India Studies in Business and Economics

Ramesh Chand
Pramod Joshi
Shyam Khadka *Editors*

Indian Agriculture Towards 2030

Pathways for Enhancing Farmers' Income, Nutritional Security and Sustainable Food and Farm Systems

सत्यमेव जयते
नीति आयोग
National Institution for Transforming India

Food and Agriculture Organization of the United Nations

OPEN ACCESS

Springer

India Studies in Business and Economics

The Indian economy is one of the fastest growing economies of the world with India being an important G-20 member. Ever since the Indian economy made its presence felt on the global platform, the research community is now even more interested in studying and analyzing what India has to offer. This series aims to bring forth the latest studies and research about India from the areas of economics, business, and management science, with strong social science linkages. The titles featured in this series present rigorous empirical research, often accompanied by policy recommendations, evoke and evaluate various aspects of the economy and the business and management landscape in India, with a special focus on India's relationship with the world in terms of business and trade. The series also tracks research on India's position on social issues, on health, on politics, on agriculture, on rights, and many such topics which directly or indirectly affect sustainable growth of the country.

Review Process

The proposal for each volume undergoes at least two double blind peer review where a detailed concept note along with extended chapter abstracts and a sample chapter is peer reviewed by experienced academics. The reviews can be more detailed if recommended by reviewers.

Ethical Compliance

The series follows the Ethics Statement found in the Springer standard guidelines here. https://www.springer.com/us/authors-editors/journal-author/journal-author-helpdesk/before-you-start/before-you-start/1330#c14214

More information about this series at https://link.springer.com/bookseries/11234

Ramesh Chand · Pramod Joshi · Shyam Khadka
Editors

Indian Agriculture Towards 2030

Pathways for Enhancing Farmers' Income, Nutritional Security and Sustainable Food and Farm Systems

सत्यमेव जयते
नीति आयोग
National Institution for Transforming India

Food and Agriculture Organization of the United Nations

Springer

Editors
Ramesh Chand
NITI Aayog
New Delhi, India

Pramod Joshi
Formerly with International Food Policy Research Institute
New Delhi, India

Shyam Khadka
Formerly with Food and Agriculture Organization
New Delhi, India

ISSN 2198-0012 ISSN 2198-0020 (electronic)
India Studies in Business and Economics
ISBN 978-981-19-0762-3 ISBN 978-981-19-0763-0 (eBook)
https://doi.org/10.1007/978-981-19-0763-0

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

सत्यमेव जयते

भारत के उपराष्ट्रपति

VICE-PRESIDENT OF INDIA

Foreword

I am happy to note that the thematic papers presented at the National Dialogue on *Indian Agriculture towards 2030: Pathways for Enhancing Farmers' Income, Nutritional Security and Sustainable Food Systems* held in January 2021 are being published. The National Dialogue organized by NITI Aayog and the Food and Agriculture Organization (FAO) of the United Nations has resulted in a wealth of information and a lot of new ideas as well as insights on agriculture and farmers' welfare. Eminent agricultural experts, farmers, scientists, academicians and civil society members who have closely examined the problems and challenges associated with Indian agriculture have greatly enriched the dialogue.

Agriculture in India has been a strong pillar of our economy, culture and civilization. With about 16.5 per cent contribution to our GDP, agriculture remains the primary source of livelihood for almost 42 per cent of the country's workforce. The sector has seen phenomenal growth since independence ensuring that the country moved from food-deficit to homegrown food security. As the thematic papers in the volume suggest, this has happened because of improvements in inputs, infrastructure, investment and institutions. We need to take this holistic, systemic approach forward to make agriculture more productive and ensure that there is significant and lasting improvement in the quality of life of farmers.

It is our moral responsibility to ensure the well-being of our hardworking farmers and agri-workers who have always risen to the occasion and never let the country down, even in challenging times like the current COVID-19 pandemic.

I am glad that the government is working on an ambitious plan to double the farmers' income and a multipronged strategy is being adopted to achieve this objective through various initiatives such as more crop per drop, soil health cards, minimization of post-harvest losses, promotion of food processing and reforming the agri-market. Ultimately, we should not only make agriculture sustainable and environment-friendly but also ensure that people have healthy and nutritious food. This requires a good deal of reflection based on the existing ground realities and the vision we have for the future. The chapters in this book provide a sound basis for this reflection because they distil important lessons and present an array of policy options for the government to choose from.

Attracting educated youth to farming is another important issue that requires the attention of all stakeholders. Towards this end, we need to chalk out initiatives that will expand the role of Indian agriculture from a purely rural livelihood sector to a modern business enterprise. This can be done by creating strong lab-farm links and farmer-industry interaction to turn farmers into 'agri-entrepreneurs' who would not only ensure the nation's food security needs but also generate employment opportunities in our villages.

I congratulate NITI Aayog and the Food and Agriculture Organization of the United Nations for organizing the conference and bringing out this publication which will help develop a roadmap for future actions to take the next big leap in the agriculture sector.

I sincerely hope that all stakeholders will find the book useful in deepening our collective understanding of different facets of a sector that has infinite potential and formidable challenges.

I am sure the policymakers will take note of global good practices adumbrated by experts and the strengths of our national ecosystem to devise a robust policy that rejuvenates this pivotal sector of our economy.

Naidu

(M. VENKAIAH NAIDU)

New Delhi
7th July, 2021

Introduction

As the Food and Agriculture Organization (FAO) of the United Nations Representative in India and as a co-organiser of this National Dialogue on *Indian Agriculture Towards 2030*, the FAO India team is honoured to have had this opportunity for a unique collaboration on the policy front. Our collaborators for this National Dialogue have been the NITI Aayog and the Ministry of Agriculture and Farmers' Welfare, Government of India. We also had the kind cooperation of two other ministries of the Government of India—the Ministry of *Jal Shakti* and the Ministry of Fisheries and Animal Husbandry and Dairying.

We started working on this Dialogue in 2019. This was a time when the government was itself considering a directional change in India's agricultural laws and policies. There was agreement within the highest levels in government that a new post-Green Revolution vision for the next decade was needed. The Honourable Vice-President, in his inaugural address at the National Dialogue and in the Foreword to this book, reiterates the direction for the needed change.

A Steering Committee under the guidance of the Member Agriculture of NITI Aayog was put together to guide the National Dialogue. The composition of the Committee embodied expertise and experience in several aspects of agri-food systems. Several scenarios on why and how India's agriculture sector should be further improved were discussed in the Steering Committee meetings.

The Steering Committee commissioned a set of discussion papers on different themes related to Indian agriculture to get perspectives from a range of stakeholders in the agri-food sector. These were presented at a national conference held during 19–22 January 2021 and were also made available online. The COVID-19 pandemic prevented us from having a large in-person event, but a virtual event allowed an equally large number to participate. The thematic discussion papers were revised on the basis of the feedback received at the conference and they now form the various chapters of this book.

To see the entire effort of the National Dialogue in this phase, with an open access book publication and a set of policy recommendations, marks a significant step in our collective journey to chart the way forward for Indian agriculture.

FAO is proud to have been in India since 1948. Its work has always been aligned with the needs and priorities of the country. This National Dialogue is also well aligned with the priority areas identified in FAO India's Country Programming Framework, by primarily focusing on the policy needs for the critical areas in agriculture and allied sectors. In doing so, FAO also leverages its position to assist the government in the incorporation of the Sustainable Development Goals (SDGs) in the national policy documents, which are intended to guide action in the coming decade. The National Dialogue particularly aligns with SDG2 towards ending hunger, achieving food security, improving nutrition and promoting sustainable agriculture.

We see this National Dialogue as what it is meant to be—a conversation to discuss the possible pathways for a transformative shift, thereby contributing to solutions for the challenges confronting agri-food systems.

We are delighted to have played a role in co-creating the space for such a dialogue to take place.

Thank you.

New Delhi, India
July 2021

Tomio Shichiri
FAO Representative in India

FAO Team

The team from FAO involved in the preparation of this book, under the guidance of the then FAOR India, Tomio Shichiri, includes (in alphabetical order):

Shalini Bhutani

Kaustuv Chakrabarti

Konda Chavva

Aditi Gupta

Rakesh Kapoor

Ananya Manchanda

Contents

Editors and Contributors

About the Editors

Prof. Ramesh Chand is currently Member—Agriculture of the National Institution for Transforming India, better known as the NITI Aayog (in the rank and status of Union Minister of State). He has a Ph.D. in Agricultural Economics from Indian Agricultural Research Institute (IARI), New Delhi. He is Fellow, National Academy of Agricultural Sciences and Indian Society of Agricultural Economics. He has been involved in policy formulation for agriculture sector for the last two decades. Prior to joining NITI Aayog, he was ICAR-National Professor and Director, National Institute of Agricultural Economics and Policy Research, New Delhi.

Dr. Pramod Joshi superannuated as Director-South Asia, International Food Policy Research Institute (IFPRI). Prior to this, he was holding the positions of Director, ICAR-National Academy of Agricultural Research Management, and Director of the ICAR-National Centre of Agricultural Economics and Policy Research. He has extensively worked towards transforming agriculture and market integration in India and many south and Southeast Asian countries. Presently, he is President of the Agricultural Economics Research Association and Secretary of the National Academy of Agricultural Sciences.

