%. However, the intensification of cropland is unlikely to be without environmental consequences. This increases the pressure on already strained water and energy resources. Agriculture is a major consumer of water (83%), and by that time, its demand will be approximately 18% higher than its current use. Notably, in the past, irrigation expansion occurred primarily by exploiting groundwater resources facilitated by subsidies on electric power. Nonetheless, this has resulted in overexploitation of groundwater in some regions, particularly in northwestern states of Punjab, Haryana, and Rajasthan. Water use efficiency is also low at 35-40%, which is roughly one-third to one-half of the efficiency levels observed in China, Brazil, and the United States.

In addition to the growing water stress, there is another equally important concern of deteriorating soil quality due to intensive agricultural practices, especially the indiscriminate and imbalanced use of chemical fertilizers. Over time, fertilizer use has increased substantially, but accompanied by a notable bias towards nitrogenous (N) fertilizers due to comparatively higher subsidies relative to phosphatic (P) and potassic (K) fertilizers. Furthermore, fertilizer use efficiency remains low at: 35-40% for N, 15-25% for P, and 50-60% for K fertilizers, which prompts increased use of fertilizers leading to their higher cost of application, while simultaneously affecting the health of natural resources and the environment.

Climate change is a looming threat to agriculture and agriculture-based livelihoods. Over the past five decades, extreme climate events such as droughts, heatwaves, and floods have reduced India's agricultural productivity growth by approximately 25%. As the frequency of such events is projected to increase, they will adversely affect crop yields and food supplies, potentially impacting the nation's food and nutritional security. Notably, approximately 14% of the country's population remains undernourished, while 35.5% of children under five years of age are classified as stunted and 32.1% as underweight.

The challenges facing the agri-food system are multifaceted and interconnected, and their management requires a comprehensive approach encompassing technological and institutional innovations, investments in infrastructure, and reforms in incentive structures. Through a careful examination of the existing policy frameworks in light of the evolving landscape of agri-food system, this study argues for a dynamic and adaptive policy framework capable of responding to emerging challenges and opportunities.

The following are some important technological, institutional, and policy measures proposed for an efficient, sustainable, and inclusive agri-food system.

Efficient management of water resources: Rainwater harvesting and groundwater recharge are crucial for maintaining sustainability of water resources. The current water use efficiency of 35-40% indicates significant room for improvement in water management practices. A 10% increase in efficiency can lead to substantial water conservation, potentially providing enough water to irrigate an additional 14 million hectares.

Micro-irrigation can significantly enhance water use efficiency. Currently, only 18% of the 88 million hectares suitable for micro-irrigation has been exploited, saving 11 billion cubic meters (BCM) of groundwater. If fully harnessed, the country can save 65 BCM of groundwater, which can irrigate 33 million hectares. Alongside, there is need for increased investment in canal irrigation systems, which have deteriorated over time. Finally, the integration of digital innovations in irrigation systems, such as smart sensors, automated controls, and data-driven decision-making tools, can help optimize water use. Realigning cropping patterns with the available water endowment is a key strategy for water conservation. This can be accomplished through a tiered water pricing system, which incentivizes low consumption and penalizes wastages, potentially resulting in a shift in cropping patterns away from water-intensive crops such as rice.

Reforms in power sector: Efforts towards water management may remain ineffective in the absence of power sector reforms. The gradual phasing out of electricity subsidies, by targeting those who require such support, is a feasible option of reducing the indiscriminate use of water and electricity. This may involve designing a region-specific tiered electricity tariff system built upon water requirements of the existing cropping patterns.

Repurposing electricity subsidies to renewable energy sources, such as solar and wind power, can reduce dependence on fossil fuels. India has a significant untapped solar power potential for agriculture. Only 1% of the 102 Gigawatt potential is currently exploited despite significant incentives for farmers to switch over to solar pumps. However, the desired outcomes cannot be achieved, as long as state governments continue to subsidize electricity for irrigation.

Reforms in fertilizer sector: The fertilizer subsidy policy exhibits a predisposition towards nitrogenous fertilizers, thereby causing an imbalance in soil nutrients, potentially compromising long-term soil health and agricultural productivity. The current NPK ratio stands at 11.8:4.6:1 as against the optimal 4:2:1. Although the government has implemented initiatives, such as Soil Health Cards (SHCs), to address these issues, their effectiveness has been limited due to lack of their integration with fertilizer subsidy distribution. Currently, the distribution of subsidized fertilizers is linked with Aadhar Cards, which serve as identifiers for individual farmers. Linking fertilizer subsidies to SHCs can optimize nutrient applications and restore the nutrient balance.

The reallocation of fertilizer subsidies to organic fertilizers and sustainable agricultural practices, such as crop rotation, intercropping, and conservation tillage, can address environmental concerns while enhancing agricultural sustainability.

Emerging technologies offer promising avenues for enhancing fertilizer use efficiency and mitigating environmental impacts. Nano-fertilizers, which release nutrients gradually and precisely, have the potential to minimize nutrient loss. Unmanned aerial vehicles (i.e., drones) equipped with sensors and GPS technology can apply fertilizers with high precision, thereby reducing the risk of nutrient runoff.

Bundled approach to mitigate climate change impacts: Farmers face multiple risks, sometimes during the same crop growing cycle. Therefore, a single strategy to mitigate risks is unlikely to be as effective as the combined implementation of multiple strategies. When jointly implemented, climate-smart practices, including resilient cultivars, efficient irrigation systems, crop diversification, and soil and water conservation, can significantly enhance resilience and productivity in agriculture.

Crop insurance serves as a significant mechanism for risk mitigation; however, its adoption is constrained by several factors, including its uncertain payoffs, and the higher and reliable payoffs of alternative risk management strategies, such as irrigation, and the financial constraints. To address these challenges, there is a need for risk zoning and differentiated premium rates as well as the provision of crop insurance as a financial package along with institutional credit. More importantly, the integration of digital innovations such as satellite-based remote sensing and unmanned aerial vehicle technology can enable more accurate risk assessment and the development of region-specific tailored insurance products.

Parametric insurance, which automates payouts based on predefined weather triggers, offers a promising alternative to traditional area-yield insurance. It streamlines claim processes and may incentivize farmers to adopt improved technologies and practices to improve productivity and resilience of agriculture.

Stability in investment in agricultural R&D: Agricultural research has considerable potential to address several challenges, including enhancing productivity and resilience, combating malnutrition, and reducing poverty.

The payoffs to investment in agricultural R&D are quite attractive; Rs 13.85 for every rupee spent. Notably, animal science research generates almost twice the return compared to crop science research.

Despite such high payoffs, agricultural R&D in India remains underfunded. In 2022-23, India spent 0.43% of its agricultural gross domestic product (AgGDP) on research, which is less than the global average of 0.93%. Private sector investment in agricultural research is low, at approximately 7% of the total, compared to 35-50% in middle-income and developed countries. Agricultural extension, which serves as a bridge between research and farming communities, also remains underfunded, accounting for only about 0.12% of the AgGDP.

Agricultural research is capital intensive and involves a long gestation period to generate output. Uncertainty in funding may disrupt the research process. Thus, there is a need for sustained public investment in agricultural research and complementing it from other sources such as philanthropic organizations and the private sector. Furthermore, R&D should prioritize high-value sectors, including animal husbandry and fisheries, as well as the management of natural resources and climate change impacts.

Crop planning: Crop diversification as a sustainable agricultural practice has several benefits such as climate risk mitigation, pest management, improved resource efficiency, and stable farm income. Aligning cropping patterns with resource endowments and climate conditions is a crucial step but is not sufficient to drive the widespread adoption of crop diversification. Understandably, farmers are primarily motivated by higher profits. Thus, there is a need for strategies, including financial incentives and market support mechanisms to offset potential revenue losses during the transition period.

High-value crops, such as fruits and vegetables, are an economically attractive option in diversification strategies; however, their successful integration into farming systems requires robust market infrastructure, including cold storage and refrigerated transport, and financial support to help farmers and other stakeholders navigate the initial capital costs and market uncertainties.

Strengthen market infrastructure and value chains: The development of market infrastructure has not kept pace with the increasing commercialization of agriculture, resulting in supply chain inefficiencies and limited ability of farmers to realize remunerative prices. Farmers sell 46–99% of their produce to local traders and other informal buyers. e-NAM (Electronic National Agriculture Market) is an important initiative towards modernizing agricultural marketing system. However, its implementation encounters several challenges, particularly inadequate infrastructure and quality control measures, which need to be addressed for better functioning. Strengthening institutional arrangements, such as Farmer Producer Organizations (FPOs), cooperatives, and contract farming, can serve as an important mechanism in linking farmers to remunerative markets, reducing transaction costs and market risks.

Reform agricultural price policy: The MSP-based procurement policy, although an income safety net for farmers, has resulted in unintended consequences for natural resources and agro-biodiversity, which may threaten the long-term sustainability of agriculture. Thus, there is a need to reform the price policy. The price deficiency approach, which compensates farmers when market prices fall below the MSP, is an important means of protecting them from market uncertainty and price fluctuations. The effective implementation of decentralized procurement can lead to more efficient and localized decision-making, potentially improving responsiveness to regional needs. Engaging the private sector in procurement can introduce market-driven efficiency and potentially expand market access for farmers. Targeted procurement through futures trading, facilitated by collectives such as FPOs and cooperatives, is an opportunity for smallholder farmers to benefit from economies of scale and reduced price risks. On the other hand, direct income support offers a more straightforward means of financial assistance, bypassing some of the complexities associated with market interventions.

Reform agricultural credit policy: Institutional credit to agricultural sector has experienced significant increase, with credit intensity (ratio of credit disbursed to AgGDP) increasing from 0.05 in 1970-71 to 0.48 in 2022-23, contributing substantially to the productivity and resilience of agriculture. However, credit allocation continues to exhibit persistent bias across enterprises, regions, and purposes. Animal husbandry, for instance, receives only 6% of the total agricultural credit despite being an important source of income for farmers. Furthermore, short-term credit dominates credit disbursements, with a share of approximately 60%, neglecting the long-term essential for private capital formation in agriculture. Additionally, the prioritizing productivity enhancement over risk management leaves farmers vulnerable to climate-related challenges. Geographically, there is a notable imbalance in credit distribution, with the southern states demonstrating significantly higher credit intensity.

Such persistent biases suggest the need for a comprehensive review and reform in agricultural credit policy, aligning with emerging challenges and opportunities. The policy should prioritize financing risk management and high-value commodities and reducing regional disparities in disbursements.

Stability in public investment in and for agriculture: Public expenditure on agriculture has increased considerably; however, as a proportion of the total development expenditure, it has remained relatively low, fluctuating between 2% and 6% over the past three decades. Uncertainty in investment is more harmful than low level of investment. Thus, there is a need for renewed emphasis on agricultural sector in development planning. Furthermore, a notable shift in investment priorities has occurred in favor of storage and warehousing, currently accounting for approximately 50% of the total development expenditure, *albeit* at the expense of investment in animal husbandry, dairy development, fisheries, soil and water conservation, and agricultural research, which are crucial drivers of agricultural growth.

While investing in post-harvest infrastructure is essential, but not at the cost of production sectors that are crucial for food and nutrition security and farmers' welfare. Furthermore, given the increasing demand for processed foods, establishing a conducive business environment for private sector investment in post-harvest infrastructure by streamlining regulatory processes is necessary.

Trade facilitation: Although India's agricultural exports have grown remarkably, there remains untapped potential for several commodities because of issues related to product quality, food safety compliance, inadequate infrastructure, and limited market intelligence capabilities.

To leverage its agricultural export potential, India must follow a comprehensive approach, including prioritizing export commodities and implementing Good Agricultural and Manufacturing Practices to enhance productivity, quality, and export competitiveness. Therefore, strengthening quality control measures along the supply chain is essential to meet international quality standards. The regulatory framework and compliance mechanisms must be revisited and aligned with global requirements. Further, investing in value addition and food processing can significantly accelerate agricultural exports of higher-value products that command premium prices in international markets.

India's substantial reliance on imports of edible oils, pulses, and fresh fruits is a significant challenge. A comprehensive approach is required to address this issue, emphasizing domestic production through targeted R&D, providing incentives to farmers, and calibrating import tariffs.

Moreover, a robust market intelligence system is essential for today's globalized world. This system can provide valuable insights into consumer preferences, regulatory requirements, and competitive landscapes in existing and potential export markets, thus enabling producers and exporters to make informed decisions regarding strategies to boost exports.

Collective or cooperative farming: Given the decreasing farm size, it is imperative to develop and promote collective or cooperative farming models to improve the economic viability of agriculture. This approach offers several potential advantages including enhanced efficiency, shared risk, and improved access to resources and markets. By combining their efforts, farmers can achieve economies of scale, thereby reducing the individual costs for equipment and inputs. Furthermore, cooperative farming can facilitate knowledge transfer and innovation, as farmers learn from each others' experiences.

De-stress agriculture from excessive employment: There is excessive pressure of employment on agriculture in relation to landholding size, making it increasingly difficult for farmers to earn livelihoods solely from agricultural activities. Rural industrialization has been slow to absorb the expanding agricultural labor force. Thus, there is an urgent need to promote agri-based start-ups and micro-, small-, and medium-sized enterprises (MSMEs) on a larger scale. These initiatives can create new employment opportunities and add value to agricultural products. By encouraging entrepreneurship and supporting the growth of agri-based enterprises, it is possible to reduce employment pressure on agriculture.

Strengthen center-state relationship: Agriculture is a state subject; however, the central government provides guidance to states regarding the programs and strategies for balancing the conflicting objectives of food security, farmers' welfare, and environmental preservation. Nevertheless, its involvement extends beyond guidance and encompasses the implementation of various schemes. States are uniquely positioned to understand the specific needs and challenges of their agricultural sectors, thereby allowing them to ensure more effective and targeted interventions. Effective collaboration and coordination between central and state governments in implementation of schemes is essential.

Improve science-policy interface and synergy among programs: Ensuring a robust science-policy interface and synergy among various agricultural strategies is essential to maximize their positive outcomes. This involves creating robust channels of communication and collaboration between researchers, policymakers, and other stakeholders. Regular impact assessments and policy reviews can help identify potential conflicts or overlaps between different strategies, allowing for timely adjustments and optimization.

The political economy of agricultural reforms is complex because of the diverse and often conflicting interests of various stakeholders in the agri-food system, including farmers, input suppliers, processors, distributors, retailers, and consumers. Each group has distinct priorities and concerns, which can result in challenges in implementing comprehensive and effective agricultural strategies. For example, while farmers may demand for higher minimum support prices, consumers may demand lower food prices. To address these challenges, a nuanced approach is necessary, involving stakeholder participation in the decision-making process, enhancing synergy between schemes or programs of different ministries and departments, and improving coordination between central and state governments.

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1 Introduction

Over the past six decades, the landscape of India's agri-food system has undergone a significant transformation. This transformation commenced in the mid-1960s with the introduction of high-yielding seeds of wheat and rice and agrochemicals (fertilizers and pesticides) resulted in a significant increase in yields of these crops within a short span of time, effectively addressing the food security concerns that had plagued the country for a long time. In development literature, this transformation is popularly known as the Green Revolution.

The initial success of the Green Revolution inspired similar transformative changes in other components of the agricultural sector, such as dairying, poultry, and fisheries. Beginning in the early 1970s, the Operation Flood Program, also termed the White Revolution, focused on promoting improved animal breeds and establishing market linkages through cooperatives, turned India as the world's largest milk producer by the end of the 1990s. Concurrently, driven by private-sector investments in breeding, health, nutrition, and value chains, poultry production system has evolved from a small-scale or backyard system into an industrialized system. Similarly, the Blue Revolution, propelled by scientific advancements in aquaculture and the mechanization of marine fishing, led to a substantial increase in fish production, making the country one of the largest suppliers of seafood to international markets.

Technological advancements in agri-food production system were supported by public investments, institutions, and incentives. Public investment prioritized irrigation, rural roads, electrification, and markets. Institutional developments focused on strengthening linkages between agricultural research and extension, rural credit flows, and establishing cooperatives for various commodities. Furthermore, to ensure that farmers derive maximum benefits from these developments, the central and state governments provided incentives in the form of subsidies for key inputs, such as fertilizers, electric power, irrigation, high-yielding seeds, and farm machinery, and introduced a price support mechanism to mitigate market uncertainty and price risks.

The effects of the transformation of the agri-food system go beyond ensuring the food security. This enhanced the country's capacity to cope with threats to food security stemming from droughts, floods, and heat waves, as well as supply chain disruptions due to pandemics and geopolitical conflicts. For instance, during the global COVID-19 pandemic, when global food prices soared, India managed to provide its population with affordable access to food. Furthermore, this transformation turned India as a key exporter of commodities such as rice, sugar, spices, cotton, bovine meat, and seafood.

The social outcomes of the agri-food system transformation are notably significant: reduced poverty and improved nutritional outcomes. Studies have shown that agricultural growth in India is more pro-poor than is growth in non-agricultural sectors (Datt and Ravallion, 2002; Datt et al., 2016). Gulati et al. (2012) found a significant positive association between agricultural performance and nutritional indicators. Furthermore, these effects of agricultural growth have not been limited to rural populations but have also percolated to urban populations.

Despite these accomplishments, 14% of India's population is undernourished (FAO, 2024). Among children under five years of age, 36% exhibit stunting and 32% are underweight (GoI, 2022). Additionally, one-fifth of adults of both sexes are overweight or obese. This paradox of the coexistence of undernutrition and overnutrition amidst abundant food supplies is a matter of concern and demands inclusivity of food system.

While addressing food and nutritional security is crucial, it is imperative to acknowledge that the agri-food production system faces significant threats from various biotic, abiotic, and structural factors. Paradoxically, the incentives designed to enhance food production have become unsupportive of sustainable development. Policies regarding input subsidies, especially for electric power and fertilizers, and MSP have now become counterproductive, causing quantitative and qualitative deterioration of natural resources, biodiversity, and the environment, particularly in intensively cultivated regions, such as Punjab and Haryana, which have been at the forefront of the Green Revolution. In this context, Chand and Singh (2023) showed that crops such as rice and wheat, which received the highest policy support, have ceased to drive agricultural growth. Negi et al. (2020) have shown that excessive emphasis on cereals has been a disincentive for crop diversification. Furthermore, cereal-centric policy has contributed to increased economic disparities across regions and among farmers. Irrigated areas specializing in rice and wheat production have disproportionately benefitted from this, whereas rainfed agriculture dominated by the cultivation of pulses, oilseeds, and millets has been at a disadvantage. Furthermore, this policy is claimed to have exacerbated the economic disparity between resource-rich and resource-constrained farmers.

Notably, in the recent decade ending 2022-23, propelled by robust demand-driven growth in livestock and fish production, the agricultural sector experienced an unprecedented growth rate of approximately 4% per annum, which seldom exceeded 3% even during the peak periods of the Green Revolution. Nevertheless, in the foreseeable future, challenges to sustaining this growth momentum will intensify, potentially compromising the capacity of the agricultural sector to produce sufficient food and non-food commodities to meet the increasing demand. Land and water resources, which are already strained, will face increasing competition from urbanization and industrialization. Furthermore, climate change exacerbates these challenges, in addition to direct adverse impacts on productivity of agri-food system. Rising temperatures, changing precipitation patterns, and more frequent extreme weather events adversely affect agricultural productivity, food supplies, and food and nutrition security. Furthermore, climatic shifts may alter the geographic suitability of certain crops (Birthal et al., 2021a).

The challenges confronting agri-food system are multifarious and interconnected. A business-as-usual approach to addressing these challenges is unlikely to sustain the recent momentum of agricultural growth and achieve a balance among food security, conservation of natural resources, and safeguarding farmers' interests. Therefore, it is imperative to reorient agri-food policies, acknowledging that addressing one challenge in isolation may precipitate another. This necessitates a reassessment of existing agri-food policies and institutional frameworks for their implementation in terms of their positive impacts and unintended consequences, shortcomings in their design and implementation, and the subsequent reshaping of existing policies and frameworks or developing new ones aligning with the overarching objectives of enhancing the efficiency, sustainability, and inclusivity of the agri-food system.

This study examines the agricultural policies within the context of the evolving agri-food system, identifies specific interventions that have become unsupportive of sustainable development, and highlights the lack of interventions in capturing emerging opportunities. Building upon this analysis, this study explores potential avenues for policy reorientation, acknowledging the interconnected nature of the challenges confronting the agri-food system, and proposes adaptive or flexible policy and institutional frameworks that effectively respond to evolving economic, environmental, and socio-political conditions.

The political economy of agricultural reforms is complex due to the diverse and conflicting interests of various stakeholders across the entire agri-food system, from genetics to end-consumption. This paper advocates for the development of demand-driven schemes or programs involving multiple stakeholders in the decision-making process, enhanced synergy between schemes or programs implemented by different ministries and departments that have a direct or indirect impact on the efficiency and sustainability of the agri-food system.