Mr. Shyam Khadka has extensive experience in strategising, designing, implementing, monitoring and evaluating a wide range of policies, programmes and projects aimed at developing agriculture, ensuring food and nutrition security and reducing poverty. After working in the Agricultural Development Bank of Nepal for 17 years, he spent 25 years in the UN system working first in UNOPS and IFAD covering a wide range of countries in East, South and South-East Asia and then as Chief of Asia and Pacific Service of the Investment Centre at FAO Headquarters. After serving as FAO Representative in India for 3 years, he retired in 2018 and now lives in Kathmandu, Nepal.

Contributors[1]

Pramod Aggarwal Borlaug Institute for South Asia - CIMMYT, New Delhi, India

Seema Bathla Centre for the Study of Regional Development, Jawaharlal Nehru University, New Delhi, India

Ramesh Chand NITI Aayog, New Delhi, India

Malavika Dadlani Indian Society for Seed Technology, New Delhi, India

Shiv Kumar Dhyani CIFOR-ICRAF, Nairobi, Kenya

Anupa Ghosh The Bhawanipur Education Society College, Kolkata, India

Duke Ghosh Global Change Research, Kolkata, India

Ashok Gulati Infosys Chair Professor for Agriculture, Indian Council for Research on International Economic Relations (ICRIER), New Delhi, India

Siraj Hussain International Council for Research on International Economic Relation, New Delhi, India

Pramod Joshi Formerly with International Food Policy Research Institute, New Delhi, India

Ritika Juneja Indian Council for Research on International Economic Relations (ICRIER), New Delhi, India

Shyam Khadka Formerly with Food and Agriculture Organization, New Delhi, India

N. K. Krishna Kumar Entomological Society of India, New Delhi, India

S. Mahendra Dev Indira Gandhi Institute of Development Research, Goregaon (East), Mumbai, India

S. Naresh Kumar Centre for Environment Science and Climate Resilient Agriculture, ICAR-Indian Agricultural Research Institute, New Delhi, India

Devashree Nayak CIFOR-ICRAF, Nairobi, Kenya

Vijay Laxmi Pandey Indira Gandhi Institute of Development Research, Goregaon (East), Mumbai, India

R. S. Paroda Trust for Advancement of Agricultural Sciences, New Delhi, India

Himanshu Pathak ICAR-National Institute of Abiotic Stress Management, Baramati, Pune, Maharashtra, India

Ravi Prabhu CIFOR-ICRAF, Nairobi, Kenya

Javed Rizvi CIFOR-ICRAF, Nairobi, Kenya

[1] The views expressed by all the authors are their own.

Joyashree Roy School of Energy, Resource and Development, Asian Institute of Technology, Pathum Thani, Thailand;
Jadavpur University (on lien), Kolkata, India

Mihir Shah Shiv Nadar University, Greater Noida, India

R. B. Singh National Academy of Agricultural Sciences, New Delhi, India

B. Venkateswarlu Vasant Rao Naik Maratwada Krishi Vidya Peeth, Parbhani, India

S. Vennila National Research Centre for Integrated Pest Management, Indian Council of Agricultural Research, New Delhi, India

P. S. Vijayshankar Samaj Pragati Sahayog, Dewas, India

Indian Agriculture Towards 2030—Need for a Transformative Vision

Ramesh Chand

1 Background

The historical experience of almost all economies shows that the share of the agriculture and allied sectors in total employment as well as in their national income falls with progress in economic development. This decline does not, however, diminish the need to address various challenges confronting the agriculture sector, which is a core concern in both developed and developing countries. Agriculture, after all, provides food for the very survival of human life. More importantly, this dependence goes beyond mere survival to adequate nutrition for an active and healthy life. The other significance of agriculture is its role in supporting and improving rural livelihoods. The kind of agriculture practised determines the maintenance of the agro-ecological balance, biodiversity, sustainable use of land, water and other natural resources, apart from ensuring social security. Agriculture also supplies the raw material that is the foundation for economic activities ranging from industrial production to trade and commerce. Agriculture is both a victim of and contributor to climate change and, therefore, it must adapt to the consequences of this change and reduce its own emissions of greenhouse gases. The challenges and opportunities of the agriculture sector are dynamic; some are common for all countries while some are country specific.

R. Chand (✉)
NITI Aayog, New Delhi, India
e-mail: rc.niti@gov.in

R. Chand et al. (eds.), *Indian Agriculture Towards 2030*,
India Studies in Business and Economics,
https://doi.org/10.1007/978-981-19-0763-0_1

2 Global Challenges

Eliminating hunger and poverty has remained on the global development agenda for a long time and several initiatives have been taken to address them. The most recent attempts include the Sustainable Development Goals (SDGs) 2030, which were preceded by the Millennium Development Goals (MDGs). The SDGs 2030 provide a very valuable benchmark to address issues like hunger, poverty, nutrition, sustainability, climate change and inclusive development. Most of these goals are directly or indirectly related to agriculture.

Despite a sizeable increase in the per capita production of food and ample grain production, hunger and malnutrition are far from being eradicated. There is evidence to show that the world is not on track to achieve the SDG 2.1 Zero Hunger target by 2030.[1]

About 2 billion people are reported to lack regular access to sufficient, safe and nutritious food. Indeed, there are reports of increase in hunger and malnutrition in recent years. Nutrition is not just about having adequate dietary energy intake (the indicator of hunger and undernutrition used by the Food and Agriculture Organisation (FAO) and other agencies of the United Nations); with rising awareness and level of economic development, the emphasis is shifting to "balanced and adequate nutrition". This shift is an important factor for changes in dietary preference, though several other causes like changing lifestyles and consumer preferences, also have a role to play. This dietary diversification, in turn, requires widespread changes in the structure of production—which is overwhelmingly focussed on staple foods—to include more of fruits, vegetables, livestock products and fish. Thus, there is a need for production diversification to match the diet diversity.

The use of agro-chemicals in agri-food production in the pre- and post-harvest stages of plant food, animal food and seafood has risen significantly. At the same time, there is also a strong public perception that the increasing use of chemicals in food production, storage, preservation, etc. is a key reason for many diseases and health hazards in humans. The estimates show that about US$110 billion is lost each year in low- and middle-income countries due to productivity loss and medical expenses resulting from unsafe food.[2] As a result, the demand for safe food is getting stronger.

Agriculture is the biggest user of water and land. Their injudicious use for agricultural production affects the environment and natural resources to a significant extent. According to the Organisation for Economic Cooperation and Development (OECD), irrigation in the agriculture sector accounts for 70% of water use worldwide. In the case of India, the share of agriculture in total water use is estimated at 80–90%. While a large section of the population does not have access to adequate water, this precious resource is used very inefficiently in farming activities. Agriculture also contributes significantly to the depletion of groundwater and rising stress on water resources. Improvement in the availability of water for human

1 http://www.fao.org/publications/sofi/2020/en/.

2 https://www.who.int/news-room/fact-sheets/detail/food-safety.

and non-agriculture uses, addressing water stress in rainfed and dryland agriculture and ensuring sustainable use necessitates the efficient and judicious use of water in agriculture.

Modern agriculture has progressed through specialisations and monoculture farming. This has reduced crop/seed and breed diversity and has also adversely affected overall biodiversity. These are still the order of the day, despite strong recommendations for cropping system and farming system approaches in production. FAO's report on *State of the World's Biodiversity for Food and Agriculture* points to the fact that many key components of biodiversity for food and agriculture at the genetic, species and ecosystem levels are in decline.[3] There is a need to internalise the ecological benefits of the farming system approach to balance the economic benefits of specialisation.

Agriculture is the principal source of livelihood in most of the developing countries and is dominated by smallholders. These farmers suffer from disadvantage of scale as well as weak institutional support and market access. The present state of industrial technology is highly labour displacing and has lowered the prospects of absorption of labour in industry and, consequently, the chances of shift of labour from agriculture to non-agriculture, which is what the standard economic development approach maintains. The challenge today is to create remunerative jobs in and around agriculture which are at par with jobs in the urban and industrial sectors.

3 Challenges at the National Level

Some of these global challenges are exacerbated in the case of India. The agriculture sector continues to constitute a significant portion of the Indian economy with a 17.7% share in gross value added as of 2019–20 and 44% share in the total workforce.[4] The sector is also crucial to attaining the SDGs, not only to address hunger and nutrition but also as a significant determinant of natural resource sustainability, GHG emissions and environment quality.

During the last three decades, agricultural output has grown at a trend growth rate of 3% per year while population has grown at 1.6% (Chand, 2017). Furthermore, while agri-food production has maintained almost the same growth rate over this period, population growth has decelerated to an estimated 1.1%. India exports more than 7% of the food it produces. The country also accumulates a huge stock of staple food, 40% of which is distributed to two-thirds of the population at highly subsidised prices. Yet India is home to the largest number of undernourished people in the world. This calls for new insights into the causes of hunger and undernutrition, as a significant number of people consume less than the normative level of diet despite the availability of food as well as adequate purchasing power.

---

[3] http://www.fao.org/state-of-biodiversity-for-food-agriculture/en/.

[4] Agriculture refers to crops, livestock, fishery and forestry.

The acceleration in the growth of food production will undoubtedly help the Indian economy, but there are several challenges that need to be tackled. India is now surplus in many commodities and needs foreign markets to sell this surplus in order to prevent a fall in prices received by farmers. The growth rate in agriculture so far has been largely driven by output price support and input subsidies. These cause serious distortions in output markets and have led to the unsustainable use of natural resources.

There are reports of farmers not getting remunerative prices for some crops as markets are not very competitive. Efficiency in production needs to improve, as does logistics. Land lease laws in the country neither allow the expansion of operational holdings nor do they encourage exit from farming.

In India, 60% of the land area is under agriculture. There are reports of land degradation because of intensive cultivation, certain agricultural practices and use of agro-chemicals like inorganic fertilisers and herbicides.

The already serious stress on India's water resources is worsening with each passing year. The groundwater level is falling at an alarming rate in large parts of the country (at least half the observation wells in the country) and 600 million people already face high to extreme water stress. Despite the rising gap between the demand and supply of water, India's policies and practices encourage the profligate use of water. The agriculture sector uses 80–90% of total water used in the country and, yet, half of the area under agriculture remains rainfed. India uses far more water than many major agricultural countries to produce the same quantity of output. The reason for this is that farmers follow flood irrigation, as both water supply to agriculture as well as power supply to extract groundwater for irrigation is either free or highly subsidised.

In most of the crops, increase in productivity has been accompanied by an increase in average cost of production, which necessitates an increase in output prices to keep incremental production profitable. There is a need for a shift in strategy from 'growth' to 'efficient growth', such that any increase in productivity is associated with a reduction in the average cost of production. This requires upgradation of agricultural technology, application of modern skills to farm practices, new innovation in farming and lowering wastages in the use of fertilisers, water and other inputs.

4 India's Commitments to SDGs and Climate Change

The SDGs—which number 17—were adopted by all United Nations Member States in 2015 as a universal call to change the world for the better by 2030. The Government of India has appointed NITI Aayog as the nodal institution for coordinating all the SDG efforts at the national and sub-national levels. Given the federal structure of the country, and the division of powers and responsibilities between the Central and state governments, states have a leading role to play in the achievement of the SDGs at the national level. The approach of cooperative and competitive federalism has resulted in the formulation of the SDG India Index, which is the world's first government-led sub-national measure of SDG progress. A dashboard with interactive visualisation, has been developed and is in the public domain.[5] The first edition of the Index was launched in December 2018, the second edition in December 2019 and the third edition in January 2021. The Index is designed to function as a tool for focussed policy dialogue, formulation and implementation of policy and moving towards development action pegged to globally recognisable metrics. It also highlights crucial gaps related to monitoring SDGs and the need for improving statistical systems at the national, state and union territory levels.

NITI Aayog presented India's second Voluntary National Review (VNR) at the United Nations High-level Political Forum on Sustainable Development, 2020. India's VNR has undergone a paradigm shift in terms of embodying a "whole-of-society" approach in letter and spirit. NITI Aayog engaged with sub-national and local governments, civil society organisations (CSOs), local communities and the private sector during the VNR preparation process. As part of this process, NITI Aayog partnered with the UN in India and CSOs to curate a consultative process, which saw more than 50 national and sub-national consultations with over 1000 CSOs from 14 population groups. In line with the theme of "Taking SDGs from Global to Local", the goal-wise account of progress on the SDGs has been emphasised with a range of diverse good practices and success stories of interventions from the states.

Climate change is now recognised as a reality and is no longer treated as a fanciful obsession of environmentalists. It has been included in the SDGs. The international community has committed to "take urgent action to combat climate change and its impacts". SDG 13 calls for strengthening resilience and adaptive capacity to climate related hazards and natural disasters. More than 191 countries have ratified the 2016 Paris Agreement after the Conference of the Parties (COP). Parties have agreed to report regularly on their emissions and on their implementation efforts to contain or reduce emissions. India ratified the Paris Agreement on 2 October 2016. India's Nationally Determined Contribution (NDC) targets[6] are three:

1. to lower the emissions intensity of gross domestic product (GDP) by 33–35% over 2005 levels by 2030. This does not restrict India's option to chase higher growth, but it calls for lower emission per unit of output.
2. to increase the share of non-fossil-based energy to 40% of the total energy mix. Households and agriculture are the best candidates for this. In agriculture, solar energy can be used to power pump sets rather than diesel. Ethanol use can also be encouraged.
3. to create an additional (cumulative) carbon sink of 2.5–3 billion tonne of CO_2 equivalent through additional forest and tree cover by 2030. This cannot happen only on forest land. There is need to promote agro-forestry on private lands.
4. Agriculture has an important role to play in each of the three targets, as it affects climate change and also gets affected by it. The country needs more food by

[5] https://sdgindiaindex.niti.gov.in/#/.

[6] https://www4.unfccc.int/sites/submissions/INDC/Published%20Documents/India/1/INDIA%20INDC%20TO%20UNFCCC.pdf.

2030, the cultivation of which requires more water, energy and land. Food has to be grown in a more hostile environment. The challenge is to produce the same or more quantity of food with lower emissions, by changing the practices and methods of production, as well as geographies. India emitted 2299 million tonnes of carbon dioxide (CO_2) in 2018. It accounts for 7% of global GHG emissions. Agriculture and livestock account for 18% of gross national emissions.

What is required is sustainable agriculture that involves simultaneous increase in production and income, adaptation to climate change and reduction in GHG emissions, while balancing crop, livestock, fisheries and agro-forestry systems, increasing resource use efficiency (including land and water), protecting the environment and maintaining ecosystem services. Alternative agricultural practices, suitable in different regions, can reduce net GHG emissions while maintaining or improving yields and adapting to more extreme weather. It is necessary to seize every opportunity available in technology, policy, institutions and community action to shift from inefficient farm practices towards long-term sustainability, efficiency and resilience in order to successfully adapt to climate change.

5 Need for a Transformative Vision

Despite myriad challenges, Indian agriculture offers substantial opportunities to contribute to economic growth, eliminate—or at least reduce dramatically—hunger and malnutrition, improve sustainability of resource use and reduce environmental footprints by aligning the crop production strategy to the natural resource endowments and enhance inclusivity. The agri-food system is undergoing some changes, but the speed of this change is much slower than what is required for achieving the SDGs, especially those related to land, water, environment and climate change. The change is also necessitated by changes on the demand side and the need to meet the goal of adequate nutrition. The pace of this change depends largely on technology and policies related to food production, marketing, distribution, public and private investments and awareness and motivation of various stakeholders.

Major changes will be witnessed in both the growth rate as well as the composition of food demand in the coming years. The most notable change will be in the per capita intake of cereals, which is showing a decline, in contrast to the rising per capita demand for horticultural crops and livestock products. This necessitates a fresh look at policies to improve food and nutrition security consistent with the shift in consumer preferences.

Considering the unprecedented challenges that agriculture is facing globally, especially in India, and the opportunities that exist, there is a need for a transformative vision for the next decade. Realising this need, a national dialogue was initiated to think through this transformation—what are its key elements and what it means for policy and practice. The areas that need special attention were identified through a collaborative process between NITI Aayog, the Ministry of Agriculture and Farmers Welfare (MoA&FW) and the Food and Agriculture Organisation of the United Nations (FAO) under the overall guidance of a Steering Committee comprising agricultural experts.

These areas were grouped into eight themes: (a) structural reforms and governance; (b) pathways for profitable, sustainable and resilient agriculture; (c) nutritive and safe food; (d) climate crisis and risk management; (e) application of science, technology and innovation; (f) pests, pandemics, preparedness and biosecurity; (g) use of water in agriculture; and (h) alternative farming, agro-ecological and biodiverse futures. Eminent experts contributed papers in the specific thematic areas, which were discussed at a national conference during 19–22 January 2021.[7] These papers, which have incorporated many of the suggestions that were proferred during the conference, are presented in chapters that follow.

Reference

Chand, R. (2017). *Doubling farmers income: Rationale, strategy, prospects and action plan*. NITI Aayog, Government of India.

[7] The virtual conference was held on 19–22 January 2021: http://www.fao.org/india/news/detail-events/en/c/1369694/.

Transforming Indian Agriculture

Ashok Gulati and Ritika Juneja

1 Introduction

Though the share of agriculture in India's gross domestic product (GDP) is only 16.5%, the sector employs the largest share of the workforce (about 42.3% in 2019) as well as the largest share of women workers (71%) in rural areas. India is still largely a rural economy, with 66% of the country's population living in rural areas (World Bank, 2019) and agriculture continues to be the mainstay of a large segment of this section of the population. Agriculture is also important for consumers, as an average Indian household spends about 45% of its expenditure on food.[1] Moreover, given that India is going to be the most populous country, surpassing China, by 2027 (according to United Nations population projections, 2019), it would be a major challenge for Indian agriculture to feed this large population, especially in the wake of the emerging challenges of climate change and the degradation of natural

[1] Computed using data from the Household Consumption of Various Goods and Services in India survey by the National Sample Survey Organisation.

[2] As per the OECD-FAO Agricultural Outlook (2019–2028), India is expected to witness an increase in per capita incomes at the rate of 6.6% per annum (OECD/FAO, 2019). However, this projection predated the COVID-19 pandemic. As a consequence of COVID-19 impact, the growth in per capita incomes may be a bit lower, but it could still be around 5.5% per annum, if not more.