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2 Structural Transformation in Agri-food System

Consistent with theories of economic development, share of agricultural sector in the national income and the workforce has declined in India (Figure 1). However, this transformation has been attenuated. While agriculture's contribution to national income has decreased substantially from 43% in 1970-71 to 18% in 2022-23 (Figure 1a), proportion of workforce engaged in agriculture has declined at a slower rate, reaching 46% in 2022-23 from 74% in 1972-73 (Figure 1b).

This disparity between sector's economic contribution and employment share highlights a critical challenge in India's development process. This suggests that while the economy has diversified, there has been a lack of employment opportunities in other sectors to absorb surplus labor from the agricultural sector. This phenomenon, often referred to as "jobless growth," underscores the need for policies that can facilitate a balanced transition of the workforce in line with the changing economic structure.

Figure 1a. % share of agricultural sector in gross value added (GVA)

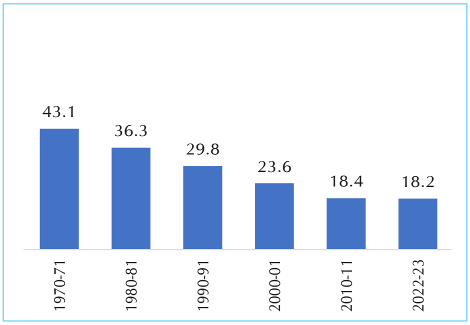
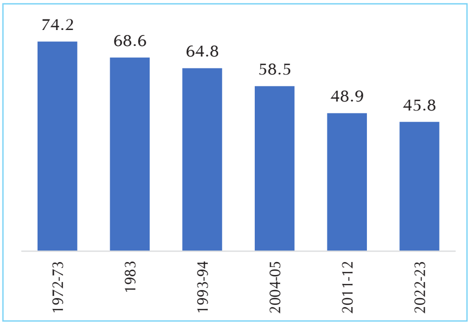


Figure 1b. % share of agricultural sector in total workforce



Source: Income share computed based on GoI (various years, a), and employment share based on GoI (various years, b).

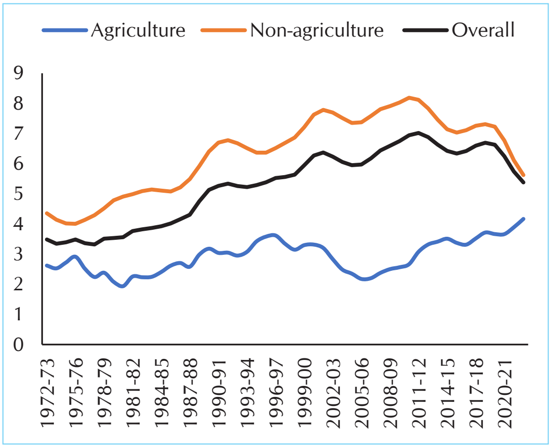
Table 1 compares the annual growth in agricultural and non-agricultural sectors. Agricultural growth has consistently lagged behind the growth in non-agricultural sector. It is noteworthy that since the mid-1990s, India's policymakers have been targeting a 4% annual growth rate for the agricultural sector, which, however, remained unattainable until the most recent decade ending 2022-23. This is encouraging; however, it coincides with a broader economic deceleration. During this period, a significant deceleration occurred in non-agricultural growth to 5.9% from 7.9% during 2002-03 to 2012-13, pulling down the overall economic growth to 5.6% from approximately 7%.

Table 1. % annual growth in agriculture and non-agricultural sectors (at 2011-12 prices)

Period	GVA Agriculture	GVA Non-agriculture	Overall
1972-73 to 1982-83	2.3	5.0	3.8
1982-83 to 1992-93	3.0	6.6	5.2
1992-93 to 2002-03	3.0	7.7	6.2
2002-03 to 2012-13	3.2	7.9	6.9
2012-13 to 2022-23	4.0	5.9	5.6

Source: Computed based on GoI (various years, a).

Figure 2. Decennial rolling growth in GVA (at 2011-12 prices) (%)



Source: As for Table 1.

To gain further insights into growth dynamics, ten-year rolling growth rates for agricultural vis-à-vis non-agricultural sectors are compared (Figure 2). Three significant patterns emerge from this analysis. First, for the first time since the beginning of the Green Revolution, the correlation between agricultural growth and overall economic growth has diminished in recent years. Second, while this growth is encouraging, it is important to note that it is characterized by greater fluctuation than growth in the non-agricultural sector, primarily because of its dependence on climatic factors. Third, notwithstanding these developments, agricultural sector remains crucial for economic development through its intersectoral linkages, specifically in terms of its contribution of labor and raw materials to the manufacturing and services sectors and its significant reliance on the latter for its requirements of inputs, machinery, equipment, and services.

Concurrently, significant changes have occurred in the agrarian structure. Landholdings have fragmented with a concomitant reduction in their average size. The number of landholdings has more than doubled from 71 million in 1970-71 to over 146 million in 2015-16 (Table 2), resulting in an increase in the proportion of marginal landholdings (≤1 ha) from 51% to 68%, and a reduction in the average landholding size from 2.28 hectares to 1.08 hectares.

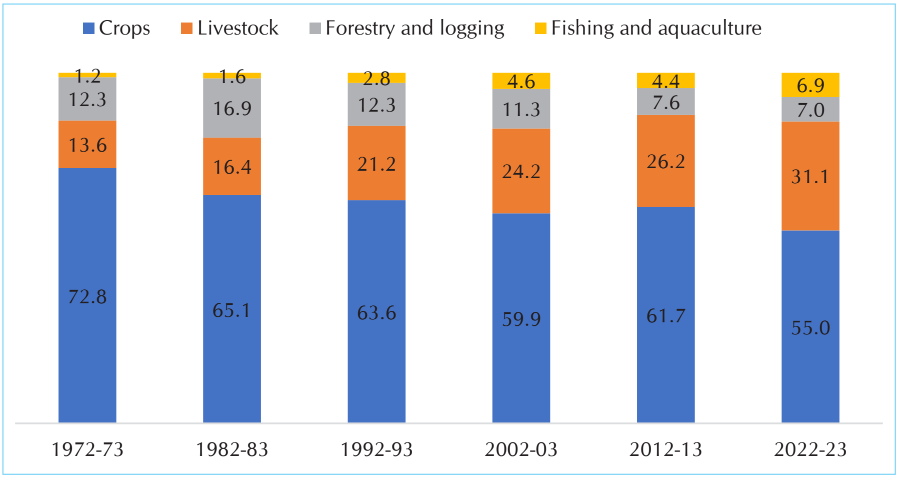
Table 2. Trend in distribution of landholdings and their average size

Year	Total holdings (million)	Distribution of holdings (%)				
		Average size (ha)	Marginal (≤1ha)	Small (1-2ha)	Medium (2-4ha)	Large (>4ha)
1970-71	71.01	2.28	50.98	18.92	15.04	15.07
1976-77	81.57	2.00	54.58	18.06	14.30	13.06
1980-81	88.88	1.84	56.39	18.08	14.01	11.51
1985-86	97.16	1.69	57.79	18.45	13.64	10.12
1990-91	106.64	1.55	59.44	18.84	13.06	8.66
1995-96	115.58	1.41	61.58	18.73	12.34	7.35
2000-01	119.93	1.33	62.88	18.92	11.69	6.51
2005-06	129.22	1.23	64.77	18.52	10.93	5.78
2010-11	138.35	1.15	67.10	17.91	10.04	4.95
2015-16	146.45	1.08	68.45	17.62	9.55	4.37

Source: GoI (various years, c).

These changes in the agrarian structure have a profound impact on the economic structure of agriculture. The declining landholding size compelled farmers to increasingly diversify towards alternative sources of livelihood, both within and outside the agricultural sector. Animal husbandry, which is an integral component of the agricultural sector, has emerged an important supplementary source of income. Its share in the gross value of output of the agricultural sector has more than doubled from 14% in 1972-73 to 31% in 2022-23 (Figure 3). Fisheries, including aquaculture and marine, have witnessed a significant increase in their share from slightly more than 1% in 1972-73 to approximately 7% in 2022-23.

Figure 3. Changes in economic structure of agriculture (%)



Source: As for Table 1.

Table 3 and Figure 4 show the growth in the components of the agricultural sector. Livestock and fisheries significantly influence agricultural growth. In the most recent decade, agricultural growth has been driven by livestock and fishery sectors. These sectors grew at an annual rate of 6% and 9%, respectively. Moreover, growth in livestock production is more resilient than the growth in other sectors, thereby contributing to the overall resilience of the agricultural sector and farmers' livelihood.

The livestock sector's impressive growth and resilience have significant implications for nutrition, income inequality and poverty. Small landholders, who are often the most vulnerable, benefit greatly from the growth in livestock production. The evidence indicate that this not only contributes to more equitable income distribution (Birthal et al., 2014a), but also provides a buffer against climatic and economic shocks (Birthal and Negi, 2012), and helps reduce poverty (Birthal and Negi, 2012). Furthermore, the expansion of the livestock production creates employment opportunities along the value chain from production to processing, transportation, and marketing.

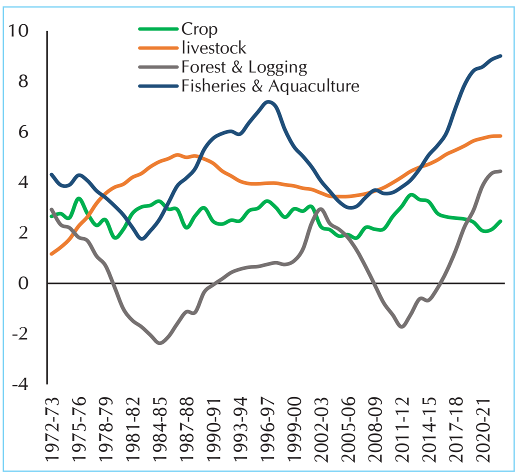
Table 3. % annual growth in value of output of subsectors of agriculture (at 2011-12 prices)

Period	Crops	Livestock	Fishing and aquaculture	Forestry and logging	Overall
1972-73 to 1982-83	3.0	4.4	1.8	-1.7	2.2
1982-83 to 1992-93	2.5	4.3	6.0	0.4	2.6
1992-93 to 2002-03	2.3	3.6	4.1	2.9	2.7
2002-03 to 2012-13	3.5	4.4	4.1	-1.2	3.3
2012-13 to 2022-23	2.5	5.8	9.0	4.4	3.9

Source: As for Table 1.

On the other hand, crop subsector grew at a much slower rate. Given the predominance of the crop subsector, it is imperative to understand its growth sources. These sources include technological advancements (improvements in crop yields, expansion of cultivated area, diversification from low-value to high-value crops, and increases in the real prices of agricultural commodities. Each of these plays a significant role in shaping the growth trajectory. Technological advancements lead to more

Figure 4. Decennial rolling growth in subsectors of agriculture (%)

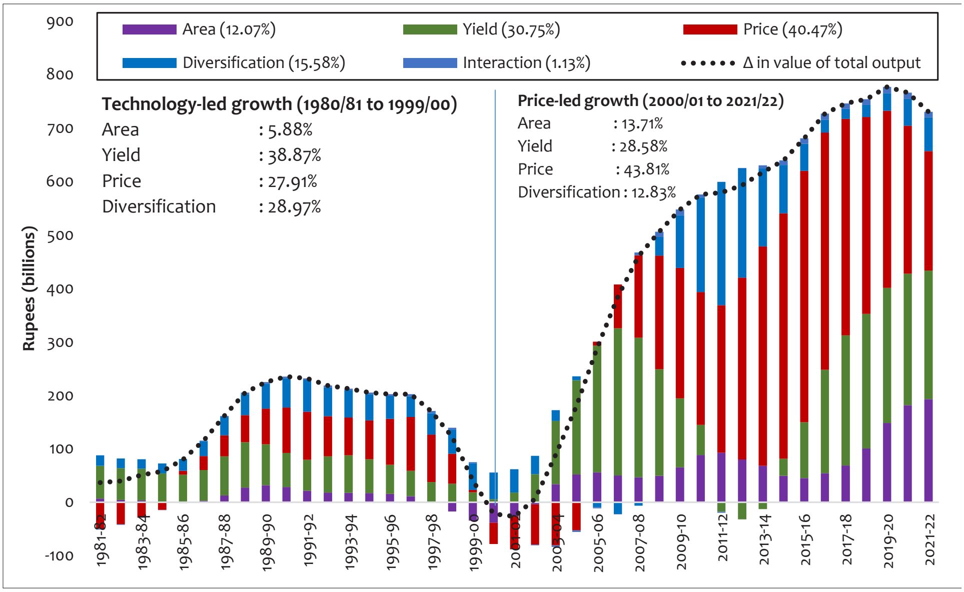


Source: As for Table 1.

efficient farming practices and higher yields per unit of land. The expansion of cultivated areas may increase total production. Crop diversification can potentially improve farmers' incomes and reduce risk, whereas changes in commodity prices can directly impact profitability of crops.

As expected, technological advancements contributed significantly to the growth of crop subsector during the initial decades of the Green Revolution (Figure 5). Between 1980-81 and 2000-01, improvements in yield accounted for approximately 40% of overall growth. The next most significant sources included diversification into high-value crops, such as fruits and vegetables, and price increases, each contributing nearly 28% to output growth.

Figure 5. Sources of growth in crop sector



Source: Authors' estimates using data on value of output of crops from GoI (various years, a), and on area and production from GoI (various years, d).

Note: Growth was decomposed following Minot et al. (2006) and Birthal et al. (2014b).

Nevertheless, the sources of growth underwent significant changes in the past two decades, with price emerging as the main driver of growth surpassing the contribution of technological advancements. Price increases accounted for 44% of growth, followed by technological advancements (29%). Notably, during this period, technological gains of the Green Revolution started decelerating, affecting farmers' income. This prompted policymakers to raise the MSP of staple foodgrains to maintain the economic viability of farming and ensure farmers' well-being. Furthermore, the contribution of diversification to growth decreased significantly to 13%. The area expansion consolidated its share, primarily because of the irrigation-led increase in the cropping intensity. These findings are consistent with those reported by Birthal et al. (2014b). Notably, while prospects of growth through area expansion are limited, price-driven growth cannot sustain in the long-run because of its inflationary pressure. Thus, the changing dynamics of agricultural growth necessitate a re-evaluation of strategies to support agricultural productivity and diversification.

Despite the above-mentioned changes in growth patterns, the agricultural sector will continue to transform. As India approaches its centennial year of independence in 2047, the share of the agricultural sector in the national income is projected to decrease steadily to 8% (Table 4). However, the sector will continue to employ a significant proportion of the workforce, approximately 29% of the total, unless the rate of labor transfer to non-agricultural sector accelerates. This indicates the need to focus on accelerating skill development programs, promoting agro-based industries, and enhancing rural infrastructure to facilitate a smoother transition of labor while simultaneously improving land and labor productivity in agriculture.

Table 4. Projections of key parameters

Indicators	2035-36	2047-48
% share of agriculture in GVA	11.9	8.0
% share of agriculture in workforce	34.9	29.1
Composition of agriculture (%)		
Crops	50.8	46.8
Livestock	34.7	38.9
Fisheries and aquaculture	8.8	10.2
Forestry and logging	6.0	4.7
No. of landholdings (million)	179	198
Distribution of holdings (%)		
Marginal	74.7	77.4
Small	16.8	16.4
Medium	7.7	6.8
Large	2.4	1.6
Average landholding (ha)	0.78	0.6

Source: Authors' estimates using data from GoI (various years, a, b, and c).[1]

Moreover, the agricultural sector itself will undergo structural transformation. Land fragmentation is projected to intensify, resulting in a significant increase in marginal holdings ($\leq$1 hectare) to 77%, consequently leading to a significant reduction in the average landholding size to approximately 0.6 hectares. This reduction in farm size will enforce further changes in the economic structure of the agricultural sector with share of crops in the total value of agricultural

[1] Projections have been made employing linear and non-linear time series models based on the underlying trends in historical data. In instances where the time series had a significant growth in recent years, a quadratic model has been applied. Conversely, if the time series exhibited consistent and steady growth, a linear model was more appropriate.

output falling to 47% and that of share of livestock and fisheries rising to 39% and 10%, respectively.

Thus, a combination of diminishing economic contribution of agriculture, persistent employment pressure and decreasing farm size is a significant challenge for enhancing the efficiency, sustainability, and inclusivity of the agri-food system. This necessitates a paradigm shift in the business-as-usual approach to agricultural development and a reorientation of agri-food policies to address the emerging challenges.

♦♦♦

3 Food Consumption Patterns, Domestic Demand, and Trade

3.1 Food consumption patterns

Upstream changes in the agri-food system have been paralleled by significant shifts in food consumption patterns downstream. As the economy grew, the household consumer expenditure pattern underwent a structural shift, characterized by a marked decrease in the share of food from 62% in 1983 to 43% in 2022-23 (Table 5). This aligns with Engel's law, which states that, as household income increases, the proportion of expenditure allocated to food decreases, even if absolute food expenditure may rise. This indicates improvements in living standards and an increase in disposable income for spending on education, healthcare, and leisure activities.

Table 5. Changing food consumption patterns

Particulars	1983	1987-88	1993-94	2004-05	2011-12	2022-23
Total expenditure (Rs/capita/month, in real terms)	916	973	1019	1157	1599	2589
Food expenditure (Rs/capita/month, in real terms)	572	587	633	580	708	1125
Share of food in total expenditure (%)	62	60	62	50	44	43
Share of commodities in total food expenditure (%)						
Cereals & its substitutes	44	36	34	30	22	10
Pulses & its products	6	7	6	6	6	4
Milk & its products	13	15	16	16	19	18
Edible oils	7	8	7	8	7	7
Eggs, meat, & fish	5	5	6	6	7	10
Fruits, nuts, & vegetables	10	12	13	15	14	20
Sugar, salt & spices	8	9	9	8	8	8
Beverages & fast food	7	8	9	11	15	23

Source: Computed using data from GoI (various years, e).

Note: Deflated using consumer price index at 2011-12 prices

Nevertheless, the decreasing share of food in household expenditure has been accompanied by a significant shift in dietary preferences away from cereals towards nutrient-rich horticultural and animal products (Table 5), often referred to as nutrition transition. The share of cereals in food expenditure has declined drastically to 10% in 2022-23 from 44% in 1983, and the share of nutrient-dense foods, including fruits, vegetables, dairy products, meat, eggs, and fish, has increased from about one-third to one-half.

Further analysis of the food expenditure patterns by commodity groups reveals a significant increase in the share of animal-source foods from 18% in 1983 to 28% in 2022-23 and doubling of the share of horticultural products (fruits, nuts, and vegetables) from 10% to 20%. Notably, the share of beverages and processed foods has experienced the most significant increase from approximately 7% in 1983 to 23% in 2022-23.

The changes in the food consumption expenditure could be due to the relative price changes of commodities, and do not necessarily reflect the changes in their actual intake. Table 6 presents the trends in intake of food commodities. There has been a consistent downward trend in cereal consumption and an increase in the consumption of nutrient-rich foods, *albeit* differentially across commodities. Between 1983 and 2022-23, per capita consumption of cereals declined by one-third. This decline is more pronounced for coarse cereals, including millets, which have been increasingly replaced by rice and wheat. Notably, India's public distribution system (PDS) has predominantly focused on providing rice and wheat and has expanded significantly over time. Pulse consumption, the primary source of protein for the majority of Indians, has remained relatively static. The consumption of horticultural and animal products has increased to 2-3 times.

Table 6. Household consumption of food commodities (kg/capita/month)

Commodity	1983	1993-94	2004-05	2011-12	2022-23
Cereals & its substitutes	13.98	12.77	11.61	10.72	9.19
Rice	6.24	6.59	6.12	5.71	5.03
Wheat	4.51	4.48	4.38	4.41	3.87
Coarse cereals	3.23	1.70	1.11	0.60	0.29
Pulses & its products	0.94	0.83	0.74	0.82	0.78
Fruits & vegetables	4.01	5.31	5.93	5.49	9.15
Edible oils	0.33	0.42	0.53	0.66	0.91
Sugar	1.26	1.40	1.23	1.33	1.45
Milk	2.98	4.26	4.29	4.78	5.50
Eggs, meat, & fish	0.31	0.38	0.42	0.47	0.96

Source: As for Table 5.

The shift towards a more diverse and nutrient-dense diet suggests an improvement in overall dietary quality. Notably, this nutrition transition is not limited to any specific consumer group but prevails across socioeconomic strata and geographical locations, encompassing both rich and poor consumers as well as urban and rural consumers (Table 7). Nevertheless, this nutrition transition has been more pronounced in low-income groups and rural areas, suggesting a trend toward convergence in dietary patterns across socioeconomic strata (Kapoor et al., 2024).