A. Gulati (✉)
Infosys Chair Professor for Agriculture, Indian Council for Research on International Economic Relations (ICRIER), New Delhi, India
e-mail: agulati115@gmail.com

R. Juneja
Indian Council for Research on International Economic Relations (ICRIER), New Delhi, India
e-mail: ritikajuneja93@gmail.com

R. Chand et al. (eds.), *Indian Agriculture Towards 2030*,
India Studies in Business and Economics,
https://doi.org/10.1007/978-981-19-0763-0_2

resources such as air, water and land. This challenge becomes more serious with the expected rise in per capita incomes[2] as well as increasing urbanisation—the urban population is estimated to be 600 million by 2030—both of which are likely to increase the demand for food, feed and fibre. Moreover, not only will there be more mouths to feed, but, as per capita income grows, there will be much higher demand for high value agriculture products such as meat, fish, dairy, fruits and vegetables (OECD/FAO, 2019). This would be very much in line with Bennett's Law of food consumption, which states that with rising incomes people consume relatively less "starchy staples" and shift to more nutritious food with proteins and vitamins.

This chapter tracks the process of structural transformation of Indian agriculture, with a view to seeing how India transformed from being a large food deficit nation to a marginally food surplus one, producing sufficient food, feed and fibre for its large and growing population. It also sheds some light on the pace and process of agricultural intensification, which is posing several challenges for sustainable and productive agriculture as India moves towards 2030. The chapter is an attempt to help policy-makers make rational choices with a view to building an efficient and competitive agriculture sector that not only achieves self-reliance in feeding India's population, but also augments farmers' incomes while simultaneously ensuring environmental sustainability.

The rest of the chapter is divided into four sections. Section 2 presents the backdrop and performance of Indian agriculture within the context of the Indian economy. It focuses on key inputs namely land, irrigation, fertilisers, labour, capital and farm mechanisation within agriculture, which define its structural contours. It also examines the changing landscape of agricultural diversification. Section 3 highlights how India traversed from food deficits to food surpluses, especially in the production of staples, milk, poultry, fruits and vegetables. Section 4 focuses on the undesirable consequences of agricultural intensification in terms of the deteriorating quality of natural resources such as water, soil, air and biodiversity. It also suggests possible remedial measures for developing sustainable agricultural intensification. Section 5 presents the way forward towards developing pathways for productive, profitable and sustainable agriculture that can not only meet the requirements of food, feed and fibre up to 2030, but also create some net surpluses for exports. This concluding section also highlights the potential role of the three Is—Innovations (technologies), Incentives (policies) and Institutions in making agriculture productive, profitable, sustainable and resilient, with improved nutrition.

2 Structural Transformation and Intensification in Indian Agriculture

Following the economic reforms in 1991, India's overall GDP growth picked up momentum, moving from 5.2% per annum between 1980–81 and 1991–92 to roughly 7.1% between 2010–11 and 2019–20 (Fig. 1). This has been accompanied by falling

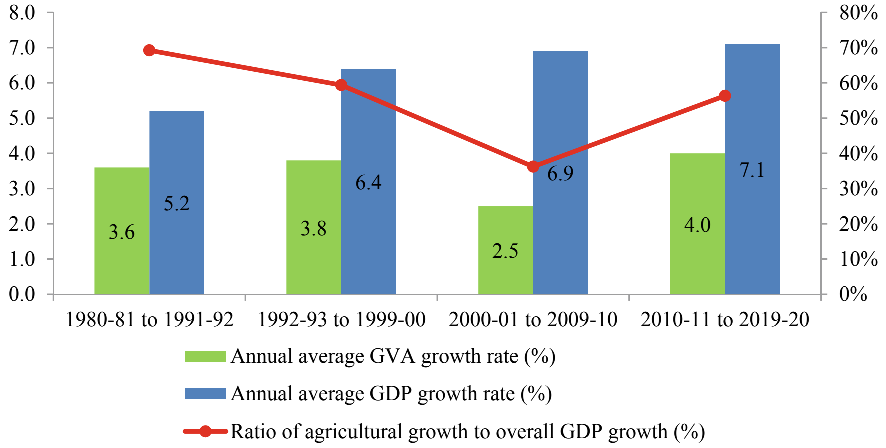


Fig. 1 Average annual growth rate in GDP and agricultural GVA. *Source* National Accounts Statistics, NSO (2019b)

growth rates of population—from 2.25% per annum during the 1980s to 1.92% during the 1990s, 1.6% during the 2000s and 1.15% per annum between 2010–11 and 2019–20—which has consequently led to a gradual decline in the poverty ratios.

Furthermore, agriculture has undergone a slow and gradual transformation from a subsistence-based and labour-intensive system to a modernised, capital and knowledge intensive one. However, this development has been accompanied by a sharp decline in its share in overall GDP (from 30% in 1981 to 16.5% in 2019).

Against this backdrop, the chapter focuses more on structural transformation and agricultural intensification in India over the last three decades, especially with respect to the key factors of production, namely land, labour, capital, irrigation, fertilisers and farm machinery. The chapter also traces the pace and performance of diversification within the agricultural sector towards livestock, horticulture and fisheries, in response to changing consumer demand with rising incomes.

2.1 Land

India is the world's seventh largest country covering an area of 328 million hectares (mha). Nearly half of this land (156.4 mha) is arable[3] and only 42.6% of the total geographical area (about 140 mha) is cultivated (as of 2015–16). India's irrigation cover is 48.7% of the country's cultivated area while its agriculture output is valued

[3] Arable land refers to land under temporary crops (double cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included. For more details see https://www.fao.org/ag/agn/nutrition/Indicatorsfiles/Agriculture.pdf and FAOSTAT (https://www.fao.org/faostat/en/#home).

at USD 524.7 billion in 2017–18[4] (Gulati & Gupta, 2019). In addition, the agricultural sector has witnessed significant changes over the years, in terms of area under cultivation, land holding and cropping patterns, cropping intensity and productivity, among other things. These are discussed in some detail in this section.

2.1.1 Changing Agrarian Structure: Shrinking Landholding Size and Swelling Bottom

According to *Agriculture Census: 2015–16* (DoAC&FW, 2019), small and marginal farmers with less than 2 hectares (ha.) of land, account for about 87% (126 million) of the total 146.4 million operational land holdings in India (Fig. 2a). Of these 126 million operational land holdings, 69% belong to only marginal farmers with less than 1 ha. of land, highlighting the fact that Indian agriculture is dominated by smallholders. Moreover, in terms of area, small and marginal farmers account for nearly 47% of the total operated area in 2015–16, pointing towards significant land inequalities (Fig. 2b). Increasing fragmentation of land is another major concern of Indian agriculture. The average size of land holdings has come down continuously from 2.28 ha. in 1970–71 to 1.08 ha. in 2015–16 (Fig. 2a); these are unviable levels that cause farmers to leave land and look for better opportunities elsewhere. As a result, large tracts of productive land are left either uncultivated or used at very low productivity levels due to lack of capital, both physical and human (NITI Aayog, 2016). This makes the adoption of new technologies difficult, and this, in turn, has adverse impacts on both farm productivity as well as farmers' incomes. Therefore, the viability of marginal and small farmers is a major challenge for Indian agriculture, calling for substantive reform in the land lease markets with the objective of creating economically viable size of holdings.

2.1.2 Changing Cropping Pattern and Agricultural Diversification

With rising incomes, consumption patterns of people shift towards high value products, as mentioned earlier. The NSSO survey, 2013 shows that an average Indian household spends about 45% of the total monthly expenditure on food (NSSO, 2013). It may be noted that even within the food basket, there is a shift in the consumption pattern. There is a sharp decline in the share of monthly expenditure on staples in both rural and urban areas—from 41.1 to 10.8% in the former and from 23.4 to 6.6% in the latter—between 1972–73 and 2011–12. Given this, the agricultural system needs to respond by diversifying towards production of higher value and more nutritious agricultural products.

[4] The value of agricultural output is INR 34.16 trillion (at current prices) in 2017–18 (the latest year for which data is available) and the exchange rate in 2017–18 was USD 1 = INR. 65.12. This would work out to around USD 525 billion. (NSO, 2019b).

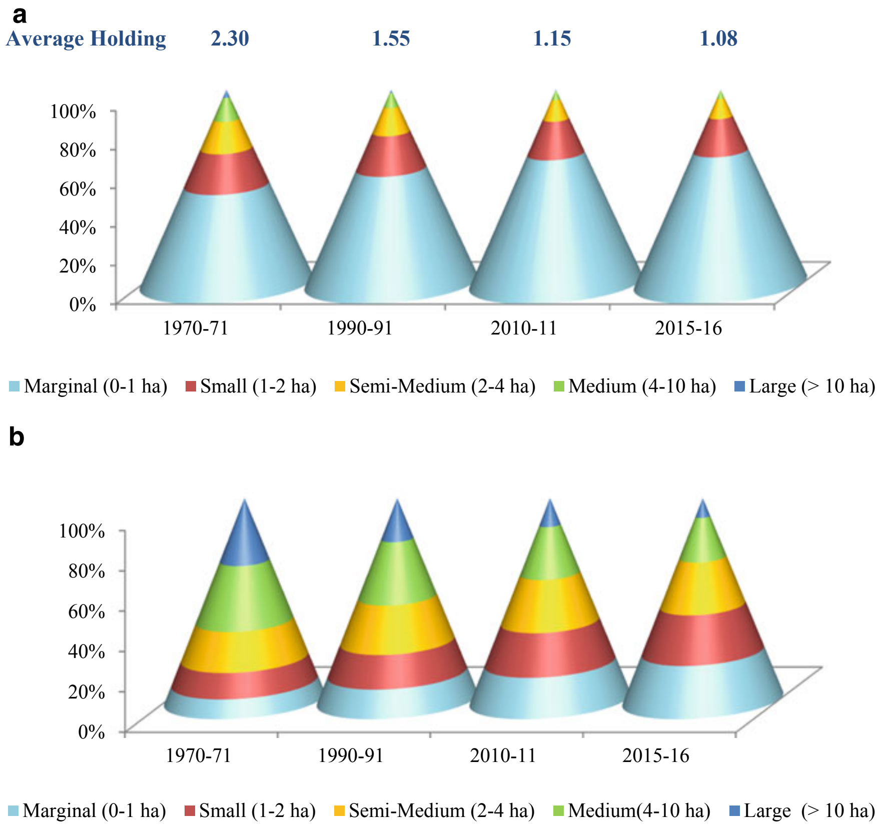


Fig. 2 **a** Percentage of operational holdings by size class. **b** Percentage of operated area by size class. *Source* Agriculture Census: 2015–16 (DoAC&FW, 2019)

India has a multiplicity of cropping systems across agro-climatic zones, mainly based on soil type, rainfall, climate, technology, policies and existing socio-economic situation of the farming community. Though the gross cropped area has increased from 172.6 mha in 1981–82 to 200.2 mha in 2016–17 and the net sown area (an indicator of effective utilisation of land) has remained around 140 mha over the same period, farmers are gradually shifting from cultivation of traditional, non-commercial crops to commercial/cash crops (Majhi & Kumar, 2018) in order to respond to changing demand patterns and tap opportunities for higher returns.