Table 7. Trend in composition of food expenditure in rural and urban areas (%)

Commodity	Rural			Urban		
	1993-94	2004-05	2022-23	1993-94	2011-12	2022-23
Cereals & its substitutes	38.48	32.85	9.29	25.79	19.16	10.57
Pulses & its products	6.03	5.59	3.56	5.56	5.59	4.34
Fruits & vegetables	12.32	14.47	19.40	14.85	14.87	19.60
Edible oils	6.99	8.36	6.05	8.03	6.89	7.77
Egg, fish & meat	5.27	6.05	9.13	6.20	7.25	10.57
Milk	15.03	15.38	18.42	17.93	20.20	17.94
Sugar, spices, etc	9.00	8.82	6.99	8.12	7.31	8.46
Beverages & processed foods	6.58	8.25	27.15	13.19	18.41	20.74
Share of food in total expenditure (%)	63.17	55.05	46.38	54.65	42.51	39.17

Source: As for Table 5.

Several economic and demographic factors, including income growth, urbanization, lifestyle changes, awareness of nutritious diets, and advancements in supply chains and the emergence of retail chains, have contributed to this transformation in food basket. As previously noted, over the past four decades, Indian economy has grown at an accelerated rate, resulting in an increase in per capita income from Rs 21962 in 1983 to Rs 99404 in 2022-23 at 2011-12 prices. This enabled consumers to access a more diverse range of foods. Furthermore, the share of the urban population in the total population increased from 23% in 1983 to 37% in 2022-23.

Despite such an impressive transformation, undernutrition, manifesting as stunting, wasting, and underweight, continues to affect a significant proportion of the population, particularly children[2]. Over time, while the incidence of

2 According to the World Health Organization (WHO), stunting is based on whether a child's sex-specific height-for-age Z score (HAZ) is 2 or more standard deviations below the WHO Child Growth Standards median. Wasting is based on whether a child's sex-specific weight-for-height Z score (WHZ) is 2 or more standard deviations below the WHO Child Growth Standards median. Underweight is based on whether a child's sex-specific weight-for-age Z score (WAZ) is 2 or more standard deviations below the WHO Child Growth Standards median. Body Mass Index (BMI) ranging between 25 kg/m^2 and 29.9 kg/m^2 is considered overweight, while a BMI greater than 30 kg/m^2 is considered obese.

stunting among children below five years of age has decreased from 48% in 2005-06 to 36% in 2019-21, it remains higher among children in rural areas (Table 8). The prevalence of wasting remains relatively unchanged at 19%, but it decreased in rural areas from 20.7% in 2005-06 to 19.5% in 2019-21, and increased from 16.9% to 18.5% in urban areas.

This transformation has also brought about new challenges, such as the overconsumption of certain foods. The prevalence of overweight and obesity has increased in adult women (15-49 years). The rate nearly doubled from 9.8% in 2005-06 to 17.6% in 2019-21. Similarly, prevalence of obesity has increased from 2.8% to 6.4%. The prevalence rates of both overweight and obesity are higher in urban populations, potentially because of sedentary lifestyles and the consumption of unhealthy food products.

Table 8. Prevalence rate of malnutrition (%)

Indicators	2005-06			2015-16			2019-21		
	Rural	Urban	Overall	Rural	Urban	Overall	Rural	Urban	Overall
Stunting	50.7	39.6	48.0	41.2	31.0	38.4	37.3	30.1	35.5
Wasting	20.7	16.9	19.8	21.4	20.0	21.0	19.5	18.5	19.3
Underweight	45.6	32.7	42.5	38.3	29.1	35.7	33.8	27.3	32.1
Overweight	6.2	17.4	9.8	12.0	22.2	15.5	15.2	22.9	17.6
Obese	1.3	6.1	2.8	3.1	9.1	5.1	4.5	10.4	6.4

Source: Computed using data from GoI (various years, f).

This dual burden of malnutrition affects physical capacity, leading to decreased efficiency and productivity. Furthermore, the development of human capital is severely compromised because malnutrition in early life can result in stunted growth, impaired cognitive development, and reduced educational attainment, limiting the potential of future generations to contribute effectively to society and the economy.

3.2 Food demand to 2047

To achieve the status of a developed nation by 2047, the centennial year of independence, the Indian economy must grow at an annual rate of approximately 8%, implying a significant increase in purchasing power for the population. At the same time, the country's population is expected to reach 1.6 billion with nearly half residing in urban areas. This evolving economic and demographic landscape is expected to precipitate further shifts in dietary patterns and the demand for diverse foods, especially nutrient-rich horticultural and animal products.

By 2047, the demand for fruits is projected to increase to 233 million tons at an annual rate of 3% and for vegetables to 365 million tons at an annual rate of 2.3% in a business-as-usual scenario (Table 9). The demand for pulses is anticipated to double to 49 million tons. Driven by a significant increase in demand for maize, cereal demand is expected to increase at an annual rate of 1.3%, reaching 353 million tons. The demand for edible oils and sugar is also projected to increase by 50% and 29% respectively.

Table 9. Demand for food commodities by 2047, million tons

Commodity	2019-20	2047-48			Required growth in production to meet food demand (% per annum)		
		BAU	HIG-1	HIG-2	BAU	HIG-1	HIG-2
Foodgrains	277	402	415	437	1.39	1.51	1.70
Cereals	251	353	363	381	1.27	1.38	1.55
Rice	103	114	114	113	0.40	0.37	0.34
Wheat	100	119	119	120	0.65	0.67	0.71
Nutri-cereals	19	29	31	33	1.60	1.79	2.09
Maize	27	86	94	109	4.39	4.75	5.32
Pulses	26	49	52	57	2.38	2.60	2.93
Animal products							
Eggs	5.0	16	18	21	4.32	4.75	5.41
Meat	7	21	24	29	4.31	4.75	5.42
Fish	12	37	41	48	4.27	4.70	5.36
Milk	186	480	527	606	3.56	3.92	4.47
Vegetables	199	365	385	417	2.28	2.48	2.78
Fruits	108	233	252	283	2.90	3.20	3.64
Sugar & products	34	44	45	45	1.05	1.08	1.13
Edible oil	22	31	32	33	1.23	1.32	1.47
Overall	850	1630	1739	1921	2.44	2.69	3.07

Source: GoI (2024a).

Note: BAU: Business as usual (continuation of 6.34% growth in net national income (NNI) during 2011-12 to 2019-20); HIG-1: High income growth (7% growth in NNI), HIG-2: High income growth (8% growth in NNI)

While demand for plant-based foods, particularly fruits and vegetables, is projected to increase considerably, increase in demand for animal-source foods (i.e., milk, eggs, meat, and fish) is expected to be even more pronounced. Milk demand is expected to increase to 480 million tons at an annual rate of 3.6%. The demand for meat, eggs, and fish is projected to increase at a more rapid rate of over 4%. In a developed-country scenario, as consumers continue to experience higher disposable incomes, they prefer higher-quality food products, potentially resulting in higher growth in demand for these commodities.

The projected changes in food demand necessitate a strategic shift in the agri-food system: enhance the production of specific crops or reallocate resources from traditional staples to more diverse and nutritionally rich commodities to prevent commodity imbalances. Fruits, vegetables, pulses, and oilseeds are key crops that require increased focus to meet the changing dietary preferences and nutritional needs. Simultaneously, the gradual reallocation of resources from rice and wheat to alternative crops is crucial. Alternatively, there is a need to enhance the competitiveness of commodities to increase their exports while preserving the natural resources.

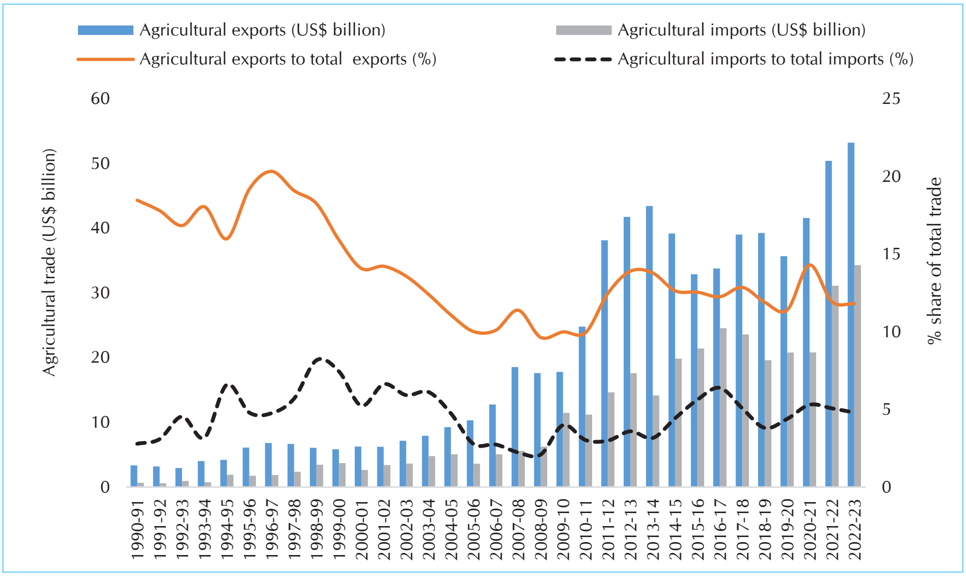
3.3 International trade

Trade can also significantly influence agricultural growth. Policies such as tariffs, quotas, subsidies, and trade agreements can either promote or hinder agricultural trade. When effectively implemented, such policies can stimulate agricultural productivity, enhance market access, and foster agricultural growth. Conversely, protectionist policies can shield domestic producers from international competition and augment their domestic production.

The expanding global market for high-value premium quality agricultural products is an opportunity for India to increase its share of global exports (Saxena et al., 2024). The landscape of India's agricultural trade has transformed in both growth and composition. Agricultural exports increased significantly from less than US$10 billion a year in the early 1990s to US$53 billion a year in 2022-23, contributing approximately 12% to the total merchandise exports (Figure 6). Concurrently, India's agricultural imports have risen from less than US$3 billion to over US$34 billion a year. Notably, despite supply chain disruptions during the COVID-19 pandemic and the ongoing Ukraine-Russia conflict, India's agricultural trade balance has consistently remained positive, primarily owing to its strategic trade policies.

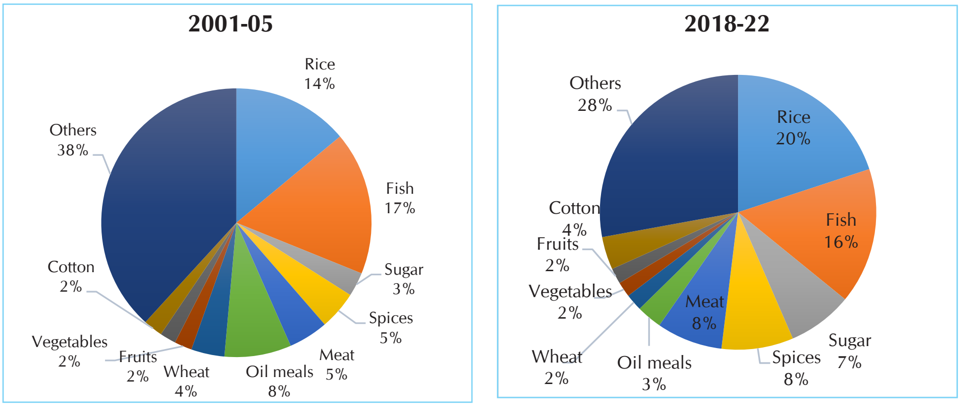
Furthermore, composition of agricultural exports and imports has changed. Exports have diversified, encompassing marine products, rice, bovine meat, sugar, and spices, shifting away from traditional commodities such as tea, coffee, and oil meals (Figure 7). Over the past two decades, the share of non-basmati rice, spices, and meat in the total agricultural exports has increased considerably.

Figure 6. Trends in agricultural trade



Source: GoI (various years, d).

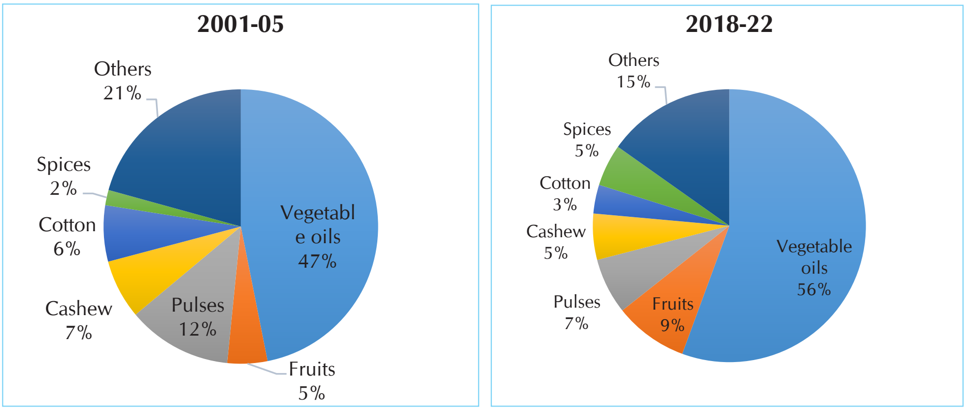
Figure 7. Composition of agricultural exports



Source: As for Figure 6.

On the other hand, agricultural imports have maintained a relatively consistent profile, predominantly comprising edible oils, pulses, and fresh fruits. The increasing imports of edible oils, which currently constitute nearly 60% of domestic demand, is a significant policy concern (Figure 8).

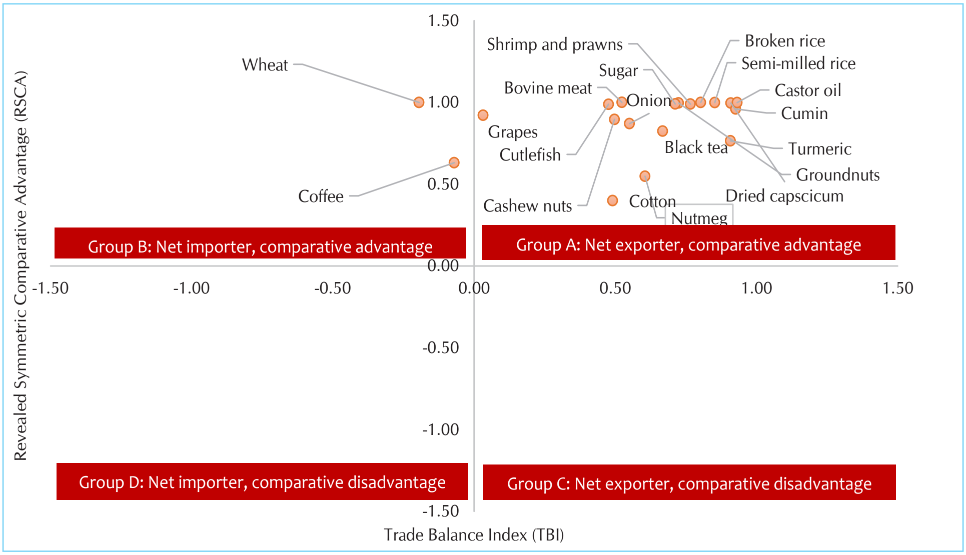
Figure 8. Composition of agricultural imports



Source: As for Figure 6.

The country has a significant comparative advantage in several commodities, including rice, cotton, tea, spices, shrimp, and bovine meat (Figure 9). This advantage is particularly pronounced for semi-milled and broken rice. The early 2000s saw a positive trade balance and strong comparative advantage for semi-milled rice, crustaceans, cashews, coffee, sugar, and black tea. Interestingly, some products, such as broken rice, grapes, and cuttlefish, were competitive in global markets, *albeit* with a relatively small trade balance. By contrast, cotton had the least comparative advantage and a negative trade balance in the early 2000s.

Figure 9. Comparative advantages in agricultural exports, 2020-22



Source: Saxena et al. (2024).

The introduction of Bt cotton enhanced cotton productivity, thereby its comparative advantage in global market. Cuttlefish also demonstrated improved comparative advantage. By 2022, most commodities, with the exception of wheat and coffee, had a positive trade balance and comparative advantage. Wheat and coffee maintain a comparative advantage but have a negative trade balance. For wheat, its lower yield compared to major exporting countries, such as the United States and Canada, and domestic consumption constrain its export capacity. India is a significant producer of coffee; however, it faces competition from Brazil and Vietnam.

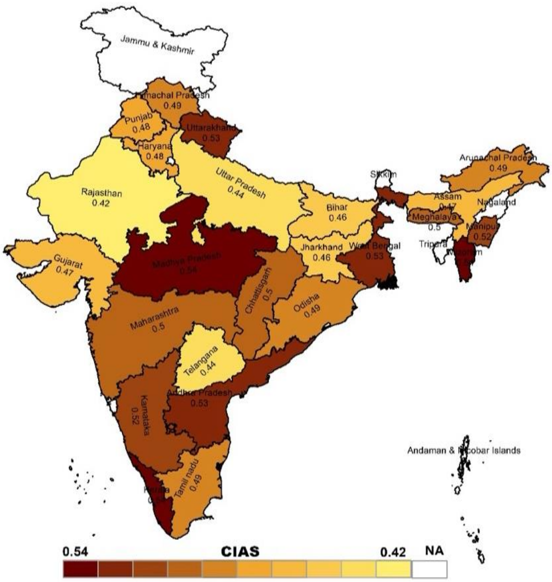
♦♦♦

4 Challenges to Agri-food System Transformation

The evolving dietary patterns and rapidly growing demand for non-cereal food products, particularly horticultural and animal products, create an opportunity for diversification of the agri-food production system. This transformation has the potential to enhance farmers' income and accelerate agricultural growth. According to Timmer (2009), diversification in agriculture is a prerequisite for agricultural transformation, and delaying the diversification phase in agriculture makes it difficult to achieve rapid productivity growth and subsequent integration into the broader economy. Negi et al. (2020), and Chand and Singh (2023) have indicated the need for a shift in agricultural policies favoring diversification into horticulture, livestock and fisheries for accelerating agricultural growth, reducing poverty, and combating malnutrition.

Furthermore, cereal-centric policies have resulted in second-generation problems: deterioration of land, water, biodiversity, and the environment, particularly in intensively cultivated regions such as Punjab and Haryana. These problems became evident during the 1990s; however, they were overlooked because of the fear that any change in the policy stance could potentially undermine hard-earned food security. Nevertheless, if these issues remain unaddressed, they could potentially affect the long-term sustainability of agri-food system, farmers' livelihoods, and national food security.

Figure 10. Composite index of agricultural sustainability (CIAS) for Indian states



Source: Chand et al. (2024).

Figure 10 shows the sustainability status of agriculture across states, measured using 51 parameters related to land and water resources, ecology and biodiversity, and socioeconomic dimensions (Chand et al., 2024). Indian agriculture is at half the way of sustainability. However, regional disparities exist in agricultural sustainability with Rajasthan facing the most severe sustainability challenges, followed closely by Uttar Pradesh and Telangana. Bihar and Jharkhand also demonstrate concerning levels of unsustainability. Given that sustainability is a consequence of a complex set of parameters, interventions to enhance it are likely to vary across states depending on the relative endowments of resources, ecological fragility and socioeconomic development. For instance, improvements in socioeconomic conditions may contribute significantly to agricultural sustainability in Bihar, Jharkhand, and Uttar Pradesh, whereas in Punjab, Haryana, and Rajasthan, the conservation of water resources is of paramount importance.

This section examines the potential challenges to the sustainable transformation of India's agri-food system in detail.

4.1 Declining land for agriculture

In recent decades, population growth, urbanization, and industrialization have resulted in increased pressure on agricultural land. From 1990-91 to 2022-23, agricultural land decreased by 2.7% from approximately 185 million hectares to 180 million hectares, although the net cultivated area remained relatively constant at approximately 140 million hectares (Table 10). Currently, approximately 30% of the total geographical land suffers from various forms of degradation, including salinity and alkalinity (GoI, 2021a). Projections suggest a further decline in both agricultural land and cropped area. By 2047, agricultural land is expected to shrink to 176 million hectares, whereas the net sown area will decrease to 138 million hectares. Nevertheless, there is potential for increasing agricultural production through intensive cultivation of cropland. Thus, the gross cropped area is projected to expand by 6.8%, reaching 234 million hectares by 2047 with an increase

Table 10. Trend in agricultural land, million ha

Year	Agricultural land	Net sown area	Gross sown area	Cropping intensity (%)
1970-71	182	141	166	118
1980-81	185	140	173	123
1990-91	185	143	186	130
2000-01	183	141	185	131
2010-11	182	141	198	140
2022-23	180	141	219	156
2035-36	178	139	222	160
2047-48	176	138	234	170

Source: Authors' estimates using data from GoI (various years, d).

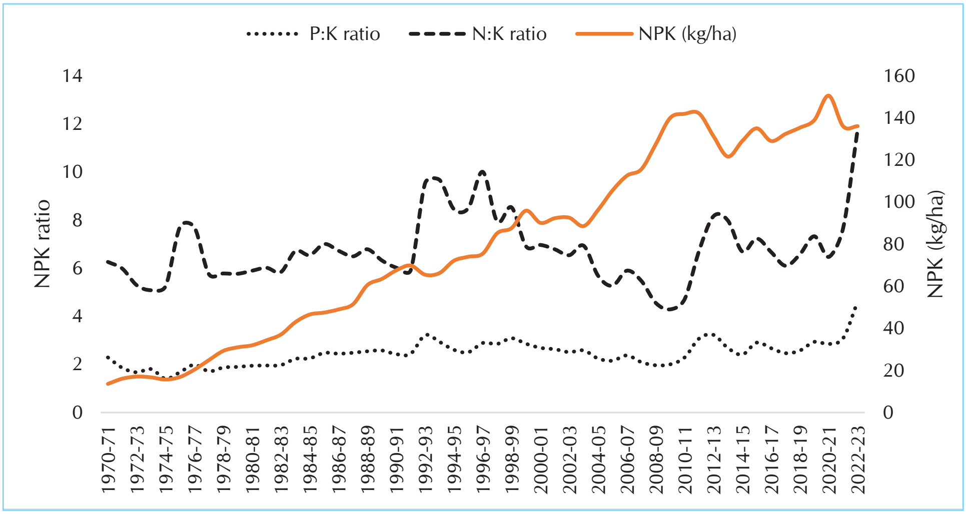
in cropping intensity to 170%. Nevertheless, the extent of intensification of existing cropland is contingent on the availability of water, which is likely to be under severe stress.

Furthermore, fragmentation of landholdings is another significant challenge in enhancing agricultural productivity and efficiency. As the average size of landholdings is projected to decrease to 0.60 hectares by 2047, farmers may encounter difficulties in achieving economies of scale and implementing modern agricultural technologies, thereby affecting the economic viability of agriculture and agriculture-based livelihoods.

4.2 Indiscriminate and unbalanced use of fertilizers

The use of chemical fertilizers such as nitrogen (N), phosphorus (P), and potash (K) has increased dramatically over the past four decades (Figure 11). Their usage pattern is significantly biased in favor of N. Their application in a ratio of 4:2:1 is considered optimal for Indian soils. Importantly, optimality in this ratio has seldom been observed. This persistent deviation raises serious concerns regarding its effects on the health of natural resources and the environment. Imbalanced application of fertilizers diminishes soil fertility, reduces crops' resilience to climate change, and negatively affects ecosystems and human health.

Figure 11. NPK use in Indian agriculture



Source: Authors' estimates using data from FAI (2023).

One of the main reasons for the persistent imbalance in nutrient use is differential subsidy rates for N, P, and K (Table 11). Owing to the significantly higher subsidy, N is approximately five times less expensive compared to both P and K. This policy-induced distortion in fertilizer pricing inadvertently incentivizes farmers to use relatively inexpensive nitrogenous fertilizers. In 2022-23, the Government of India provided fertilizer subsidies worth Rs 666 billion at 2011-12 prices (Figure 12). Notably, the share of fertilizer subsidies in the total expenditure on agricultural subsidies declined considerably from 60% in 2011-12 to 37% in 2019-20.

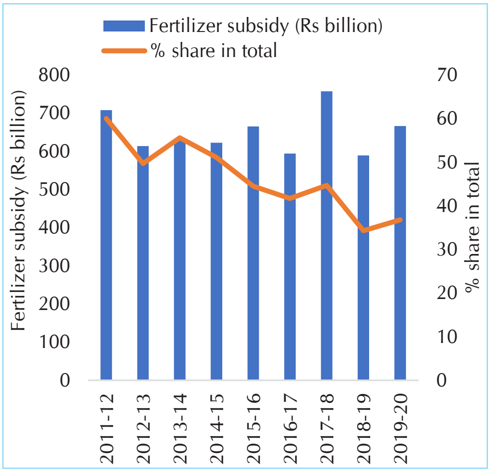
Table 11. Relative prices of fertilizer nutrients (Rs/kg) (As on 31st March, 2023)

Nutrient prices	N	P	K
Economic price (EP) (Rs./kg)	110.9	132.2	86.61
Subsidies (% of EP)	88.39	50.63	27.31
Market price (% of EP)	11.61	49.33	72.69
Ratio of market price (in relation to N)	1.00	5.07	4.89

Source: As for Figure 11.

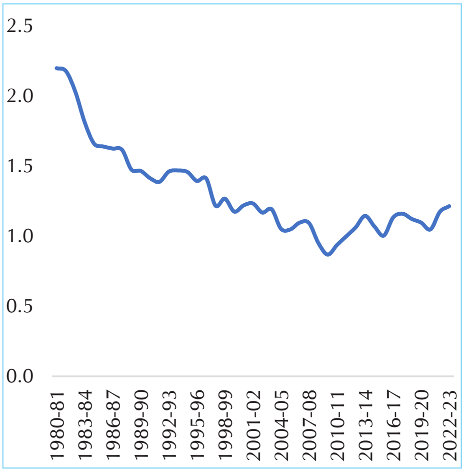
Furthermore, low nutrient use efficiency is a significant concern. Nutrient use efficiency has been reported 30-45% for N, 15-25% for P, and 50-60% for K (Gupta et al., 2021; Singh, 2023). Low use efficiency coupled with distorted prices compels farmers to apply increased quantities of fertilizers, which are less expensive, expecting higher crop yields. However, the effect of additional fertilizer application has diminished (Figure 13). This trend has only recently

Figure 12. Trend in fertilizer subsidies (at 2011-12 prices)



Source: As for Figure 11.

Figure 13. Ratio of index of agricultural production to index of NPK consumption

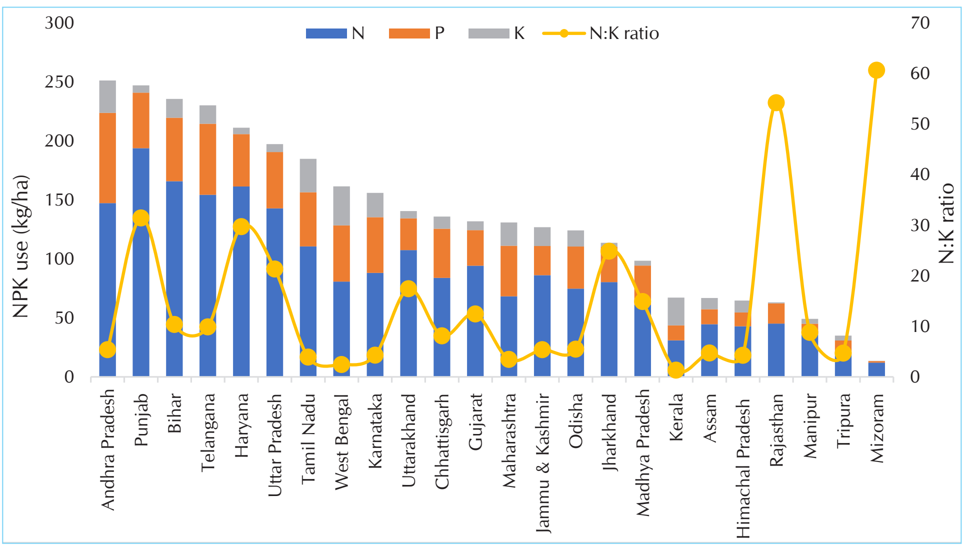


Source: Authors' estimates using data from FAI (2023), and GoI (various years, d).

stabilized owing to the increasing use of neem-coated urea, nano-fertilizers, and improved methods of application.

However, significant regional disparities exist in fertilizer use (Figure 14). States such as Punjab, Haryana, and the western part of Uttar Pradesh have a more intensive use of fertilizers, while the eastern and north-eastern states have substantially lower application rates. Moreover, with the exception of Tamil Nadu, Karnataka, West Bengal, and Maharashtra, the NPK ratio is considerably skewed towards nitrogen. Regional variation in soil nutrients is a critical factor to consider when determining optimal nutrient ratios. Although a 4:2:1 ratio of NPK is often claimed to be optimal, it may not be suitable for all soil types and crops. Several factors, such as soil pH, organic matter content, mineral composition, and local climatic conditions, can significantly influence plant nutrient availability and uptake.

Figure 14. Regional disparities in NPK use, 2022-23



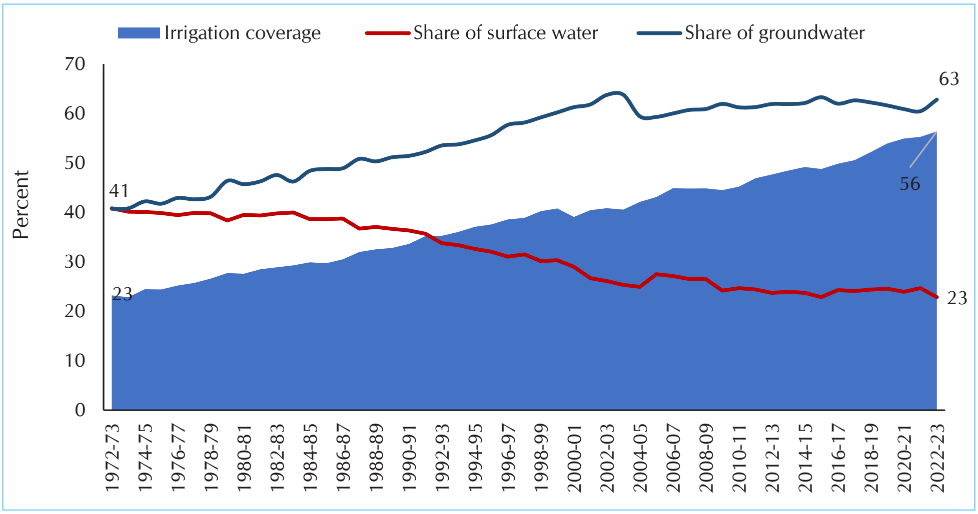
Source: As for Figure 11.

4.3 Inefficient use of water amidst growing demand

In India, water scarcity is a pressing issue. The country has a potential water endowment of 1,869 billion cubic meters (BCM) of which 1123 BCM is utilizable. Of the utilizable water, 83% is used for agricultural purposes, underscoring the critical role of irrigation in enhancing agricultural productivity and resilience to extreme climate events such as droughts and heat waves (Birthal et al., 2015a; Birthal et al., 2021b).

The irrigation system has expanded and transformed over time. Irrigation coverage expanded from a relatively low level of 23% of the net sown area in the early 1970s to approximately 56% in 2022-23 (Figure 15). Nevertheless, this expansion occurred at the expense of groundwater extraction. As agricultural intensification progressed, farmers' dependence on groundwater increased, with its share rising from 41% in the early 1970s to 63% in 2022-23. This shift in irrigation sources can be attributed to factors such as the cultivation of water-intensive crops, subsidies for electric power for agriculture, and availability of cost-effective pumping technologies.

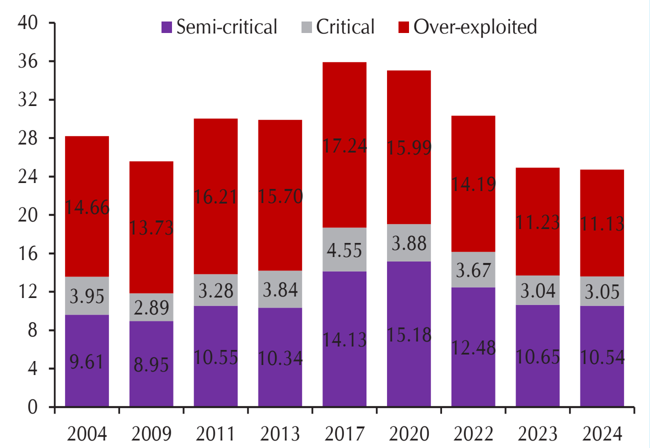
Figure 15. Trend in net irrigated area and share of surface and groundwater



Source: Computed by authors using data from GoI (2024b).

This increasing reliance on groundwater has led to its overexploitation, particularly in the north-western states of Punjab, Haryana, and Rajasthan. At the national level, approximately 11% of the assessment units have been overexploited and 14% are at the critical or semi-critical stages of exploitation (Figure 16). Notably, studies have

Figure 16. Status of groundwater extraction (%)

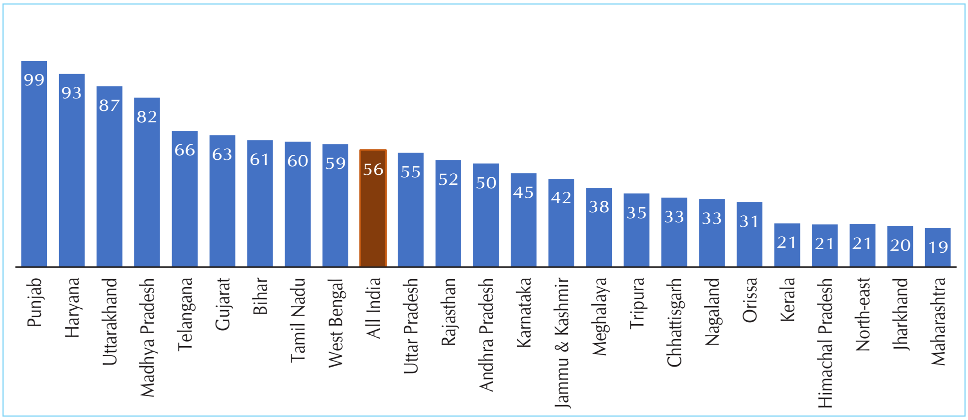


Source: GoI (2024c).

reported that while irrigation remains important for enhancing crop yield and resilience to climatic shocks, its effects on both have slowed (Birthal et al., 2015a; Birthal et al., 2021b).

Nevertheless, significant disparities exist in the endowment and utilization of water resources (Figure 17). While both surface water and groundwater are abundant in the eastern states of Bihar, West Bengal, and Odisha, these resources have not been effectively utilized. Conversely, semi-arid regions, including the states of Punjab, Haryana, and Rajasthan, have higher levels of irrigation but at the cost of overextraction of groundwater resources (Figure 18). This contrast between water-abundant regions with low irrigation development and water-scarce regions with high irrigation development and overexploited water resources underscores the necessity for a balanced and sustainable approach to water resource management and irrigation development.

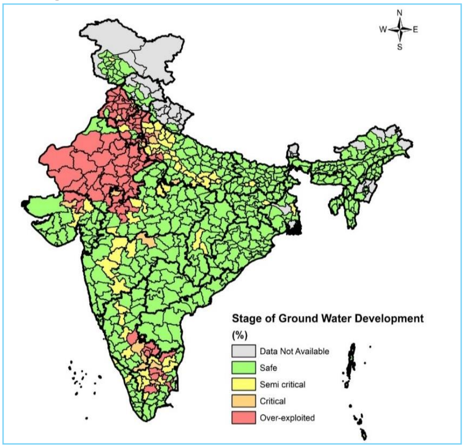
Figure 17. Regional variation in irrigation (% of net cropped area), 2022-23



Source: As for Figure 15.

While water demand for irrigation has increased, its use efficiency remains low; 30-40% for surface irrigation and 60-65% for pressurized irrigation systems. This inefficiency is particularly pronounced compared with other countries such as China, Brazil, and the United States (GoI, 2016). To produce the same quantity of output, India uses 2-3 times more water than these countries.

Figure 18. Spatial variation in groundwater extraction, 2023



Source: Prepared using data from GoI (2024c).

Driven by the compounding effects of the growing population, urbanization, and industrialization, per capita water availability declined by 30% from 2209 cubic meter in 1991 to 1544 cubic meter in 2011 (Figure 19a) which is approximately 10% less than the stressed norm of 1700 cubic meter. It is projected to decrease to 1140 cubic meters by 2050. As agricultural production system intensifies, absolute demand for water for irrigation will increase by 18%, although its proportion of the total utilizable water will decrease to 74% (Figure 19b).

Figure 19a. Per capita water availability (cubic metre/annum)

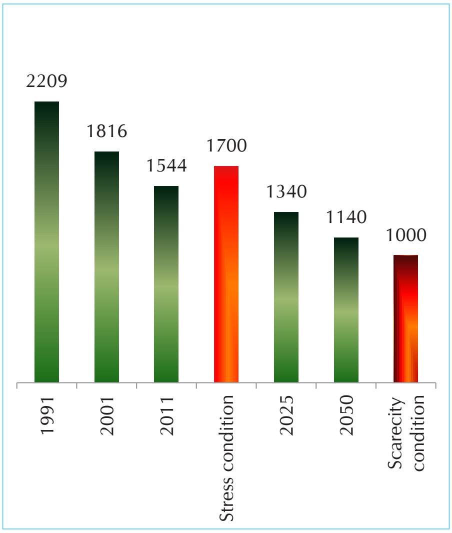
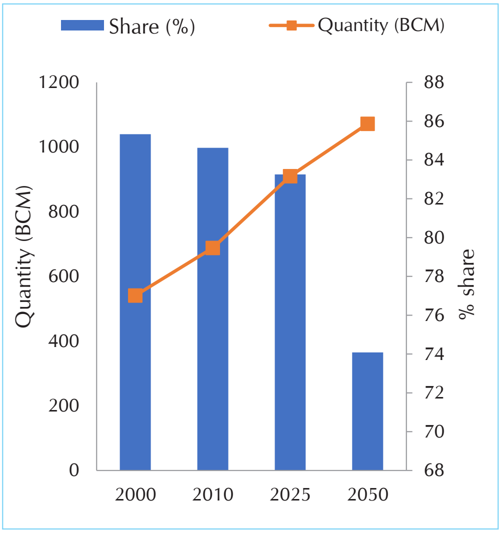


Figure 19b. Water demand for irrigation



Source: GoI (various years, g).

4.4 Excessive reliance on non-renewable energy sources

There is a strong relationship between groundwater and energy use in agriculture. As reliance on groundwater increases, energy use in agriculture also increases. This is evident from the significant increase in well density, number of electric pumps, and corresponding electricity consumption. Well density, defined as the number of wells per hectare of net sown area, increased from 42 in 1982-83 to 158 in 2017-18 (Figure 20a), and the proportion of electricity-operated wells almost doubled from 39% in 1986-87 to 76% in 2024 (Figure 20b). The electricity consumption in agriculture experienced a 13-fold increase from 127 Kwh/ha in 1983-84 to 1620 Kwh/ha in 2022-23 (Figure 21).

Figure 20a. Trend in well density (number/1000 ha)

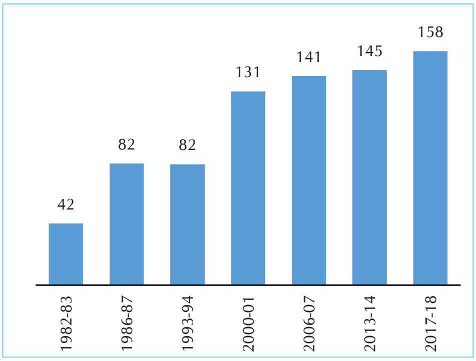
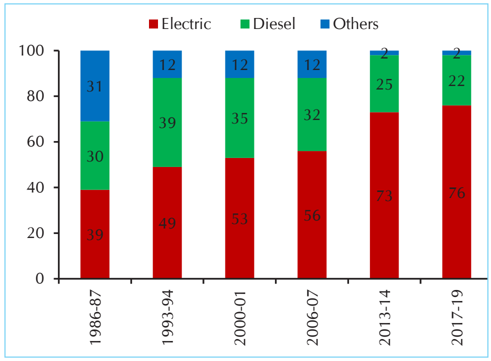
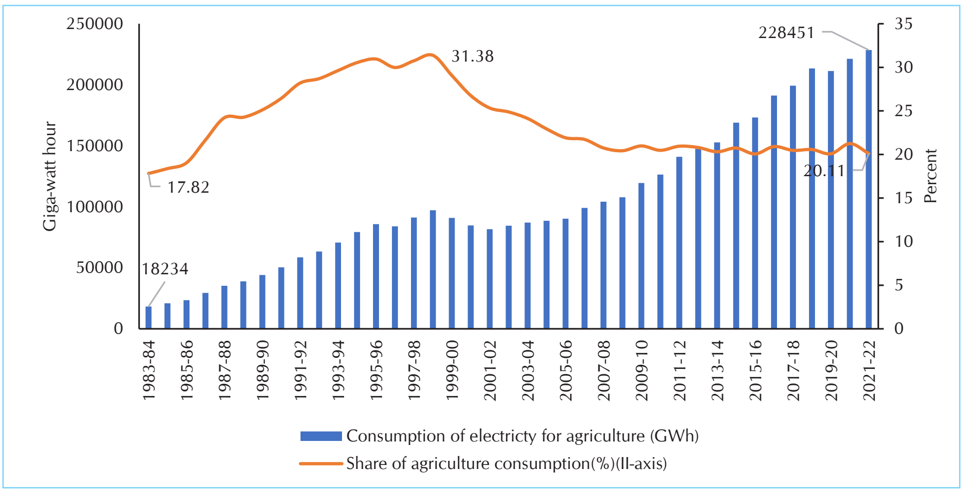


Figure 20b. Sources of energy for groundwater extraction (%)



Source: GoI (various years, h).