As shown in Fig. 3, food grains (cereals, millets and pulses) used to occupy 73% of the gross cropped area in the triennium ending (TE) 1982–83, but this gradually reduced to 63% in TE 2016–17 (latest data available), even as the share of oilseeds and fruits and vegetables has increased over the same period. This indicates that farmers are increasingly moving towards more commercial crops such as oilseeds, fruits and vegetables, spices, etc. compared to staples (Majhi & Kumar, 2018).

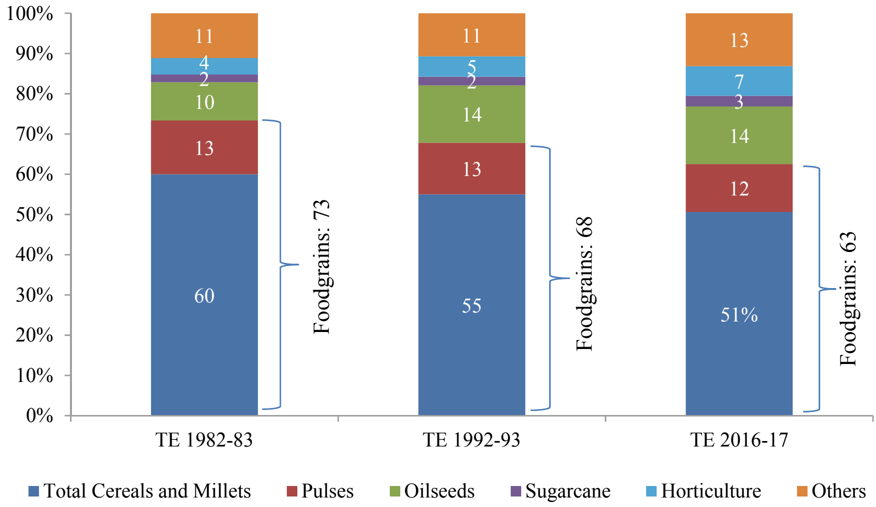


Fig. 3 Changing cropping patterns (percentage area under major crops). *Source* Land Use Statistics at a Glance (DES, 2017)

Though food grain production still dominates in terms of area cultivated, the change in the value of different segments of agriculture, including livestock and fishery, is the real indicator of agricultural diversification. Figure 4 presents these changing shares over the period TE 1982–83 to TE 2018–19 and clearly shows the move away from staple crops to cash crops, horticulture and livestock products. The

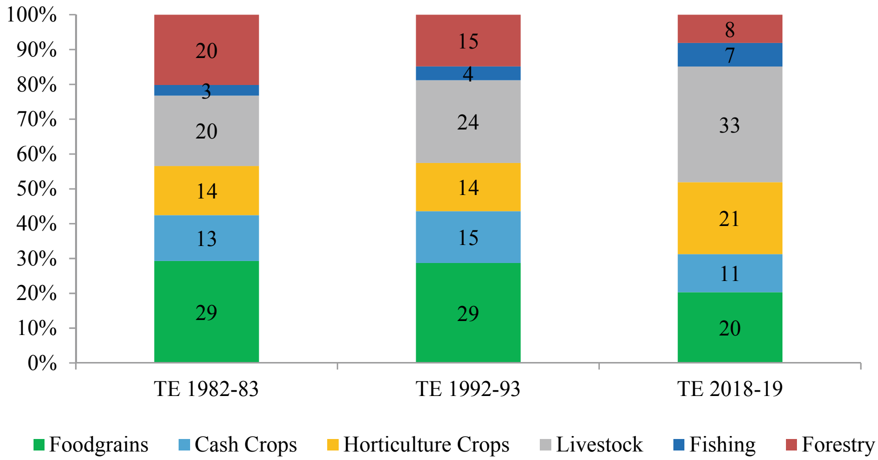


Fig. 4 Changing shares in value of output (percentage). *Note* Cash crops include oilseeds, sugar and fibres and horticulture crops include fruits and vegetables, floriculture and spices and condiments. *Source* National Accounts Statistics, NSO (2019b)

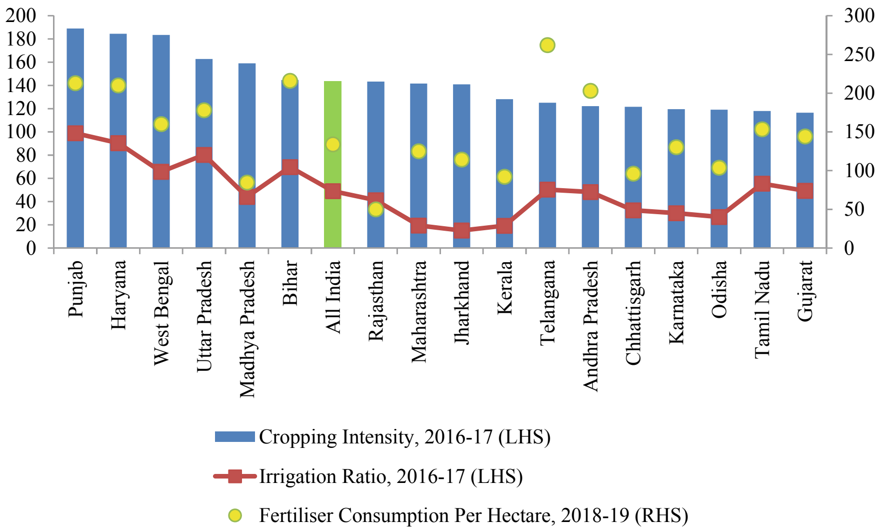


Fig. 5 State wise cropping intensity, irrigation ratio and per hectare fertiliser consumption.[5] *Source* Land Use Statistics at a Glance (DES, 2017) and Fertiliser Association of India, 2019

increase is particularly sharp in the case of livestock and horticulture crops. In fact, the value of livestock today is much higher than the value of food grains, and that of horticulture crops now equals the value of grains.

2.2 *Water for Irrigation*

Cropping intensity represents the number of crops grown on the same field in different seasons during an agricultural year. It is measured as a percentage of gross cropped area to net sown area (DES, 2017). Higher cropping intensity implies intensive use of land for agriculture (Deshmukh & Tanaji, 2017). The availability of water for irrigating the crops (either through rainfall or other irrigation sources) is one of the most crucial factors affecting cropping intensity. In India, cropping intensity has improved gradually from 123.1% in 1980–81 to 143.6% in 2016–17 (DES, 2017). The state-wise analysis of cropping intensity (Fig. 5) shows large spatial variation. The highest intensity is in Punjab (189%), followed by Haryana (184.4%), West Bengal (183.4%) and Uttar Pradesh (162.7%). Medium cropping intensity can be seen in Madhya Pradesh (159%), Bihar (144.6%), Rajasthan (143.4%) and Maharashtra (141.6%). States like Andhra Pradesh, Chhattisgarh, Karnataka, Odisha, Tamil Nadu and Gujarat suffer from lower cropping intensity, much below the country's average,

[5] 2016–17 is the latest year for which data for cropping intensity and irrigation ratio is available from the land use statistics of the Directorate of Economics and Statistics, Department of Agriculture, Cooperation and Farmers Welfare in the MoA&FW.

as they have low irrigation cover and low rainfall. This shows that there is a positive correlation between irrigation developments and cropping intensity, with some exceptions like Kerala, which has high rainfall.

At an all-India level, fertiliser consumption (in terms of NPK[6]) has increased significantly from 2.17 kg/ha. in 1961–62 to 134 kg/ha. in 2018–19. However, there are significant inter-state variations. Among the major states, the per hectare consumption is the highest in Telangana (262 kg), followed by Bihar (216 kg), Punjab (213 kg), Haryana (210 kg), Andhra Pradesh (203 kg), Uttar Pradesh (178 kg), West Bengal (160 kg) and Tamil Nadu (153.5 kg). In the remaining states, the consumption per hectare is lower than the all-India average. Figure 5 shows fertiliser consumption per hectare of gross cropped area in major states.