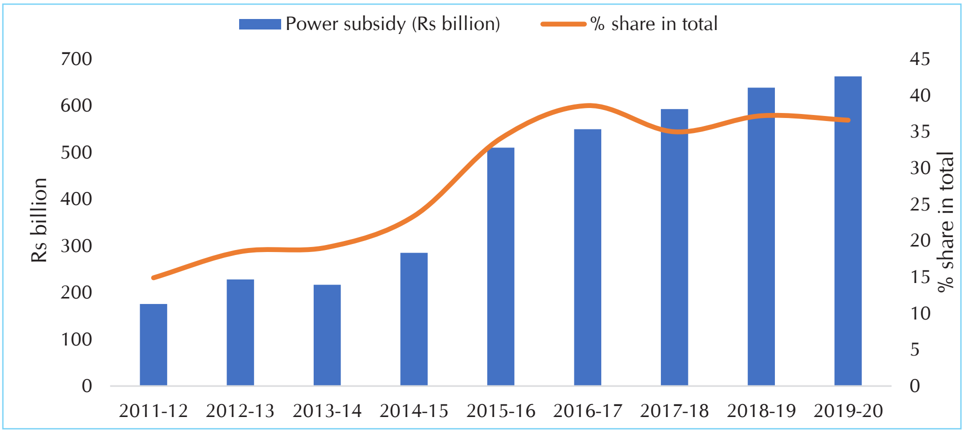
Figure 21. Trend in electricity consumption in agriculture



Source: GoI (various years, d).

The increase in energy intensity can be largely attributed to the heavily subsidized electric power for agriculture. Most state governments provide subsidies for electricity for agricultural purposes. Over time, there has been a significant increase in electricity subsidies. The real expenditure on electricity subsidies has seen a dramatic surge, from Rs 176 billion in 2011-12 to Rs 663 billion in 2019-20 (Figure 22). As a proportion of the total subsidy expenditure, the share of electricity subsidies increased from 15% in 2011-12 to 37% in 2019-20. This trend raises questions about the sustainability of such subsidy policies, their impact on agricultural practices, and the potential long-term consequences for both the agricultural sector and broader economy.

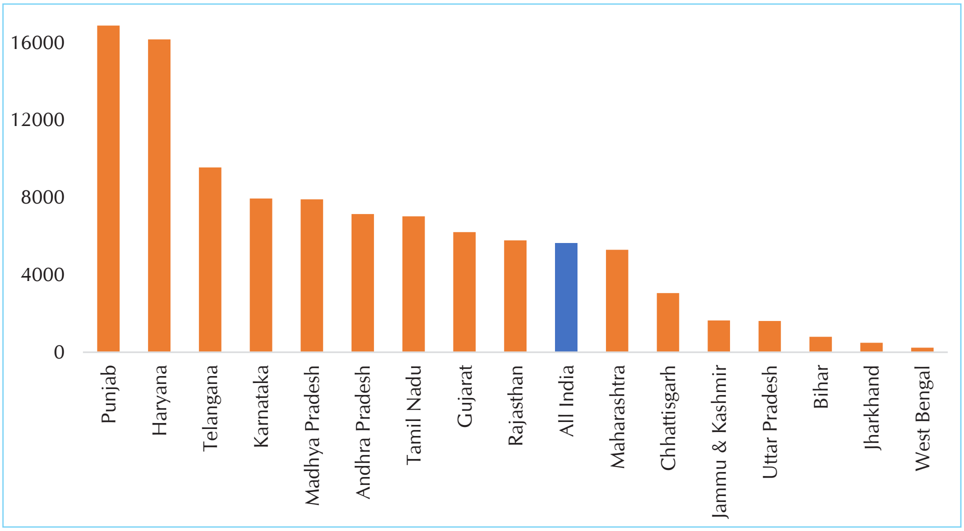
Figure 22. Trend in power subsidies (at 2011-12 prices)



Source: Authors' computations based on data from PFCL (various years).
Note: The subsidies were deflated using the wholesale price index at 2011-12 base.

However, there are significant regional disparities in electricity consumption in agriculture and subsidy rates. While Punjab incurs the highest expenditure on electricity and fertilizer subsidies, followed by Haryana, subsidies are significantly lower in the eastern states of Bihar, Jharkhand, and West Bengal (Figure 23).

Figure 23. Inter-state variation in power subsidies (Rs/ha of net sown area), 2019-21 at current prices



Source: Authors' computations based on data from PFCL (various years).

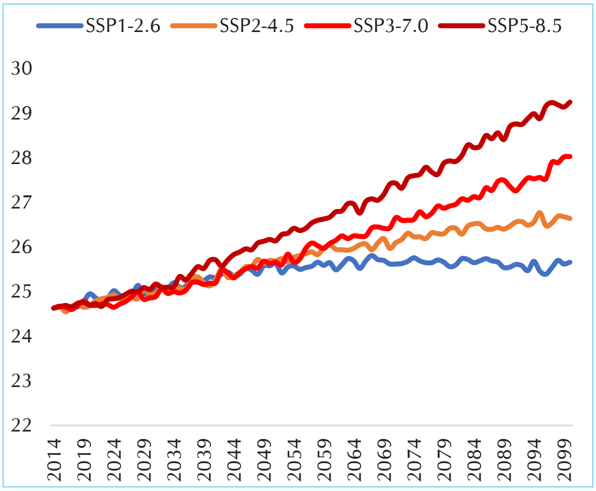
4.5 Looming threats of climate change

Agriculture is a source, victim, and solution to climate change. In India, agricultural sector contributes approximately 14% of the total greenhouse gas emissions, with ruminants and rice cultivation being the primary sources. Changing climate patterns, including rising temperatures, altered precipitation regimes, and increased frequency of extreme weather events, can significantly disrupt agricultural activities. Their effects extend beyond direct impacts, potentially causing degradation of water and land resources, compromising biodiversity and ecosystem health, and altering the dynamics of pests and diseases of crops and livestock.

Developing countries that lack resources for investment in research and infrastructure to build resilience in agriculture are more vulnerable to climate change. According to Ortiz-Bobea et al. (2021) since 1960, climate change has reduced the productivity growth of world agriculture by 21%, with more pronounced effects (25-30%) in developing countries. Evidence from India is consistent with these findings. Birthal et al. (2020) showed a 25% reduction in agricultural productivity growth owing to extreme climate events (i.e., droughts, floods, heat waves, and cold waves) over the past five decades. Similar to Ortiz-Bobea et al. (2021), they also found that underdeveloped regions are more affected by climate change. Furthermore, droughts have been found to cause significantly more damages than other extreme events.

Climate change is projected to intensify in the future. The Intergovernmental Panel on Climate Change (IPCC) predicts a 1.5°C increase in global temperature above pre-industrial levels by the mid-century. Figure 24 presents projections of mean temperature for India under different Shared Socioeconomic Pathways (SSP). The SSP2-4.5, (modification of earlier RCP4.5-Representative Concentration Pathways) is considered the most plausible climate scenario for India, indicates 0.67°C increase in temperature between 2023 and 2047. In contrast, the extreme

Figure 24. Projections of mean temperature under different SSPs (⁰C) in India



Source: World Bank (2025).

scenario RCP5-8.5 indicates a more alarming situation with a temperature increase of 1.1°C.

Birthal et al. (2021a) assessed the yield changes for important crops under the RCP 4.5 scenario for the medium-term (2040-2060). They reported yield being over 5% less for paddy, chickpea, pigeon-pea, and rapeseed-mustard than without climate change (Table 12). However, under the extreme climate scenario RCP 8.5, the difference is considerably larger for all crops. Furthermore, they also found that climate change may not influence area shares of crops but may result in regional shift of some crops. For example, chickpea shows a strong tendency to shift to southern region from north-western and central regions.

Table 12. Impacts of climate change on crop yields in medium term (2040-2060) (%)

	Winter crops				Rainy crops					
Climate scenario	Wheat	Chickpea	Rapeseed-mustard	Barley	Paddy	Maize	Millets	Pigeon-pea	Groundnut	Cotton
RCP4.5	-3.1	-6.61	-5.08	-3.76	-5.52	-4.72	-3.92	-5.97	-3.8	-1.83
RCP8.5	-7.08	-15.1	-11.59	-8.59	-21.22	-18.13	-15.06	-22.95	-14.6	-7.03

Source: Birthal et al. (2021a).

The ripple effects of extreme climate events extend beyond the farm, affecting the entire agricultural supply chain, leading to reduced food availability and increased price volatility. In the absence of adequate food security measures, this situation may lead to an increase in poverty rates and the prevalence of malnutrition, particularly among women and children (Hazrana et al., 2025).

4.6 Environmental pollution due to agricultural byproducts

India's agricultural sector generates huge quantities of byproducts, with crop residues and dung being the major components. Crop husbandry produces approximately 755 million tons of crop residues annually, with two-thirds utilized for various purposes such as animal feed, fuel, and construction materials. However, of the remaining one-third approximately three-fourths being burnt. This practice releases particulate matter and noxious gases into the atmosphere. The livestock sector, comprising 303 million ruminants (i.e., cattle and buffaloes), generates approximately 1271 million tons of dung annually, of which one-third is utilized as cooking fuel in rural areas, the remainder is primarily used as manure.

The management of these agricultural byproducts presents significant challenges. The current practices of crop residue burning and unscientific manure management cause environmental pollution and health hazards. Open field burning of crop residues also negatively impacts soil health and microbial populations. Similarly, inefficient manure management practices result in increased greenhouse gas emissions, particularly methane.

4.7 Underdeveloped markets and value chains

India's agri-food production system has transitioned from subsistence to commercial production, with farmers marketing 46–99% of the output of different commodities (Table 13). However, the market infrastructure has not kept pace with this trend. There has been little improvement in the number of regulated markets and their area coverage (Birthal et al., 2024). On average, one market serves approximately 20000 hectares of net cropped area. The country also has a significant deficit in storage infrastructure, especially for perishable commodities, including fruits and vegetables. In 2022-23, it had a cold storage capacity of 33 million tons, as against a production of 110 million tons of fruits and 213 million tons of vegetables.

Table 13. Disposal of marketed surplus to different agencies, 2018-19

Crop	% of output sold	% share in marketed surplus					
		Local market	APMC	Government agencies	Farmer collectives	Private and others	All
Paddy	70.6	62.4	4.7	16.8	5.1	10.9	100
Wheat	58.1	66.1	12.7	13.5	3.3	4.3	100
Jowar	74.4	89.1	4.0	1.5	0.8	4.6	100
Bajra	55.7	82.4	10.1	3.8	0.0	3.7	100
Maize	81.5	88.1	3.7	1.9	0.5	5.8	100
Ragi	46.3	75.0	19.3	0.0	0.0	5.7	100
Gram	80.7	70.1	15.1	3.1	3.9	7.8	100
Arhar	83.6	72.4	20.6	1.5	0.3	5.2	100
Urad	88.2	86.3	9.3	2.9	0.9	0.5	100
Moong	66.9	85.8	10.9	0.7	0.2	2.4	100
Masur	66.0	76.6	6.5	0.1	6.0	10.8	100
Groundnut	82.9	54.7	18.6	0.6	0.2	26.0	100
Mustard	80.6	75.0	13.2	6.3	0.1	5.4	100
Soybean	85.2	63.1	21.6	6.7	1.0	7.6	100
Coconut	70.7	80.7	3.9	0.0	0.3	15.0	100
Sugarcane	97.7	14.2	3.0	11.2	21.1	50.4	100
Cotton	97.4	61.8	14.3	8.0	0.5	15.2	100
Potato	82.1	84.0	6.3	0.7	0.0	9.0	100
Onion	99.4	87.5	5.2	0.0	0.0	7.4	100

Source: Authors' estimates using data from GoI (2021b).

Inadequate market infrastructure results in reduced market access for farmers, increased transportation costs, and potential post-harvest losses. This also contributes to price volatility and diminished bargaining power for farmers, particularly smallholders. Furthermore, it enhances farmers' reliance on local traders to dispose of their produce. Table 13, which also presents the disposal patterns of farm produce, reveals the significant dependence of farmers on local traders. Insufficient infrastructure leads to inefficiencies in the supply chain, higher trade costs, and increased price margins.

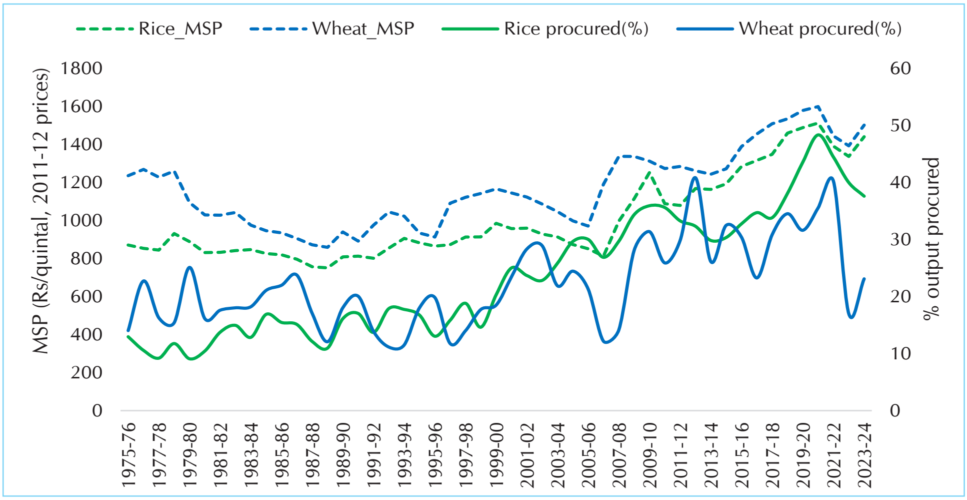
The food processing sector is crucial for transformation of raw commodities into high-value products, reducing post-harvest losses, and enhancing farmers' income. India is a major supplier of many value-added products such as frozen bovine meat, marine products, spices, dairy, and fruit pulp to global markets. This sector has experienced steady growth, driven by rising domestic and global demand, agricultural surplus, technological advancements, government support, and export opportunities. Increasing disposable incomes, urbanization, and changing dietary habits have fuelled growth in demand for processed foods. Government initiatives, including the Pradhan Mantri Kisan Sampada Yojana (PMKSY), Production Linked Incentive Scheme (PLIS), and Pradhan Mantri Formalisation of Micro Food Processing Enterprises (PMFME), have strengthened the ecosystem.

Despite its potential, the sector faces multiple challenges. Supply chain inefficiencies, such as weak farm-to-fork linkages and lack of primary processing, reduce competitiveness. Compliance with global food safety standards is a major hurdle for small and medium enterprises (SMEs). High capital requirements and limited access to credit deter small processors from scaling operations.

4.8 Excessive policy emphasis on cereals

Government of India has significantly intervened in agricultural markets through the procurement of farm produce at government-determined, pre-announced MSP to reduce market uncertainty and price risk for farmers. However, procurement efforts have primarily concentrated on rice and wheat, the principal staple crops. The MSP for both rice and wheat (at 2011-12 prices) has experienced a notable increase, particularly since the mid-1990s, incentivizing farmers to sell their produce to the government procurement system. In 2022-23, the government procured approximately 57 million tons of rice and 19 million tons of wheat, representing 42% and 17% of their respective production levels (Figure 25).

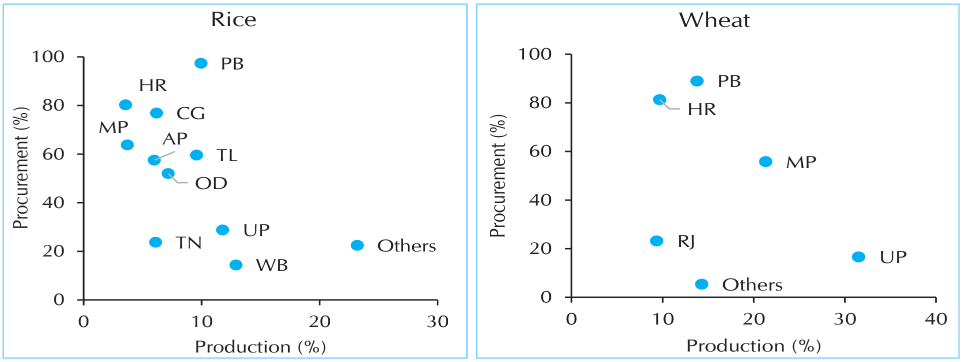
Figure 25. Procurement of rice and wheat



Source: GoI (various years, d).

The disproportionate emphasis of price policy on rice and wheat has led to their intensive cultivation and consequently degradation of groundwater resources, particularly in Punjab and Haryana (Kishore et al., 2025). Punjab and Haryana together contribute more than 28% to the total procurement of rice and 50% of wheat, approximately double than their share in production of both crops (Figure 26). Procurement at the MSP discourages diversification of production portfolio (Negi et al., 2020) and private investment in markets and value chains. Moreover, India's public stockholdings of foodgrains have come under scrutiny by member countries of the World Trade Organization (WTO) for their potential distortionary effects on global food markets.

Figure 26. Spatial distribution of production and procurement of rice and wheat, 2021-22



Source: GoI (2023).

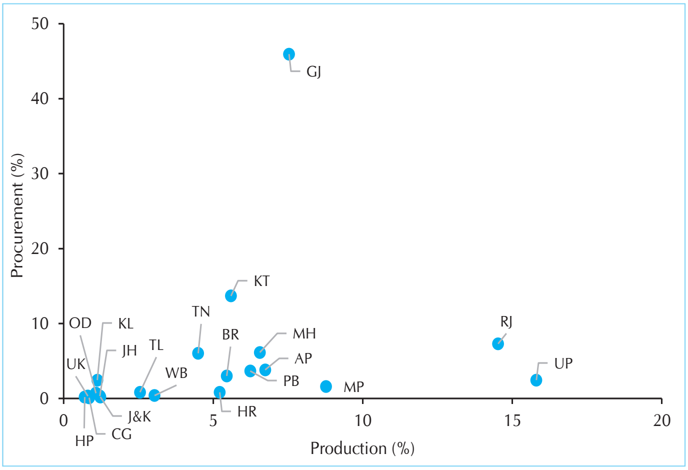
Note: AP- Andhra Pradesh; CG- Chhattisgarh; HR- Haryana; MP- Madhya Pradesh; OD-Odisha; PB-Punjab; RJ- Rajasthan; UP- Uttar Pradesh; TN- Tamil Nadu; TL-Telangana; WB-West Bengal.

4.9 Poor market linkages for livestock products

Expansion of market infrastructure for livestock products has not kept pace with the growth in their production. Most trade in livestock and livestock products occurs in informal markets. Although dairy cooperatives have experienced significant expansion; the proportion of milk output procured by them has increased from 6.6% in 1980-81 to 10% in 2015-16 and subsequently it remained relatively stable.

Moreover, spread of dairy cooperatives has remained limited to a few regions. Gujarat accounts for a disproportionate share (45%) of total milk procurement compared to 9% in production (Figure 27). Regional disparities are also reflected in the concentration of the private dairy industry (Birthal and Negi, 2012). Most private dairy firms are located in Punjab, Haryana, Uttar Pradesh, and Maharashtra, which have a higher milk production potential, leaving the eastern and north-eastern regions largely underserved by cooperatives and private sector. The poultry industry stands out as an exception, achieving a high level of industrialization (Nanda Kumar et al., 2022). However, its value chains are predominantly concentrated in the southern states, including Telangana, Andhra Pradesh, Tamil Nadu, and Karnataka.

Figure 27. Spatial distribution of production and procurement of milk, 2022-23



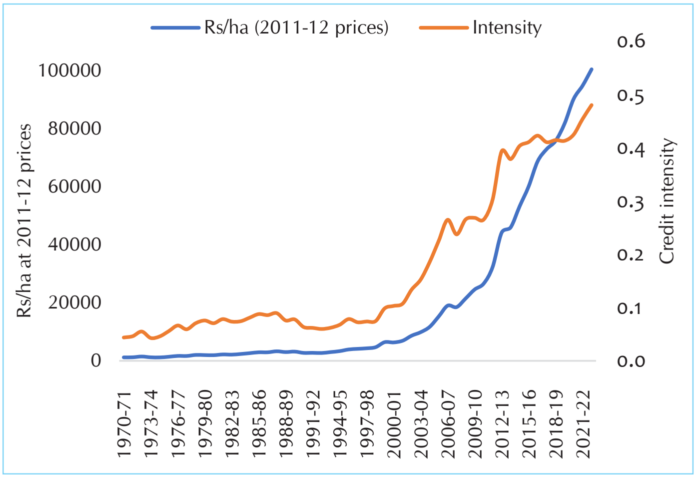
Source: NDDB (2023).

Note: AP-Andhra Pradesh: BR-Bihar; CG-Chhattisgarh; GJ-Gujarat; HR-Haryana; HP-Himachal Pradesh; J&K-Jammu & Kashmir; JH-Jharkhand; KT-Karnataka; KL-Kerala; MP-Madhya Pradesh; MH-Maharashtra; OD-Odisha; PB-Punjab; RJ-Rajasthan; TN-Tamil Nadu; TL-Telangana; UP-Uttar Pradesh; UK-Uttarakhand; WB-West Bengal

4.10 Lack of targeting of institutional credit

The availability of financial resources enables agricultural producers to adopt advanced technologies and invest in the agricultural infrastructure. Over the past five decades, flow of institutional credit to agricultural sector has increased significantly, from approximately Rs 1219 to over Rs 100000 per hectare of net cropped area between 1970-71 and 2022-23 (at 2011-12 prices), resulting in credit intensity (i.e., the ratio of outstanding credit to AgGDP) increasing from 0.05 to 0.48 (Figure 28). Notably, the flow of credit has accelerated significantly in the past two decades.

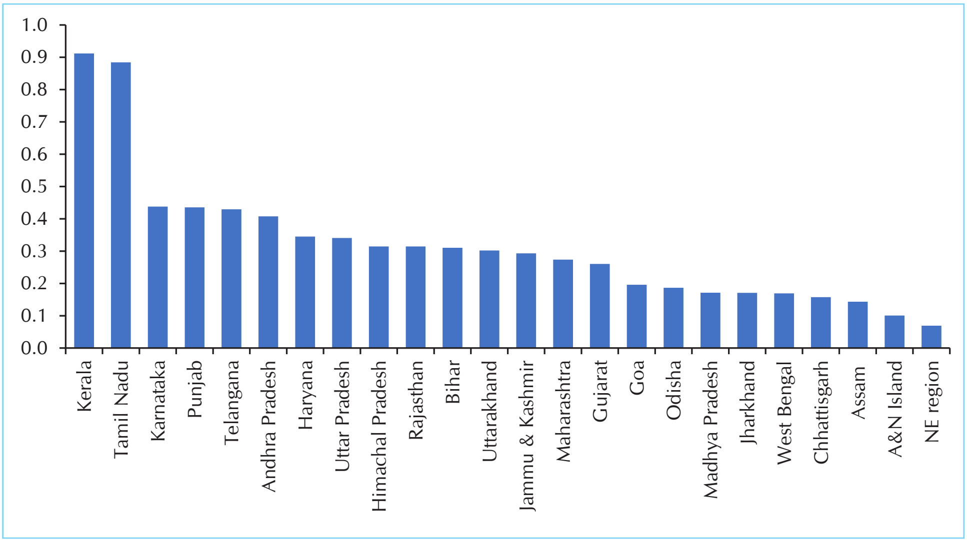
Figure 28. Trend in institutional credit to agriculture



Source: Authors' estimates based on data GoI (2023) and RBI (2024).

However, significant biases exist in credit allocation across enterprises and regions. Animal husbandry, which has been driving agricultural growth, has remained underrepresented in credit allocation, receiving only 6% of the total agricultural credit (Birthal and Negi, 2012). Additionally, a significant proportion (60%) of the total credit is allocated to meet short-term financial requirements, ignoring the long-term requirements for capital formation. Furthermore, credit policy has predominantly focused on productivity enhancement, neglecting risk management, which is becoming increasingly crucial due to climate change. Finally, a significant regional imbalance exists in credit disbursements, with the southern states having disproportionately higher credit intensity (Figure 29).

Figure 29. Regional disparities in credit intensity



Source: As for Figure 28.

The implications of these patterns are evident. Neglecting high-value sectors, such as animal husbandry and fisheries, could result in missed opportunities to accelerate agricultural growth, enhance farmers' income, reduce poverty and combat undernutrition. Emphasis on productivity enhancement at the expense of risk management renders farmers vulnerable to climate-related challenges. Regional disparities in credit disbursements may exacerbate existing economic inequalities among states. An insufficient emphasis on long-term credit may adversely affect capital formation in agriculture, essential for long-term sustainability of agricultural growth.

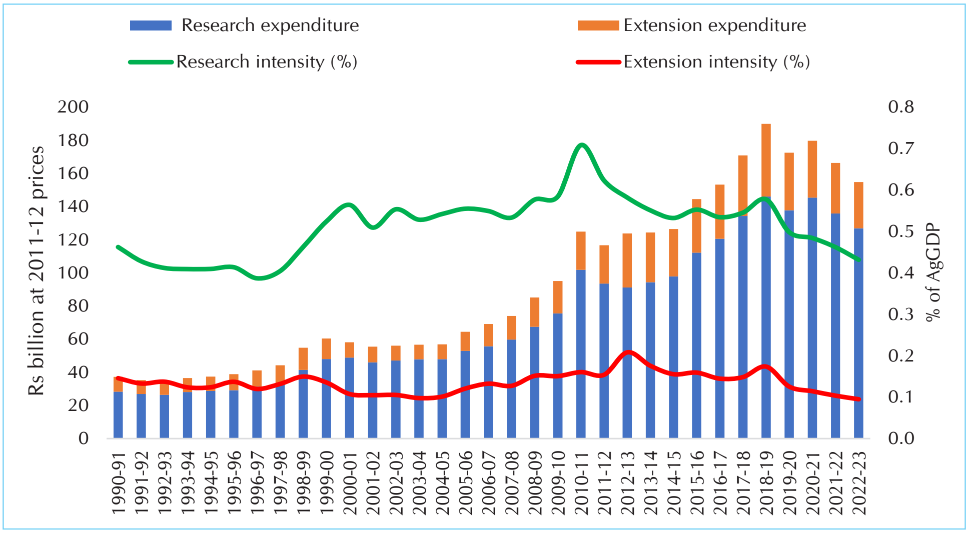
4.11 Underfunding of agricultural R&D

Agricultural research, a remedy to multiple challenges, has remained underfunded in India. In 2022-23, the country spent Rs 127 billion (at 2011-12 prices) on agricultural research, nearly quadrupling the amount spent in 1990-91 (Figure 29). Nevertheless, as a proportion of agricultural gross domestic product (AgGDP), it seldom exceeded 0.7%. After attaining a peak of 0.71% in 2011-12, it declined to 0.43% in 2022-23, not even half of the global average of 0.93% and considerably less than 1-5% in several developed countries (Jayne et al., 2023). It is noteworthy that India has yet to attain a research intensity of one percent that developed countries like the US had in the 1960s (FAO, 2023).

Similarly, agricultural extension system remains inadequately developed to address the farmers' growing requirements of technical advice and information. Approximately half of farm households have access to technical advice or information, but only a small proportion (10%) relies on the government extension system (Kandpal et al., 2024). The expenditure on public extension system comprises approximately 0.12% of the AgGDP, or one-fifth of the total R&D expenditure (Figure 30).

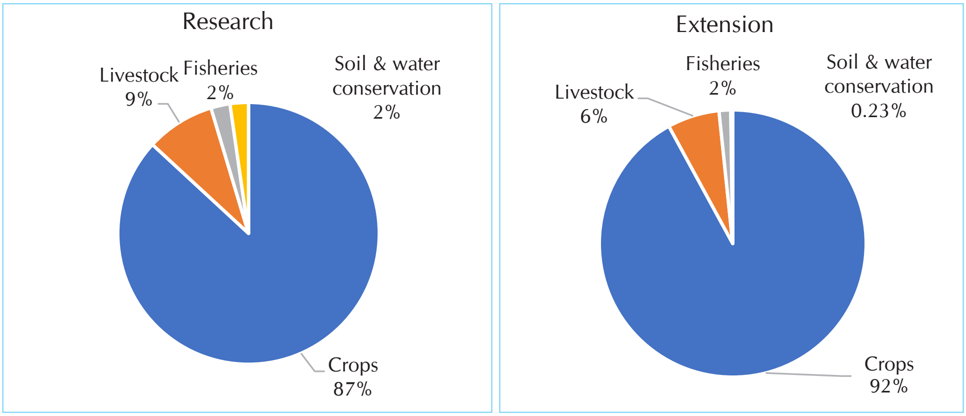
Moreover, both research and extension efforts have predominantly concentrated on crops, whereas livestock and fisheries, which have been driving agricultural growth, have received significantly less resources than their economic contributions (Figure 31). In addition, the allocation of both research and extension resources to natural resources is minimal. Inadequate resource allocation for research on livestock and fisheries could result in missed opportunities for diversification-driven agricultural growth, which is crucial for reducing poverty and addressing malnutrition. Insufficient funding for research on natural resources may compromise the long-term sustainability of agriculture.

Figure 30. Trends in public investment in agricultural R&D



Source: Authors' estimates based on data from GoI (various years, i), and GoI (various years, a).

Figure 31. Sectoral allocation of agricultural R&D investment, 2019-2023

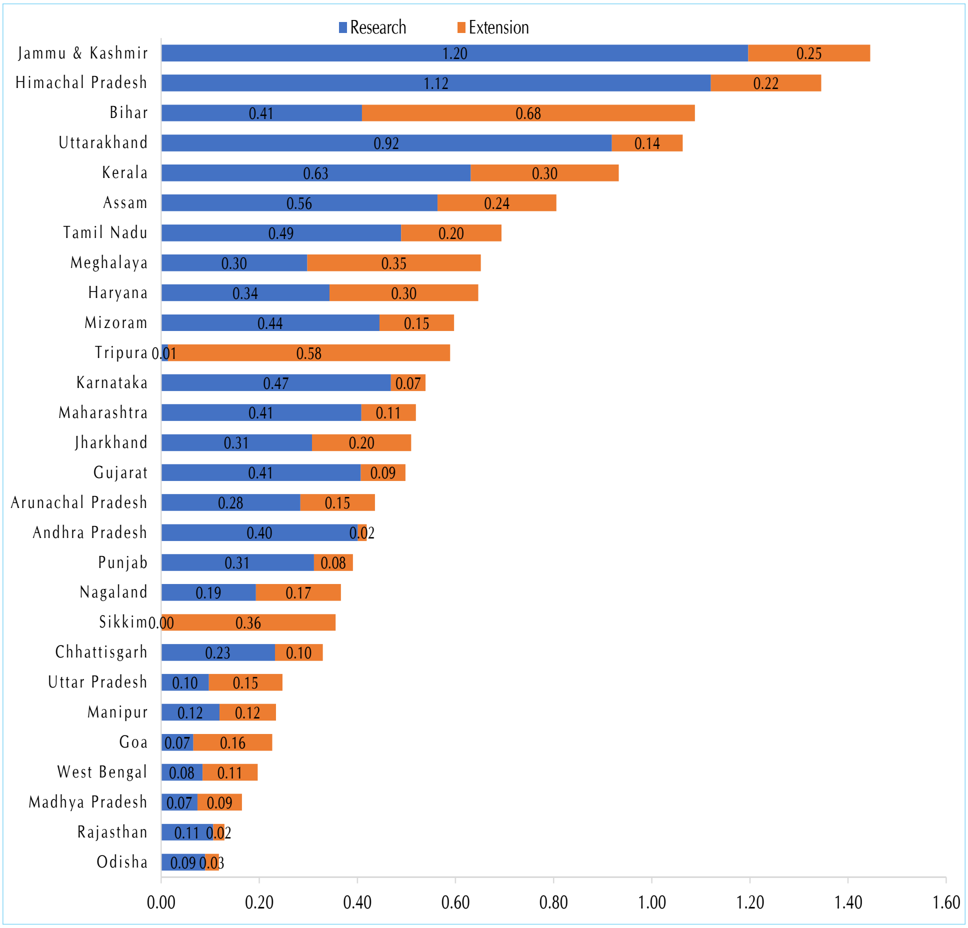


Source: GoI (various years, i).

Significant regional disparities exist in R&D expenditure. States in the Himalayan region, including Jammu & Kashmir, Himachal Pradesh, and Uttarakhand, along with Kerala, Assam, and Bihar, allocate a higher percentage, ranging from 0.80% to 1.45% of their agricultural GDP (Figure 32). Tamil Nadu, Haryana, Meghalaya, Mizoram, Tripura, Karnataka, Maharashtra, Jharkhand, and Gujarat allocate between 0.50% and 0.69% of their agricultural GDP. Conversely, the allocation is less than 0.25% in Odisha, Rajasthan, Madhya Pradesh, West Bengal, and Uttar Pradesh, which collectively account for 43% of the country's net sown area.

Unfortunately, spending on agricultural R&D has not only remained much less than the desired level of approximately one percent of AgGDP, but also has fluctuated over time. Agricultural research is capital-intensive and involves a prolonged gestation period; hence, insufficient investment coupled with significant fluctuations can potentially impede the continuity of scientific progress, which in turn affect food and nutritional security, and farmers' livelihoods.

Figure 32. State-wise spending on R&D as percent of AgGDP, 2011-2020

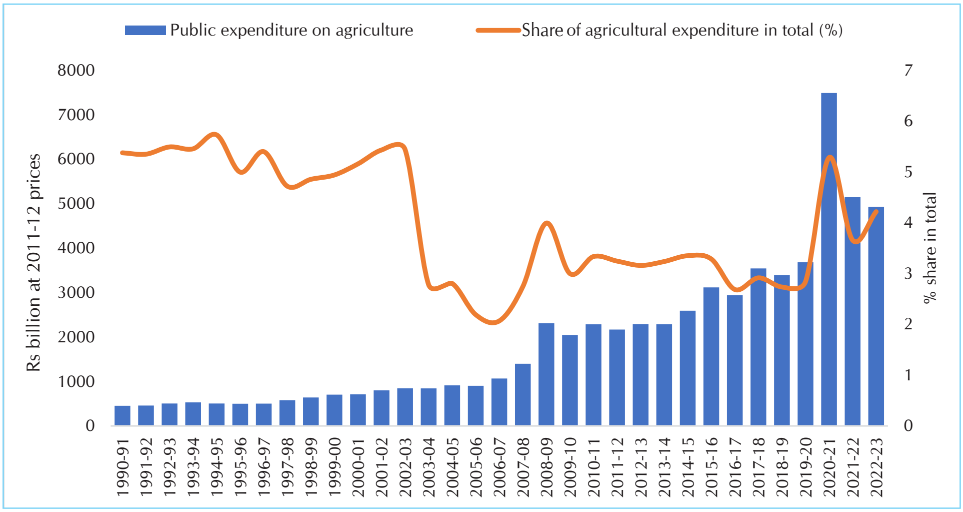


Source: As for Figure 30.

4.12 Lack of sustained investment in agriculture

Public expenditure on the agricultural sector, measured in 2011-12 prices, has increased considerably from a modest Rs 452 billion in 1990-91 to Rs 7491 billion by 2020-21 (Figure 33). However, this trend has not been uniform. The period spanning 1990-91 to 2002-03, experienced slow growth in public investment. Thereafter, there was a more pronounced increase in it, but with significant fluctuations. It reached its peak in 2020-21, possibly due to increased government support to agriculture during the COVID-19 pandemic. However, this peak was followed by an equally sharp decline, with investment dropping to Rs 4927 billion in 2022-23.

Figure 33. Trend in public sector investment in agriculture



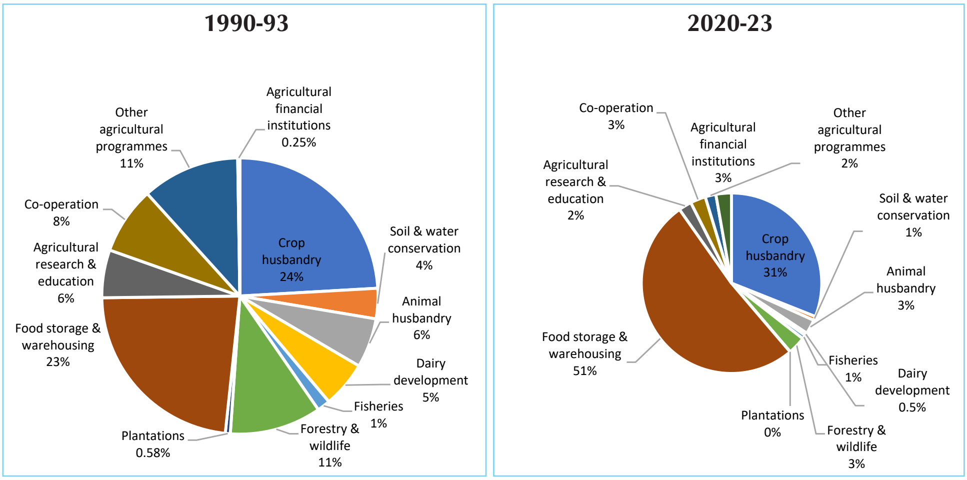
Source: As for Figure 31.

Nonetheless, as a proportion of the total development expenditure, agriculture's share seldom exceeded 6% (Figure 34). It remained between 5% and 6% during the 1990s, followed by a gradual decline, reaching a minimum of 2.1% in 2006-07. It subsequently increased but remained below 4% until 2019-20. Thereafter, it rose to 5.3% in 2020-21. This pattern of expenditure indicates a lack of a sustained policy emphasis on agriculture in development planning.

Furthermore, the investment priorities have undergone significant changes over the past three decades. The share of storage and warehousing in the total investment has more than doubled, reaching 51% in 2020-23 from 23% in the early 1990s. Crop husbandry remains the second-largest component, consolidating its share to 31% in 2021-23 from 24% in 1991-93. Nevertheless, their shares have increased at the expense of other activities. Animal husbandry and dairy development have experienced a substantial decrease in their share, from 11% to 3%. Likewise, share of fisheries and soil and water conservation has been reduced significantly. Of particular concern is the decline in allocation for agricultural R&D from 6% to 2%.

These changes reflect concerns about the agricultural sector's long-term viability and ability to diversify as well as the potential consequences for both rural communities' livelihoods and ongoing efforts for environmental preservation. Failure to prioritize livestock and fisheries sectors may lead to undernutrition, fewer economic prospects for farmers, and reduce agricultural growth. Similarly, insufficient allocation for natural resource management may thwart efforts to check the degradation of land, water and biodiversity. Moreover, underinvestment in agricultural research can impede innovation, limiting the capacity of the agricultural sector to adapt to the changing market demands and emerging challenges of climate change.

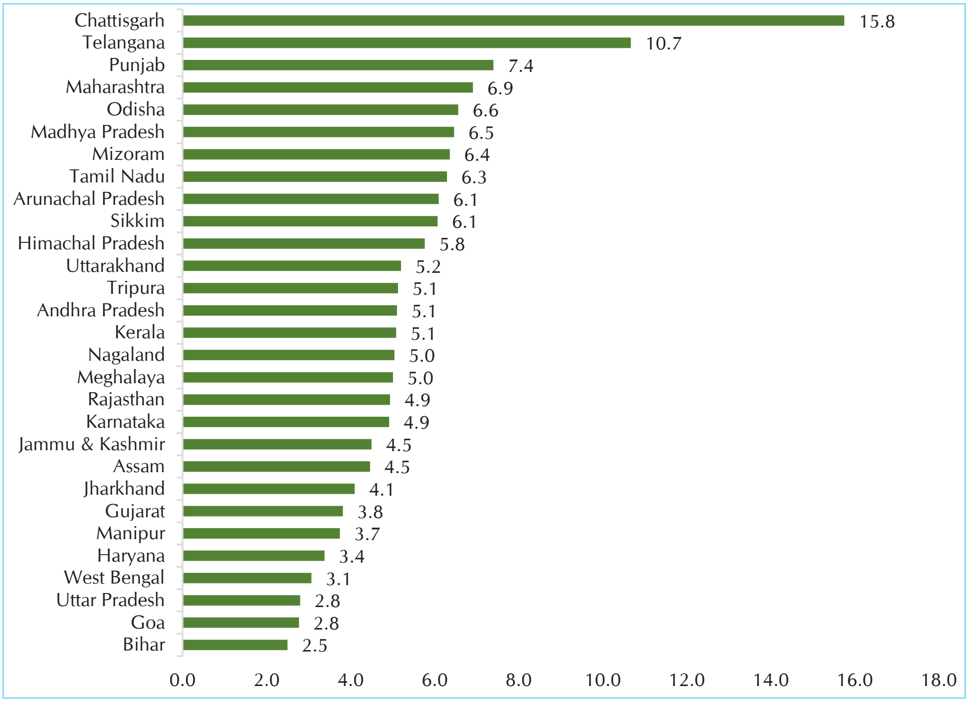
Figure 34. Composition of agricultural development expenditure



Source: As for Figure 31.

Furthermore, there is significant regional variation in agricultural investment (Figure 35). Himachal Pradesh, Uttarakhand, Tripura, Andhra Pradesh, Nagaland, Meghalaya, Rajasthan, and Karnataka allocate approximately 5% of their total development expenditure to agricultural sector, aligning closely with the national average. On the other hand, Bihar, Uttar Pradesh, West Bengal, Haryana, Manipur, Gujarat, Jharkhand, Assam, and Jammu & Kashmir allocate less than the national average. Notably, Chhattisgarh and Telangana accord a very high priority to agriculture in development planning, allocating 16% and 11% of their total development expenditure, respectively.

Figure 35. % share of agriculture in total expenditure, 2020-2023



Source: As for Figure 31.

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5 Reshaping Agricultural Policies

The assessment of the current policy frameworks in light of the changing economic landscape and environmental challenges suggests the need for a fundamental shift in agricultural policies. This paradigm shift is crucial to effectively address and adapt to emerging challenges, capitalize on new opportunities, and meet evolving societal needs. The new policy paradigm must balance among ensuring food security, preserving natural resources, and protecting farmers' interests.