2.3 Labour

In a developing economy like India, with a large and young population, a shift in the pattern of employment away from the agricultural sector to higher productivity jobs in urban areas is generally a positive indicator of structural transformation. This is the "pull factor" that is displayed in most of the developing countries over a period of time. But sometimes, there could be a "push factor" too—since agriculture cannot sustain the workforce, job-seekers are pushed to urban areas to take up any work that can give them some sustenance. Over the last four decades, the absolute number of workers in India has increased from 180.7 million in 1971 to 481.7 million in 2011, indicating an addition of close to 6 million workers to the workforce every year (Census of India, various issues). Moreover, the absolute number of workforce employed in the agriculture sector has increased from 125.7 million to 263.1 million during the same period, though in terms of percentage, this share has declined from 66.5% in 1981 to 42.3% in 2019 (Fig. 6), which points towards the structural transformation in Indian agriculture. This has been accompanied by a rather steep decline in the share of agriculture in total GDP from 31.7% in 1981 to 16.5% in 2019, a decline of about 48% of its former value (Fig. 6). What is striking is that rather than converging, the two shares are still on a diverging path; this is a matter of concern because it keeps the labour productivity in agriculture low, severely affecting value addition. Raising labour productivity will require raising land productivity by (a) pumping in more capital; (b) creating employment opportunities in off-farm jobs such as food processing, cold storages, construction sector; (c) skill formation; and (d) 'diversification' towards high value agricultural activities such as dairy farming, poultry rearing, horticulture and fisheries.

Surprisingly, within the agriculture workforce, between 1971 and 2001, the composition of cultivators and labourers has always been skewed in favour of the former. In 1971, 62.2% of the total workforce employed in agriculture were cultivators and only 37.8% were agricultural labourers. This ratio kept changing gradually

---

[6] N – Nitrogen (urea), P– Phosphorus and K – Potassium.

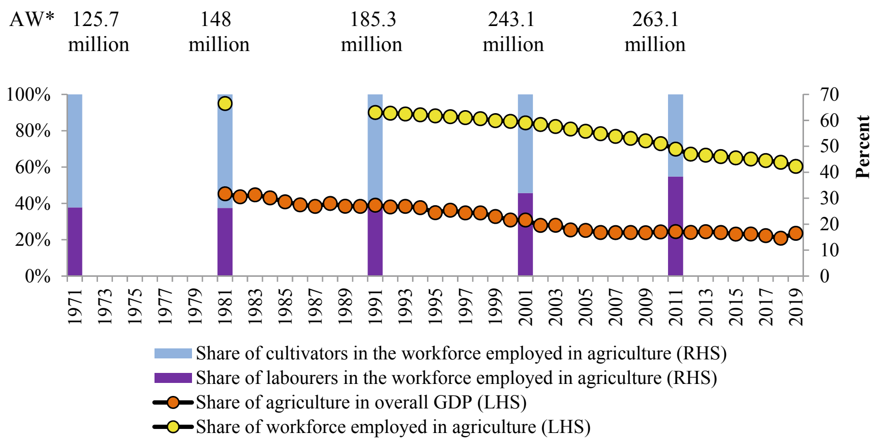


Fig. 6 Share of agriculture in total GDP, share of workforce employed in agriculture and composition of agriculture workforce. *AW = Agriculture workforce. *Source* World Bank (2019), NSO (2019b) and Census of India (various issues)

over the years and by 2011, for the first time, the share of cultivators in the total agriculture workforce reduced to 45.2%, while that of agricultural labourers increased to 54.8% (Fig. 6). One of the possible reasons for the declining share of cultivators could be the increasing fragmentation and continuous shrinking size of land holdings, which has reduced profitability in cultivating smaller farms due to lack of economies of scale. As a result, these cultivators either shift to non-farm activities and leave their land fallow or lease it out to agri-labourers (Subramanian, 2015). Another factor could be the relatively slow migration of labour out of agriculture due to lack of skills or slower growth of non-agriculture sectors. Yet another factor could be high growth rates of population in rural areas, especially among the agri-labour. Understanding the relevant causes for the changing pattern of agriculture workforce is a matter of further study.

2.3.1 Increasing Role of Women in Indian Agriculture

According to the Census of India 2011, women represent about 33% of cultivators and 47% of agricultural labourers. Moreover, the Periodic Labour Force Survey (PLFS), covering the period July 2018 to June 2019, reported that during 2018–19, 53.2% of male workers and 71.1% of female workers in rural India were engaged in the agricultural sector. Also, the share of operational holdings cultivated by women has registered an increase from 11.7% in 2005–06 to 13.9% in 2015–16 (DoAC&FW, 2019; NSO, 2019a).

The concentration of women farmers is observed to be highest (28%) among small and marginal farmers, according to the *Economic Survey 2018–19* (DEA, 2019). The *Survey* further reported that women play a significant role in agricultural

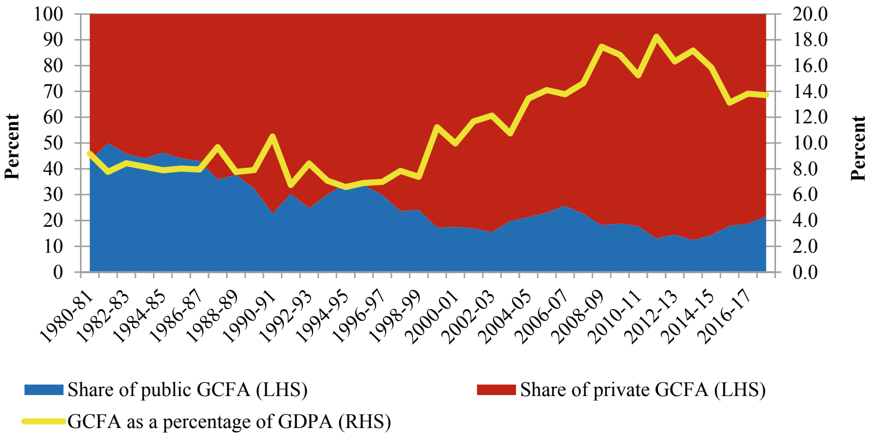


Fig. 7 Gross capital formation in agriculture as a percentage of agriculture GDP. *Source* National Accounts Statistics, NSO (2019b)

activities ranging from crop production, livestock production, horticulture to post-harvest operations, agro/social forestry and fisheries. Women contribute over 70% to the total primary milk production (World Bank, 2020)[7] and comprise 72% of the workforce engaged in fisheries (FAO, 2016). Based on the statistics, agricultural experts opine that with growing rural to urban migration, there is 'feminisation' of the agriculture sector, and that women in agriculture are the potential 'agents of change' for better nutrition and sustainable development of the sector. Therefore, it is imperative to strengthen women's participation in agriculture through their social and economic empowerment.

2.4 Capital

Capital, and its efficient utilisation, is one of the key variables that determines the growth and performance of a sector. Gross capital formation in agriculture (GCFA), from both the public and private sectors, as a percentage of agricultural GDP or GDPA (in current prices) increased from 7.8% in 1980–81 to 13.7% in 2017–18. It peaked in 2011–12 at 18.2%, but has been falling since then, which is a cause of concern (Fig. 7). The moot point that arises in this context is whether this is sufficient to provide 4% growth in agriculture GDP on a sustainable basis, especially when the capital-output ratio in agriculture hovers around 4:1 (Gulati & Juneja, 2019). The obvious answer is "no", and that points to the need for propelling investments

[7] *Accessed from* http://documents1.worldbank.org/curated/en/963861597014201705/pdf/India-National-Dairy-Support-Project.pdf *dated March 20, 2021.*

in agriculture either through government expenditure or by incentivising the private sector.

It is worth noting that in the early 1980s, the shares of public and private investment in agriculture were almost equal. However, in the following years, the share of public investment fell drastically and came down to 21.6% in 2017–18 (Fig. 7). This indicates that it was largely private investment that enabled and drove agricultural growth over this period. If the private sector is expected to further propel agriculture growth, farmers need to be given the right incentives. This may include higher expenditure on research and development (R&D), better infrastructure, agri-marketing reforms, innovations, switch in policy from input subsidies to direct income support on per hectare basis and opening up of the land lease market. One way to measure the incentive structure for farmers is the producer support estimate (PSE), which, in India, has been found to be negative 14.4% of gross farm receipts[8] during the 2000–01 to 2016–17 period (OECD/ICRIER, 2018). This suggests that Indian farmers have been taxed much more than they have been subsidised. The negative PSE (support) is basically the fallout of restrictive marketing and trade policies that do not allow Indian farmers to get remunerative prices for their output (Gulati & Gupta, 2019). This needs the immediate attention of policymakers.

In October 2020, the Government of India legislated three laws to liberalise agri-markets—the Farmers Produce Trade and Commerce (Promotion and Facilitation) Act, 2020 (FPTC), the Farmers (Empowerment and Protection) Agreement on Price Assurance and Farm Services Act, 2020 (FAPAFS) and the Essential Commodities (Amendment) Act, 2020 (ECA). The intention was to make agri-marketing much more efficient, as these laws would have facilitated private investments in building efficient supply chains for agri-produce. However, many farmer unions—notably from Punjab and Haryana—protested against these laws as they feared an adverse impact on the Agricultural Produce Marketing Committee (APMC) *mandi* system and the minimum support price (MSP) for wheat and paddy that they had been getting for decades. After a year-long protest at the borders of Delhi against these three contentious farm laws, the Prime Minister, Narendra Modi, announced, on 19 November 2021, the decision to repeal the three laws in the upcoming winter session of the Parliament. According to agri-experts, the laws were meant to reform India's agricultural sector and strengthen small and marginal farmers, and their withdrawal will have many economic and political implications that are yet to be evaluated (Gulati, 2021). In addition to the rolling back of the farm laws, protesting farmers are now demanding a law for MSP, which, experts feel, is both financially as well as economically unsustainable and dangerous for the economy. However, the government has refrained from sharing any information on this.

[8] Gross farm receipts are measured by the value of total production (at farm gate prices), plus budgetary support.

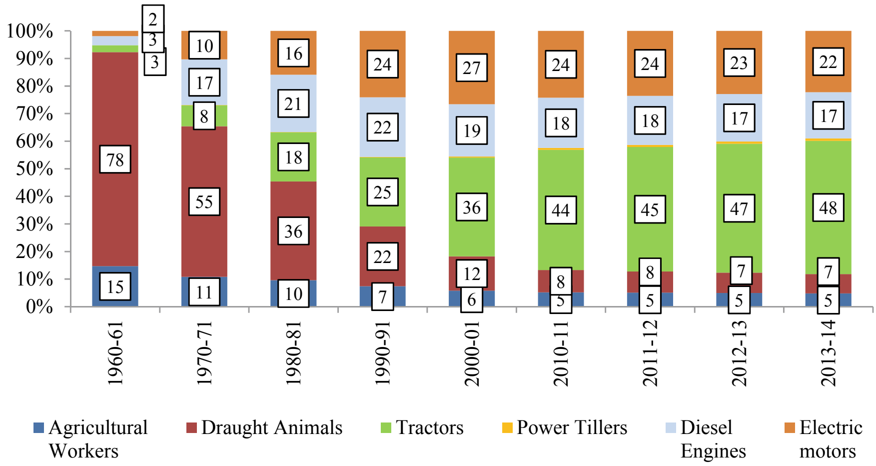


Fig. 8 Percentage availability of farm power from different farm power sources. *Note* For converting various sources of farm power into a comparable yardstick, it is assumed that one human power is equated to 0.05 kilowatt (kW); one draught animal power equals 0.38 kW; one tractor equals 26.1 kW; one power tiller equals 5.6 kW; one electric motor equals 3.7 kW; and one diesel engine equals 5.6 kW. *Source* Singh et al. (2014)

2.5 Farm Mechanisation

Another dimension of agricultural transformation is how machine power substitutes human and draught animal power in farming. India has also witnessed a clear shift from traditional agriculture processes to more mechanised processes over the years. The use of animal and human power in agriculture and related activities has reduced drastically from 97.4% in 1951 to about 66% in 1971 and about 12% in 2013–14 (the latest year for which data is available). The contribution of mechanical and electrical sources has increased from 2.6% in 1951 to about 34% in 1971 and about 88% in 2013–14. Out of the total farm power available, tractors contribute about 48% in 2013–14 (Fig. 8).

2.6 Knowledge Intensive Agriculture

Increase in the expenditure on agriculture knowledge and innovation systems is another important indicator of structural transformation in the agricultural sector, as it shows the sectoral shift towards knowledge-based agricultural systems. In a study conducted by Gulati and Terway (2018) on the impact of investment and subsidies on agricultural GDP growth and poverty reduction, it was estimated that for every rupee invested in agricultural research and education (R&E), agriculture GDP increases by INR 11.2. Moreover, for every million rupees spent on agricultural

R&E, 328 people are brought out of poverty. In India, over the years, the ratio of expenditure on agricultural knowledge and innovation systems as a percentage of agricultural gross value added (GVA) improved from 0.38% in 2000–01, touched 0.64% in 2010–11 but fell back to 0.35% in 2018–19. When compared with other countries like China, which spends about 0.8% of its agricultural GDP, India's share is quite low. Therefore, in order to improve the sector's total factor productivity, India needs to invest more in agricultural R&E (Gulati & Gupta, 2019).

3 From Food Deficit to Surplus

While we have observed long term trends in the structural transformation of agriculture, with respect to land, labour, irrigation, fertilisers, capital and farm mechanisation, the key question is: were they able to provide enough food, feed and fibre to Indians, as the population grew from 330 million in 1947 to 1.38 billion in 2020? In this context, this section describes how Indian agriculture made significant strides in the production of staples, milk, poultry, fisheries, fruits and vegetables and, lately, in cotton. All this was made possible with the induction of innovative technologies, along with supportive policies and institutions.

Staple crops In 1943, India, then under British rule, faced one of the most severe famines, the Bengal Famine, which is said to have claimed 1.5–3 million lives because of starvation. In 1947, when India became independent, its staple supplies were in a precarious state. The First Five Year Plan (1951–56) was mainly devoted to agriculture, with then Prime Minister Jawaharlal Nehru declaring "everything else can wait, but not agriculture". Yet, in the Second Five Year Plan (1956–61), the focus of development shifted towards heavy industrialisation, and India signed a Public Law (PL) 480 with the United States of America for food aid against rupee payments. Unfortunately, during the mid-1960s, India was again hit by consecutive droughts and food grain production fell by 17 million metric tonnes (MMT)—from 89.4 MMT in 1964–1965 to 72.4 MMT in 1965–1966 (Gulati & Juneja, 2018b). This plunged the country into an unprecedented 'ship to mouth' crisis as it leaned heavily on food aid of about 11 MMT per year of wheat under PL-480 for survival (Gulati, 2019).

This crisis sowed the seeds of the famous Green Revolution. Imports of high-yielding miracle seeds of wheat from Mexico (Lerma Rojo 64-A and Sonora 64) developed by Norman E. Borlaug, and of rice (IR 8) from the Philippines, developed by Peter Jennings and Henry M. Beachell, formed the backbone of the Green Revolution (Gulati & Juneja, 2018b). Commercialisation of these high-yielding variety seeds, together with the institutionalisation of the Food Corporation of India (FCI) and the Agricultural Prices Commission (APC),[9] extensive irrigation, fertilisers and farm mechanisation played a key role in ensuring food security for the country. As a

[9] This is now the Commission on Agricultural Costs and Prices (CACP).

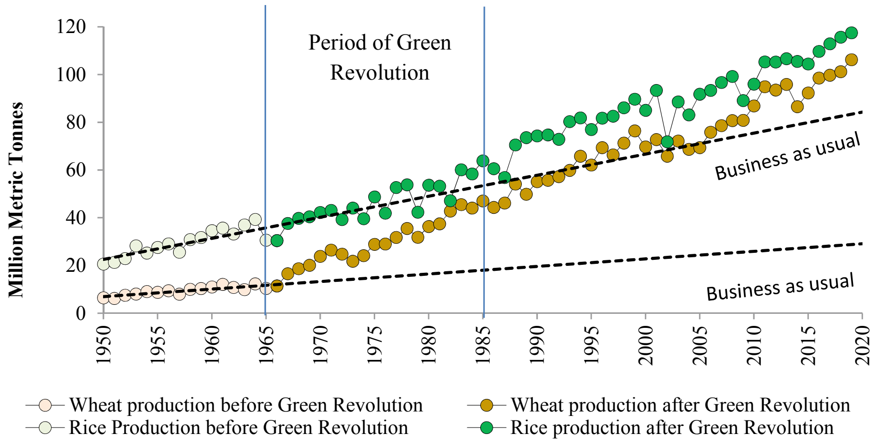


Fig. 9 Production of wheat and rice in India. *Source* Agricultural Statistics at a Glance, various issues, Directorate of Economics and Statistics, MoA&FW

result of all these interventions, India today is the second largest producer of wheat and rice in the world, with 106.2 MMT and 117.5 MMT production respectively in 2019–20 (Fig. 9), and is also the largest exporter of rice with about 12.7 MMT exported at USD 7.7 billion in 2017–18.

Livestock After the Green Revolution, Indian agriculture witnessed significant transformation in the dairy sector from the 1970s through the mid-1990s. It was essentially driven by institutional engineering through 'Operation Flood' and expansion in herd numbers. Verghese Kurien, who spearheaded 'Operation Flood', transformed the system of milk collection from smallholders under a co-operative structure, homogenising, pasteurising and distributing it to mega cities as far as 1,200 miles away in bulk coolers designed to keep the temperature controlled at 39 degrees Fahrenheit (3.9 degrees Celsius), through an organised retail network (Gulati & Juneja, 2018b). The de-licencing of the dairy sector in 2002 encouraged private participants to enter the sector and further increase production. As a result, India emerged as the largest milk producer in the world with 187.7 MMT in 2018–19 from 17 MMT in 1950–51 (Fig. 10), leaving the United States of America (97.7 MMT) and China (45 MMT) way behind.