5.1 Enhance and prioritize public investment in agriculture

Inadequate and inconsistent public investment slows down improvements in infrastructure, markets, institutions, and R&D systems, which may consequently lead to low agricultural productivity and susceptibility to climate shocks, ultimately adversely affecting farmers' livelihoods and food and nutrition security. Hence, a renewed emphasis on agriculture in developmental planning is imperative to achieve the desired objective of efficient, sustainable, and inclusive transformation of agri-food system.

Furthermore, it is important to prioritize investment in the agricultural sector to maximize its efficiency and social outcomes. While it is indisputable that investment in post-harvest management infrastructure is essential to support agricultural growth, investment in activities that enhance agricultural productivity and farmers' income, preserve natural resources, and mitigate climate risks remains critical. The livestock and fisheries offer particularly promising opportunities for accelerating growth, improving nutrition, and alleviating poverty. Nonetheless, a decline in their may restrict the realization of their production potential. Notably, growth in the livestock production has largely been driven by an increase in the number of animals. This approach is unsustainable and puts additional pressure on already strained resources. Feed and fodder scarcity is the main constraint. The country is deficit in all types of feed: dry fodder (23%), green fodder (11%), and concentrate feed (29%) (USDA, 2023). The shortage is expected to worsen owing to competing demands for land and climate change impacts. Furthermore, the livestock sector confronts the challenge of inadequate animal breeding services, as evidenced by the low success rate of approximately 35% for artificial insemination. The diminishing utility of male cattle due to decreasing landholdings and increased mechanization of agricultural operations necessitates promotion of sex-sorted semen technology, which offers producers a choice of offspring (Thakur and Birthal, 2023). Furthermore, improving the efficiency of animal health services is crucial given the significant prevalence of foot and mouth disease (FMD) and the emergence of diseases such as lumpy skin disease (LSD).

The fishery subsector, which has also experienced a rapid growth in the recent decade, is facing significant challenges. Overexploitation of marine resources has resulted in declining fish stocks, while environmental degradation poses a threat to aquatic ecosystems. Inadequate post-harvest infrastructure further exacerbates these issues, leading to substantial losses and reduced quality of fish products. It is therefore, essential to reorient the production landscape towards cage farming and mariculture, and invest in post-harvest infrastructure.

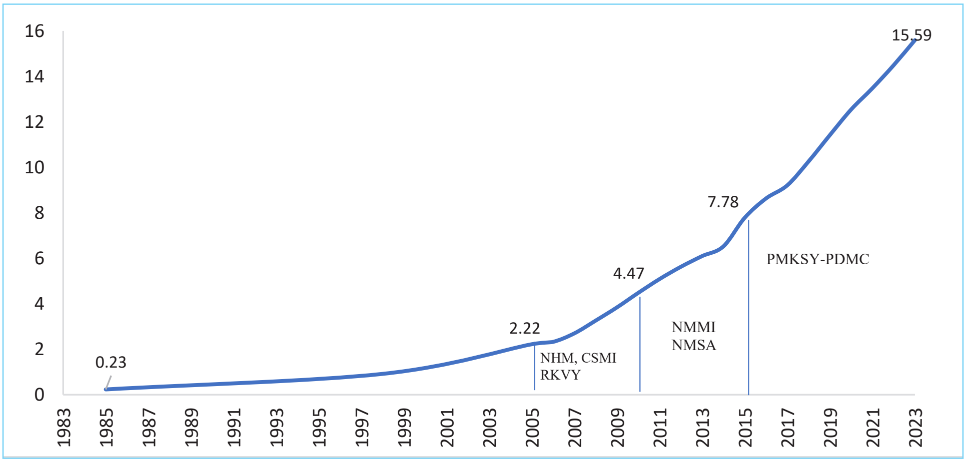
Management of natural resources and addressing climate change impacts must be critical priorities for sustainable development of agriculture. As temperatures continue to rise and extreme weather events become more frequent, the need for effective resource management and climate adaptation strategies has become increasingly important. Natural resources, including land and water, are under pressure from population growth, urbanization, and economic development.

5.2 Holistic management of water-energy nexus

Sustainable agricultural development necessitates a comprehensive approach to the water-energy nexus. This entails strategies, such as the capture and storage of rainfall water, enhancement of groundwater recharge, diversification of crop portfolios, and application of efficient irrigation methods, including pressurized systems, to reduce water consumption.

Improving water use efficiency can significantly address growing water scarcity. There is significant potential to enhance water use efficiency from the current 35-40% to 60%. A 10% increase in water use efficiency could irrigate an additional 14 million hectares (Swaminathan, 2006). Towards this, Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) aims to enhance irrigation coverage and promote water-efficient practices, including pressurized irrigation systems such as drips and sprinklers (Srivastava et al., 2024a). Although there has been a notable expansion in area under pressurized irrigation, the potential remains underutilized (Figure 36). Only 18% of the potential 88 million hectares for micro-irrigation has been exploited. Currently, micro-irrigation saves approximately 11 billion cubic meters of groundwater; if fully harnessed, approximately 65 BCM of groundwater can be conserved, which can irrigate 33 million hectares or can be used for other purposes (Srivastava et al., 2024a).

Figure 36. Trend in micro-irrigation, million hectares

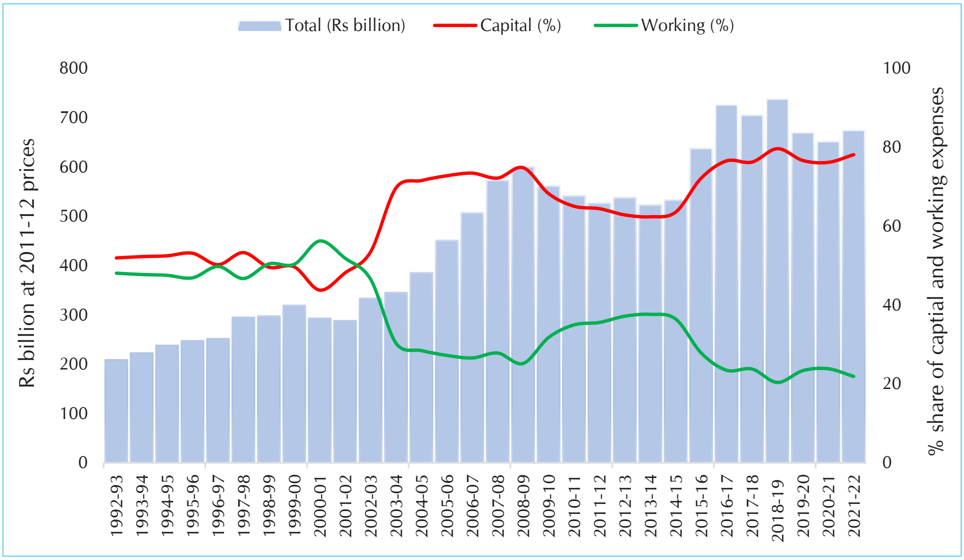


Source: Srivastava et al. (2024a).

Note: NHM- National Horticulture Mission, CSMI- Centrally Sponsored Scheme on Micro-Irrigation, RKVY- Rashtriya Krishi Vikas Yojana, NMMI-National Mission on Micro-Irrigation, NMSA- National Mission on Sustainable Agriculture, PMKSY- Pradhan Mantri Krishi Sinchayee Yojana, PDMC- Per Drop More Crop.

Rejuvenating canal irrigation is crucial for reducing pressure on groundwater resources. This requires a significant increase in investment for the operation and maintenance of canals, which has declined in recent decades (Figure 37). The conjunctive use of surface water and groundwater can prevent falling groundwater levels.

Figure 37. Trend in expenditure on major and medium irrigation projects

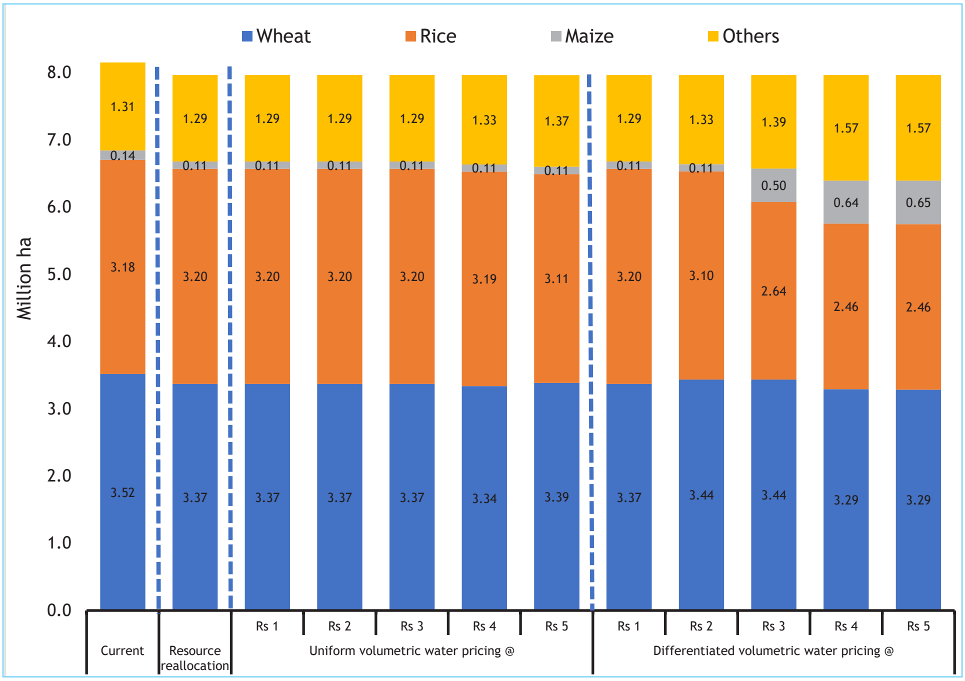


Source: As for Figure 31.

The integration of digital innovations (e.g., sensors and IoT-enabled controllers) in irrigation systems offers solutions for conserving water and electricity resources. Vatta et al. (2018) showed that the use of tensiometers for irrigation scheduling can reduce the consumption of water and electricity by approximately 13%.

Effective management of groundwater resources is unlikely to be achieved without simultaneous reforms in the power sector. Gradual reduction or targeting electricity subsidies to those who require them can help promote the efficient use of energy and conservation of water resources. The implementation of a tiered volumetric pricing system of water can help reduce the area under water-guzzling crops, such as paddy (Figure 38), and thus a significant reduction in water consumption (Figure 39).

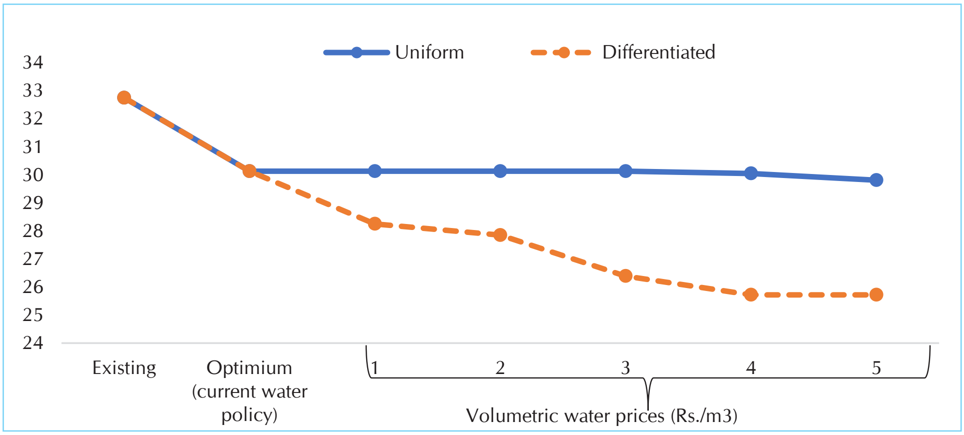
Figure 38. Water pricing and cropping pattern in Punjab



Source: Chand et al. (2022).

Note: Resource reallocation indicates optimization with existing policies; uniform water pricing means charging unfirmly from all the farmers; differentiated pricing implies that those who use water over and above 4488 m³/ha pay for an additional tariff, while those using less than this pay lower tariff.

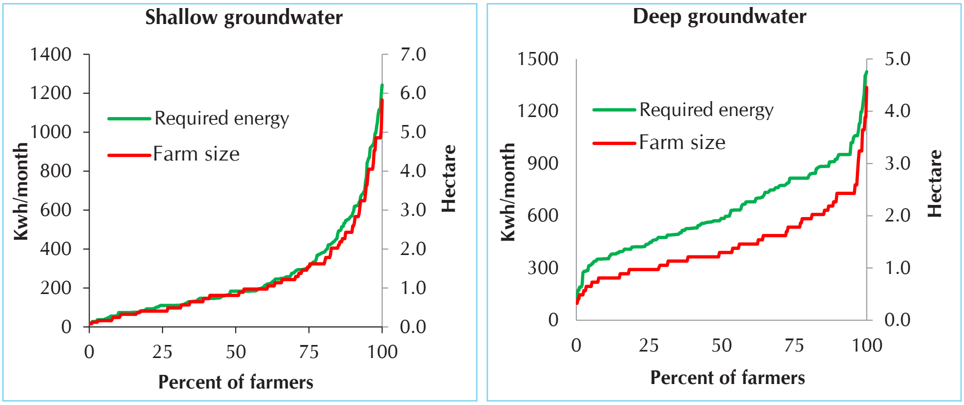
Figure 39. Impact of volumetric pricing on water use in Punjab (BCM)



Source: Chand et al. (2022).

Similarly, the implementation of a tiered electricity tariff system based on crop water requirements is another promising approach. Figure 40 presents the energy requirements for two different groundwater environments in Uttar Pradesh: shallow groundwater (Sitapur district), and deep groundwater (Baghpat district). There is a significant variation in electricity requirements across regions and farm sizes. In shallow groundwater areas, 80% of farmers, particularly those with marginal and small landholdings, require less than 400 kWh per month. Conversely, in deep groundwater areas, only 28% of the farmers require 460 kWh monthly. This marked disparity underscores the necessity of a targeted subsidy approach that considers variations in water requirements and water levels.

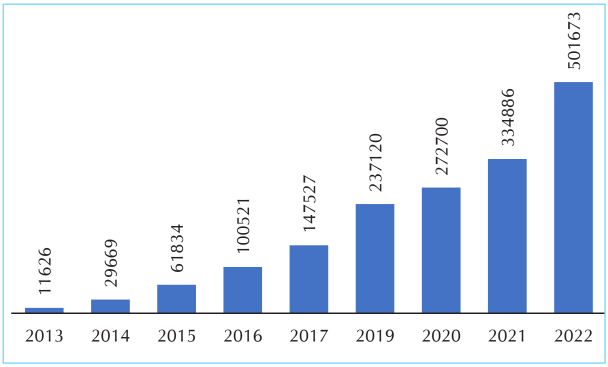
Figure 40. Required electric power to meet irrigation requirement of existing cropping pattern in Uttar Pradesh



Source: Srivastava et al. (2024b).

Redirecting subsidies to renewable energy sources such as solar and wind power is one of the most significant approaches for addressing the energy scarcity challenge. Srivastava et al. (2024a) have calculated that solarization of existing groundwater pumps has a capacity to generate 102 Gigawatt (GW) of energy. However, only one percent of this has been exploited with the installation of approximately 500,000 solar pumps (Figure 41). If all water pumps are solarized, it will not only address the challenge of energy security, but also reduce CO_2 emissions by 45 million per annum from approximately one million tons at present.

Figure 41. Trend in solar pumps for irrigation (number)



Source: Srivastava et al. (2024a).

5.3 Repurpose fertilizer subsidies

The current subsidy regime disproportionately favors the use of N over P and K, resulting in nutrient imbalance and adverse effects on the soil and water health. To promote balanced application of NPK, it is imperative to align the subsidy structure with the nutrient requirements of various crops and soil conditions. The Government of India has implemented several initiatives to optimize fertilizer utilization. The most recent intervention is the provision of Soil Health Cards (SHCs), which provides comprehensive information on soil nutrients. However, given the increasing trend in the consumption of different fertilizers without balanced application, this initiative appears to have been ineffective. This can be attributed to the linkining of subsidized fertilizers with the Aadhar Cards rather than SHCs. Mandatory linking of the distribution of fertilizer subsidies to SHCs can be a significant intervention for improving soil health.

Nano-fertilizers have the potential to enhance fertilizer use efficiency, potentially resulting in a reduction in fertilizer consumption. The use of unmanned aerial vehicles, such as drones, for fertilizer application may further contribute to the reduction in fertilizer use. Furthermore, the Government of India's initiative to establish 10,000 Bioinput Resource Centers will promote local bioinputs, including organic fertilizers. The promotion of natural farming represents another significant intervention aimed at restoring soil health. These interventions are likely to improve soil health and decrease the burden of the subsidies.

The reallocation of fertilizer subsidy expenditures to environmentally friendly agricultural practices, such as the incorporation of legumes in cropping systems, conservation tillage, biofertilizers, and biostimulants, can address environmental concerns and promote sustainable agriculture (Kumara et al., 2024).

Carbon trading presents a potential mechanism to incentivize farmers to adopt sustainable farming practices. However, carbon markets in agriculture face numerous challenges. A significant obstacle lies in accurate quantification and valuation of ecological services provided by sustainable farming techniques. This necessitates the use of monitoring technologies, standardized carbon accounting methodologies, and rigorous validation procedures to ensure the veracity of carbon credits. Moreover, it is imperative to establish institutional frameworks to facilitate payments of carbon credits to farmers. Recognizing the potential of carbon markets, the Government of India has initiated efforts to develop protocols that provide a regulatory framework for carbon trading within the agricultural sector.

5.4 Crop planning

Crop diversification is one of the best options for sustainable development of agriculture. It offers several benefits, including mitigation of climate risks, reduced infestation of insect pests, improved resource use efficiency, and higher and stable farm incomes.

Crop plans are often developed considering local natural resource endowments and climatic conditions. However, such resource-based crop planning is an essential but not a sufficient condition for crop diversification. Farmers will not replace an existing crop with another if their potential profits do not match. For example, in Punjab and Haryana, there are hardly any crops, except fruits and vegetables, that can generate as much revenue as paddy (Table 14). To address this challenge, policymakers should consider mechanisms to offset the potential revenue losses from crop switching. Furthermore, high-value crops, such as fruits and vegetables, provide significantly higher profits and must be supported by markets, and finances.

Table 14. Economics of cultivation of paddy vis-à-vis other crops in Punjab, 2019-22

Crop	Gross return (Rs/ha)	Cost of cultivation (Rs/ha)		Revenue terms of trade	Financial net return (Rs/ha)	
		Cost A2	CostA2 + FL		Cost A2	Cost A2 + FL
Punjab						
Paddy	136636	48349	54599	1.00	88287	82037
Cotton	142239	52765	60658	0.96	89474	81582
Maize	63921	50663	60475	2.14	13258	3446
Moong	102047	26791	29328	1.34	75256	72719
Haryana						
Paddy	134220	47121	55240	1.00	87099	78980
Cotton	78017	35940	50946	1.72	42077	27072
Maize	52914	50833	58079	2.54	2081	-5165
Jowar	71109	50778	94147	1.89	20330	-23038
Bajra	39929	19097	29367	3.36	20832	10562
Moong	17030	9643	12844	7.88	7387	4187

Source: Authors' estimates using data from GoI (various years, j).

Note: FL represents the imputed value of family labor. Cost A2 includes all actual expenses in cash and kind in production, including expenses on seeds, fertilizer, manure, labor, insecticides and pesticides, hired machinery, irrigation charges, land revenue, interest in working capital, depreciation on implements and machinery, and so on.

5.5 Bundled approach for resilience to climate change

Climate-smart practices, which encompass a range of technologies and agronomic practices, have the potential to enhance the resilience of agriculture, while maintaining productivity. Notably, when implemented independently or in combination, these practices demonstrate a significant positive impact on agricultural productivity and resilience (Table 15). Therefore, it is essential to acknowledge the urgency of implementing climate-smart agricultural programs, with a focus on integrating various practices that function synergistically to enhance agricultural productivity, increase resilience to climate risks, and mitigate greenhouse gas emissions.

Furthermore, the successful adoption of climate-smart agricultural practices necessitates the establishment of robust extension services, the utilization of digital technologies, and the development of knowledge-sharing networks among farmers, researchers, and policymakers.

Table 15. Average treatment effects of risk management strategies (%)

Strategy	Mean farm income	Downside risk
Risk mitigation	24.51	-11.20
Risk transfer	14.35	-6.83
Risk coping	10.42	-13.02
Risk mitigation + transfer	40.58	-12.90
Risk mitigation + coping	15.41	-10.86
Risk transfer + coping	16.80	-12.35
Risk mitigation + transfer + coping	32.23	-15.84

Source: Birthal et al. *(2021c).*

Crop insurance is an important risk-mitigation mechanism. A nationwide program on crop insurance is implemented in India; however, its coverage has rarely exceeded 30% of the cultivated area owing to several factors such as lack of awareness, liquidity constraints, and delay in claims, among others. However, the primary reason is the uncertain payoff from crop insurance compared with that from other mitigation measures, such as irrigation. Birthal et al. (2022) found that the risk and productivity benefits of crop insurance are lower than those of irrigation (Table 16). However, benefits of crop insurance and irrigation are almost equal in *rainfed* environments, but benefits of insurance are significantly lower in irrigated environments. This regional variation indicates the need to tailor risk management strategies to specific agricultural contexts.

Table 16. Average treatment effects of crop insurance vis-a-vis irrigation (%)

	Overall	**Low rainfall**	**High rainfall**
Mean farm income			
Insurance	6.91	4.29	11.7
Irrigation	19.74	25.88	12.34
Insurance + irrigation	25.73	32.73	16.85
Downside risk			
Insurance	-6.84	-5.11	-8.92
Irrigation	-13.74	-17.02	-10.22
Insurance + irrigation	-16.50	-22.76	-13.81

Source: Birthal et al. *(2022).*

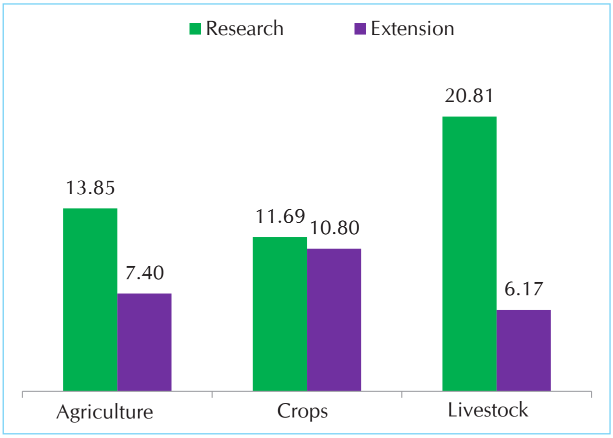
Further, premium for crop insurance is to be paid before the crop-growing season, when farmers face competing demands on their limited financial resources. Therefore, farmers tend to prioritize immediate requirements such as the purchase of seeds and fertilizers, rather than buying an insurance contract. Until recently, in India, crop insurance was provided as a package, along with short-term crop loans.

Digital innovations in crop insurance have the potential to significantly enhance farmers' risk management and improve the overall efficiency of insurance programs. Satellite-based remote sensing technology for risk zoning and premium differentiation can help the development of tailored insurance products that more accurately reflect specific risks in different agro-climatic regions. This approach can be complemented by the deployment of drones for detailed field-level assessments, which offers precise and timely information regarding crop conditions.

Parametric insurance is an innovative alternative to traditional area-yield insurance. It automates payouts based on predefined weather triggers, and reduces the requirements for physical loss assessments. Parametric insurance streamlines the claims process, enabling faster and more efficient compensation for the farmers. Moreover, decoupling payouts from actual crop losses is an incentive for farmers to adopt best practices to maximize crop yields.

5.6 Sustainable increase in agricultural R&D investment

Figure 42. Payoff to investment in agricultural R&D (Rs/rupee spent)



Source: Kandpal et al. (2024).

Investment in agricultural R&D has proven highly beneficial on many counts. Kandpal et al. (2024) estimated a payoff of Rs 13.85 for every rupee spent on agricultural research in India (Figure 42). The payoff from animal science research is almost twice that from crop science research. This implies (i) the need for sustained public investment in agricultural research and (ii) a greater allocation of resources for animal science research. Note that at an equal rate of growth, livestock has a more pro-poor effect than the crop sector (Birthal and Negi, 2012). Gulati and Terway (2018) showed that every million rupees spent on agricultural research in India could help 328 individuals escape poverty.

Furthermore, investment in crop biofortification research has been demonstrated to yield improved nutritional outcomes compared to food fortification (Fuglie et al., 2022). Investment in research on climate adaptation and mitigation has been shown to significantly enhance agricultural resilience compared with investments in other measures (Birthal et al., 2015a; Coger et al., 2021; Fuglie et al., 2022).

The substantial economic and social outcomes of agricultural research underscore the necessity to increase public investment in R&D to at least match the global average of approximately one percent of AgGDP. Besides, efforts should be made towards exploring additional sources of funding from philanthropic organizations and the private sector. Currently, private sector investment constitutes only approximately 7% of the total investment in agricultural research (Kandpal et al., 2024) compared to 35-50% in middle-income and developed countries (Pardey et al., 2016). Nevertheless, there is a concern that the private sector, driven by profit motives, may charge exorbitant prices for research outputs, potentially rendering these unaffordable for smallholder farmers. Moreover, it is apprehended that private investments may potentially crowd out public investments. Kandpal et al. (2024) have reported a complementary relationship between public and private investments in agricultural research. Hence, facilitating the participation of the private sector in research can leverage additional resources, expertise, and innovations. This requires various mechanisms, including streamlining regulatory, fiscal incentives, and strong protection of intellectual property rights.

Furthermore, given the emerging challenges and opportunities in agriculture, farmers' information requirements on technologies, inputs, natural resource management practices, markets, prices, and trade are expected to increase exponentially. Notably, investment in extension services also generates significant returns; Rs 7.84 for every rupee. Several other studies have demonstrated that information-based agricultural decisions lead to significant improvements in farm incomes, ranging from 11% to 18% (Birthal et al. 2015b; Varshney et al., 2022; Birthal et al., 2023). Farmers rely on both formal and informal sources, and the effect of formal sources on farm income is significantly greater (Birthal et al., 2015b; Birthal et al., 2023).

Agricultural research is a complex and resource-intensive activity that requires substantial initial investment and long-term commitment. Moreover, the long gestation period inherent in agricultural research compounds financial requirements, as it may take several years or even decades to realize tangible outputs. Thus, inconsistent or inadequate investment can lead to gaps in knowledge, missed opportunities for breakthrough discoveries, and slowdown in the development of agricultural innovations.

Of equal importance is the prioritization of agricultural R&D that aligns with national development goals and adapts to changing economic and environmental conditions. There is a need to reorient the research agenda by placing greater emphasis on high-value sectors, natural resource management, and climate change mitigation and adaptation.

5.7 Reform agricultural credit policy

Despite significant increase in the flow of institutional credit to agriculture, the credit policy must be redesigned to address the biases in credit allocation across activities and regions. First, the credit policy remains anchored to productivity enhancement, neglecting risk management. Integrating climate finance as an essential component of the agricultural credit policy can leverage its potential to mitigate climate change (Table 17). Second, the enhanced focus of the credit policy on livestock and fisheries is essential to harness their potential for income generation, employment creation, and poverty alleviation. Third, there is a need to enhance long-term credit for capital formation, which can have a significant impact on sustainability of agriculture. Currently, approximately 40% of the total credit is allocated for capital formation. Furthermore, reduction in regional imbalances in credit disbursements is essential for balanced agricultural development.

Table 17. Average treatment effects of credit (%)

Source	Productivity	Downside risk
Formal credit	21.43	-13.05
Informal credit	11.82	-11.24
Both	24.01	-16.31

Source: Birthal et al. (2025).

5.8 Strengthen circular economy

Agriculture generates significant quantities of byproducts, often considered as waste, which can be transformed into valuable resources. For example, crop residues can be incorporated into soil to enhance organic matter content, improve soil structure, increase water retention capacity, reduce the need for synthetic fertilizers, and promote soil biodiversity and carbon sequestration. The residues also serve as important sources of animal feed. The importance of agricultural byproducts extends beyond soil improvement and animal feed, encompassing bioenergy production, such as biogas or biofuels, which contribute to renewable energy sources and reduce the dependence on fossil fuels. Additionally, agricultural waste can be processed into value-added products, such as compost, biochar, and packaging materials.

Likewise, animal dung can be used for biogas or bio-CNG production, offering multiple environmental benefits such as reducing methane emissions by relacing fossil fuels. The resulting biogas could be used for heating, electricity generation, and transportation. Moreover, the process yields a nutrient-rich slurry, which serves as an excellent organic fertilizer.

Policies should offer financial incentives in terms of tax breaks, subsidies for eco-friendly equipment, and low-interest loans for agribusinesses to adopt circular economic practices. Furthermore, investment in infrastructure should be strategically planned to transform agricultural waste into valuable resources.

5.9 Strengthen market infrastructure and value chains

Underdeveloped market infrastructure and value chains are significant challenges for farmers. In the past, initiatives have been taken to improve efficiency and transparency in markets, the most recent being the launch of an online trading platform, the e-NAM in 2016, to allow farmers to sell their produce to buyers across the country, provide real-time price discovery, and reduce information asymmetry and transaction costs. As of March 31, 2024, 1410 regulated markets and 3979 FPOs have been linked with e-NAM.

However, its implementation faces challenges, primarily of the inadequate infrastructure in many agricultural markets. The lack of proper storage facilities and insufficient quality control measures makes it difficult to standardize produce across different markets. Addressing these infrastructure gaps is essential for e-NAM to achieve its goal of creating a truly integrated national agricultural market.

Similarly, the Open Network for Digital Commerce (ONDC) is poised to transform agricultural supply chain by creating an open-source network for all aspects of digital commerce. ONDC does not exclusively focus on agricultural commodities; it has significant implications for the marketing of farm produce. This would enable smallholder farmers and agricultural businesses to participate equally in the digital economy.

Farmer producer organizations (FPOs), cooperatives, and contract farming offer several benefits beyond beyond market access. These create economies of scale, share risks, and leverage the collective bargaining power. By aggregating produce and standardizing quality, these institutions can meet the volume and quality requirements of large buyers including supermarkets, processors, and exporters. These also help to reduce post-harvest losses and improve overall supply chain efficiency. Additionally, by acting as intermediaries, these organizations can facilitate better access to credit and insurance products tailored to the needs of farming communities.

Investment in food processing is essential to bridge the gap between agricultural production and consumer demand for processed foods. Improving ease of doing business with a single-window clearance system for food processing enterprises can streamline regulatory approvals. Increased investment, low-interest loans, and microfinance schemes can provide access to affordable credit to micro-, small-, and medium- enterprises (MSMEs) to improve their competitiveness. Establishing research system for food technology, safety standards, and sustainable packaging solutions can promote innovation.

5.10 Reform agricultural price policy

For a long time, MSP-based procurement policy has persisted without any significant realignment with changing market dynamics and environmental challenges. There is no denying that this system serves as an income safety net for farmers, but given its negative externalities on natural resources, it is imperative to rethink the price policy that strikes a balance between food security, conservation of natural resources, and farmers' interests.

There are several options for reforming price policy. The price deficiency approach, which involves compensating farmers for the difference between open market prices and MSP, is an important solution for reducing the government's fiscal burden while protecting farmers' interests without distorting cropping patterns and global markets. However, the scheme is vulnerable to moral hazards such as price manipulation by buyers and the disposal of substandard produce by sellers. Hence, the effectiveness of this approach depends on the establishment of robust implementation mechanisms for price monitoring and quality assessment.

The decentralized grain procurement scheme introduced during the late 1990s to empower states in the procurement of foodgrains has not achieved significant success, except in a few states, such as Chhattisgarh, Madhya Pradesh, and Odisha. A potential solution could be the central government procuring the requirements of strategic reserves while leaving procurement of requirements for the PDS and welfare schemes to the states and allowing inter-state trade.

Through another scheme called the Pilot of Private Procurement & Stockist Scheme (PPPS), the Government of India authorizes states to engage the private sector to procure farm produce (mainly oilseeds) at the MSP from registered farmers in the notified areas during the notified period when the open market prices fall below the MSP. The scheme provides 15% of the MSP as a service charge, which is deemed low for a profitable business, given 13-16% incidental charges of the pooled grain cost in the present MSP-based procurement system. This scheme needs to be revisited to address existing shortcomings.

The current open-ended procurement system allows farmers to sell unlimited grains at the MSP, which implies that the benefits of the MSP are directly proportional to the level of output or marketed surplus. Notably, nearly half of smallholder farmers (≤2 ha) produce in excess of their consumption requirements (Kishore et al., 2025). However, their participation in the MSP-based procurement system is restricted because of their small marketable surplus. To reduce the fiscal burden and improve equity in the procurement system, the government should consider implementing targeted procurement strategies that focus on procurement from smallholder farmers.

Futures' trading can be a potential means of mitigating price risk. However, for individual farmers it is difficult to participate in it due to scale limitations. Nonetheless, they may participate in futures trading through collectives such as FPOs and cooperatives. These organizations can engage in 'put options' by paying a premium (approximately 5% on the strike price), which also allows for selling in the open market if the market price exceeds the strike price during the lock-in period, albeit forfeiting the premium. Given the incidental change of 15% in the current procurement system (Kishore et al., 2025), the government may consider subsidizing the premium to enhance the attractiveness of futures trading in agriculture. Nevertheless, frequent government intervention in the form of bans on futures' trading in commodities is a significant barrier. For futures' trading to operate effectively, there is a need for long-term policy for agricultural commodity derivatives. A well-regulated futures market can facilitate price discovery and mitigate the fiscal burden of price support mechanisms.

Direct income support for farmers, such as through the PM-KISAN scheme, is a viable alternative to the existing price support system. This approach aligns with the World Trade Organization (WTO) provisions. The most flexible strategy involves direct payments decoupled from production and prices, which fall within the Green Box category. These payments are not subject to support limitations, and offer the greatest policy flexibility. Furthermore, India can use production-linked payments with output restrictions under the Blue Box category, which does not impose caps on support levels. However, support measures tied to production without limitations require careful design. Such measures fall within the Amber Box category and must be maintained within the de minimis threshold, which is 10% of a commodity's output value. Hence, schemes should be designed in such a way that these align with the provisions in the Green and Blue Boxes.

5.11 Trade facilitation

To fully capitalize on its export potential, India must invest in developing and modernizing commodity- and location-specific production technologies, improve post-harvest handling and storage facilities, and enhance quality control measures throughout the supply chain. Furthermore, efforts should be made to strengthen the country's regulatory framework and compliance mechanisms to align with international standards.

Establishing a robust system of market intelligence is essential for gaining competitive advantage in the contemporary dynamic business environment. This approach involves systematic collection, analysis, and dissemination of pertinent information regarding market trends, consumer preferences, and competitors. Furthermore, the application of advanced technologies, such as artificial intelligence and big data analytics, can facilitate more precise and informed decision-making.

Integrating blockchain technology into supply chains is a promising solution for improving food safety measures and building consumer confidence through comprehensive tracking, monitoring, and traceability systems for agricultural products.

India's significant reliance on imports of edible oils, pulses, and fresh fruits is a significant challenge. A comprehensive approach emphasizing domestic production through targeted R&D, providing incentives to farmers, and calibrating import tariffs is essential to reduce import dependence. Evidence indicates that technological advancements can facilitate increased production, while simultaneously protecting domestic producers from an influx of inexpensive imports (Balaji et al., 2022).

5.12 De-stress agriculture from excessive employment pressure

The declining size of landholdings will make it increasingly difficult for farmers to generate sufficient livelihoods solely through agricultural activities. Consequently, farmers seek income opportunities in rural non-farm sector, including the labor market and small-scale enterprises, to supplement their income and mitigate economic constraints. This shift in income sources is evident in recent data, which show a continuous decline in the share of agriculture, in the income of farm households (Saxena et al., 2023). This trend highlights the growing importance of diversifying income streams for rural communities to maintain economic stability and improve living standards.

However, current pace of rural industrialization has been insufficient to absorb the expanding labor force, creating a pressing need to promote agri-based start-ups and MSMEs on a broader scale. This approach serves multiple purposes, fostering entrepreneurship and innovation in agriculture-related industries. It not only diversifies rural economies, but also has the potential to create a more robust and sustainable agricultural ecosystem. This ecosystem can provide supplementary income opportunities for farming communities, thereby reducing their dependence on farming. Additionally, the development of agri-based enterprises can lead to improved value chains, enhanced processing capabilities, and better market linkages, ultimately benefiting the farmers and contributing to rural development.

5.13 Encourage collective or cooperative farming

Given the decreasing farm size, it is imperative to develop and promote collective or cooperative farming models to improve the economic viability of agriculture. This approach offers several potential advantages including enhanced efficiency, shared risk, and improved access to resources and markets. By combining their efforts, farmers can achieve economies of scale, thereby reducing the individual costs for equipment and inputs. Furthermore, cooperative farming can facilitate knowledge transfer and innovation, as farmers learn from each other 's experiences and methodologies.

5.14 Synergy among policies and strategies

Policymakers must recognize that strategies implemented in isolation may result in unintended consequences. A salient example is the heavily subsidized electricity for agriculture in some states, such as Punjab and Haryana, which has led to the over-extraction of groundwater resources. Efforts to contain this through regulations have not been successful because of the excessive procurement of rice and wheat at the MSP (Kishore et al., 2024). Hence, an integrated approach to policymaking is imperative for aligning strategies to address the complex challenges. To this end, there is a need for collaboration among diverse stakeholders, including government agencies, industry representatives, academic institutions, and civil society organizations. Such an integrated approach could result in a more efficient resource allocation and enhanced policy outcomes.

5.15 Effective coordination between central and state governments

Agriculture is the subject of the states. Nevertheless, the central government guides states and provides financial support for the implementation of various schemes. Notable examples include the Pradhan Mantri Kisan Samman Nidhi (PM-KISAN), which provides direct income support to farmers; the Pradhan Mantri Fasal Bima Yojana (PMFBY), the crop insurance scheme; the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM), which promotes solar energy for agriculture; and the Pradhan Mantri Krishi Sinchayee Yojana (PM-KSY) that focuses on irrigation infrastructure and optimal use of water resources. In addition, the central government provides fertilizer subsidies to farmers. Notably, the central government contributes over 60% of the total development expenditure on the agricultural sector in the country.

States are uniquely positioned to understand the specific needs and challenges of their agricultural sectors, thereby allowing them to ensure more effective and targeted interventions. Effective collaboration and coordination between the central and state governments in the implementation of various programs is essential. This includes regular dialogue and information sharing, joint planning and monitoring mechanisms, and flexible policy frameworks that allow state-specific adaptations. These can lead to more efficient resource utilization, reduced duplication of efforts, and improved policy outcomes. Additionally, it can foster innovation in agricultural sector by leveraging the strengths of both the central and state-level institutions.

5.16 Science-policy interface

The science-policy interface facilitates evidence-based solutions to address complex challenges in the agri-food system. It facilitates the sharing of knowledge and information among stakeholders, as well as feedback on performance and implementation constraints. More importantly, the science-policy interface contributes to determining R&D priorities. Thus, it is imperative to establish robust communication channels between scientific institutions and policymaking bodies through regular briefings, workshops, and policy forums and to provide evidence in an appropriate format and timely manner tailored to the needs of policymakers.

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Epilogue

During the past six decades, propelled by technological advancements in and for agriculture and facilitated by strategic investments in irrigation and rural infrastructure, as well as the provision of incentives such as minimum support prices and input subsidies, India's agri-food system has undergone a significant transformation, addressing food security concerns that have plagued the country for long. However, agri-food system now faces complex challenges of depleting groundwater resources, fragmenting landholdings, increasing frequency of extreme climate events, and inefficient supply chains that threaten its long-term sustainability.

These challenges are inter-connected, and policymakers should recognize that addressing one challenge in isolation may potentially exacerbate another. This interconnectedness necessitates a systems thinking approach, considering the broader implications of policy decisions across multiple domains. Consequently, addressing these requires an integrated approach, encompassing the prioritization of public investment in agriculture, strengthening of research and development systems, reforms in markets, price policy, financial institutions, and subsidy regimes.

Overall, this paper advocates for an adaptive policy framework that can respond to changing economic, environmental, and socio-political circumstances to facilitate the efficient, sustainable, and inclusive transformation of agri-food system. The framework aims to strike a balance between these often-competing interests, ensuring that the transformation of the agri-food system benefits all while maintaining its long-term viability and resilience in the face of emerging challenges.

Nonetheless, the political economy of agricultural reforms is complex because of the diverse and often conflicting interests of various stakeholders, including farmers, input suppliers, processors, distributors, retailers and consumers. Each group of stakeholder has distinct priorities and concerns, which can result in challenges in implementing comprehensive and effective agricultural policies. For example, while farmers may advocate for higher minimum support prices, consumers may prefer lower food prices. To address these challenges, an integrated approach is necessary, involving stakeholder participation in the decision-making process, enhancing synergy between schemes or programs implemented by different ministries and departments, and improving coordination between central and state governments.

The paper raises critical questions for researchers working across the agri-food system landscape. It emphasizes the necessity for comprehensive and interdisciplinary studies to generate robust scientific evidence on various aspects, including the efficacy of diverse technologies and agricultural practices, environmental impacts, consumer preferences, market intelligence, supply chains and logistics, and the integration of digital innovations in the food system. Furthermore, this paper suggests to undertake more field-based evidence that can provide empirical insights into the real-world implications of various interventions and strategies, which is essential for informing policy formulation, devising appropriate strategies, and conducting concurrent evaluation to address emerging challenges and capitalize on opportunities.

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