Another transformational change in the agricultural sector came during 2000–2001 in the poultry sector. Policy innovations such as liberalisation of imports of grandparent poultry stock, vertical integration of operations and contract farming between large integrators and small farmers, driven by the private sector, ushered in the Poultry Revolution. This transformed the sector from a mere backyard activity into a major organised, commercial one. As a result, India today is the third largest producer of layers (eggs) in the world, producing around 88 billion eggs in 2017 and accounting for about 5% share in world production. It is also the fifth largest producer of broilers (poultry meat), producing 3.4 MMT in 2017 and accounting for

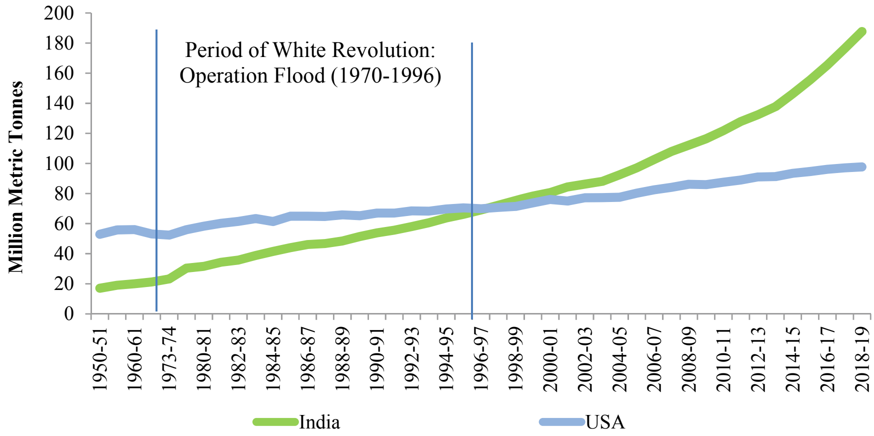


Fig. 10 Production of milk in India and United States of America. *Source* DoAHD&F (2017)

3% share in world production (DoAHD&F, 2017). Furthermore, almost 80% of eggs and poultry meat production come from organised commercial farms, mainly owned and managed by private entities (Gulati & Juneja 2018b).

Horticulture crops Over the last decade, the horticulture sector comprising of fruits and vegetables, spices and floriculture has contributed significantly to agricultural growth. Horticultural production has now overtaken food grains output. According to many experts, this has been made possible largely because of the National Horticulture Mission (2004–05), which ushered in the Golden Revolution, making India the second largest producer of fruits and vegetables globally, next only to China. According to 2018–19 estimates, fruit production has reached 97.97 MMT, up from 28.6 MMT in 1991–92, while vegetable production has increased from 58.5 MMT to 183.17 MMT over the same period.

Cotton In the case of fibre, cotton is an important commercial crop globally. The introduction and widespread commercialisation of Bt cotton in 2002 (the only genetically modified (GM) crop in India so far) along with huge investments in R&D by private seed companies, paved the way for the Gene Revolution in the agricultural sector. This led to a remarkable breakthrough in cotton production, doubling output from 13.6 million bales in 2002–03 to 37.5 million bales in 2019–20 (Fig. 11), resulting in India surpassing China in 2014–15 to become the largest cotton-producing country in the world (DCD, 2017). It is also worth noting that Bt cotton cultivation covers more than 90% of the total area under cotton in the country. Moreover, forthcoming impact evaluation study of Bt cotton by Gulati and Juneja estimated that after the release of Bt cotton in 2002–03, India cumulatively gained USD 84.7 billion in savings on the import of cotton as well as extra exports of raw cotton and yarn compared to the business-as-usual scenario.

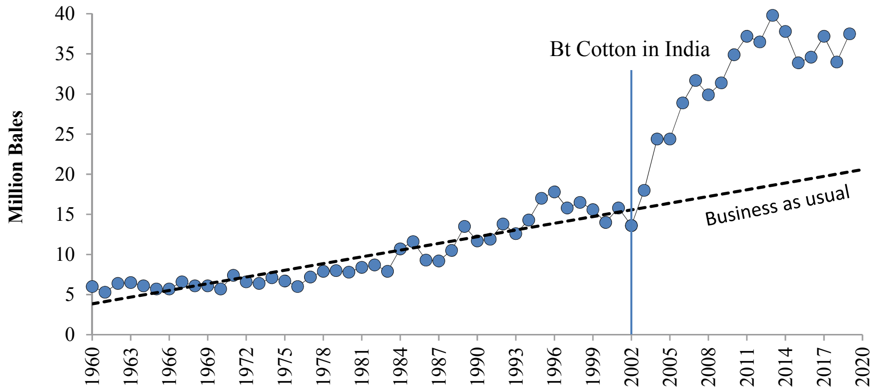


Fig. 11 Cotton production in India. *Source* USDA (2019–20)

Rising concerns: Despite the success and widespread adoption of Bt cotton in India, several concerns have been expressed from time to time by non-government organisations (NGOs), civil society groups and farmers on the risks associated with GM crops (Gulati & Juneja, 2018a). Some of these concerns include: (a) enhanced sucking pest damage in Bt cotton; (b) increase in secondary pests such as mired bugs and spodoptera; (c) emergence of pests resistance; (d) environment and health implications in terms of toxicity and allergenicity; and (e) farmers' exposure to greater risk of monopoly in seed business (Seetharaman, 2018; Kathage & Qaim, 2012). This is why the Ministry of Environment, Forest and Climate Change has halted the release of Bt brinjal and mustard for commercial cultivation on safety grounds.

However, not many studies have been conducted to evaluate the biosafety of GM crops for humans, so there is no scientific basis to halt their progress in India, based on rumours and ideological beliefs. Therefore, it is imperative that the government ensure transparent and credible regulations for biosafety assessment and management. Otherwise, the ambiguity over whether GM cotton has benefited Indian farmers and whether they are safe will continue to prevail and the debate about whether India should progressively adopt other transgenic varieties (including GM food crops) will continue to rage.

India has thus showcased an impressive growth trajectory from a food scarce country to a food sufficient and to a food surplus one. All these revolutions in agricultural production, triggered by innovations, incentives and institutions, have successfully made India a net exporter of agricultural produce. As a result, agricultural exports, in nominal US dollar terms, increased significantly from USD 6.1 billion in 2001–02 to USD 43.6 billion in 2013–14 (Fig. 12). However, after achieving this peak, exports declined slightly due to falling global prices. On the other hand, agricultural imports also increased sharply, from USD 4 billion in 2001–02 to USD 18.7 billion in 2016–17, and came down slightly thereafter. Overall, however, agricultural trade as a percentage of agricultural GDP showed an increase from 4.7% in 1990–91

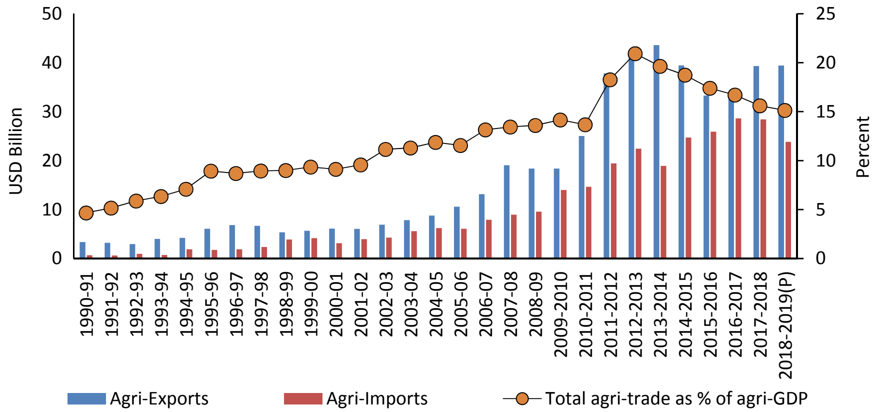


Fig. 12 Agricultural exports and imports and share of agricultural trade in agricultural GDP. *Source* World Bank (2019)

to 20.9% in 2012–13. Thereafter, it slipped from this peak and stood at 15.1% in 2018–19 (Fig. 12).

One of the questions for the future decade is whether India will maintain this surplus in food, feed and fibre? A report of a working group set up by NITI Aayog, *Demand and Supply Projections Towards 2033*, assessed the demand requirements of various agricultural commodities and made supply projections for the years 2021–22, 2028–29 and 2032–33 (NITI Aayog, 2018). The findings of the report are summarised in Table 1.

Table 1 Aggregate demand and supply estimates, 2032–33

Commodities	Demand estimates (MMT)	Supply projections (MMT)	Net surplus (MMT)
Rice	120.84	151.6	30.76
Wheat	113.46	138.8	25.34
Coarse Cereals	**67.48**	**61.7**	**-5.78**
Cereals	301.78	352.3	50.52
Pulses	**35.23**	**33.9**	**-1.33**
Food grains	337.01	386.2	49.19
Oilseeds	**99.59**	**59.9**	**-39.69**
Milk and products	292.15	329.7	37.55
Fruits	203.55	202.6	-0.95
Vegetables	360.77	362.8	2.03

Source NITI Aayog (2018)

According to the working group report, India will have sufficient supply of food grains towards 2032–33 and beyond. However, there will be a marginal deficit of around 5–7 million tonnes of pulses and coarse cereals. In addition, chronic shortage of feed and fodder is also expected, given that the indirect demand for coarse grains as feed for the growing livestock and poultry sector is likely to increase at a rapid pace. Moreover, in the case of oilseeds, the situation looks grim as the country is going to face a massive deficit of around 40 million tonnes.[10] In other commodities such as milk, meat, fruits and vegetables, there appears to be a reasonable balance between demand and supply in the years to come.

4 Undesirable Consequences of Agricultural Intensification and Mitigation Measures

As the previous sections set out, agricultural intensification led to the replacement of human labour with machine labour, rainfed lands received higher irrigation cover resulting in increased cropping intensity, fertiliser consumption increased on per hectare basis and, above all, more knowledge flowed into the agriculture sector. However, the process of resource intensification, which gave India the much-needed food, feed and fibre security, also caused some unintended negative consequences. In particular, it adversely affected the natural resources and environment, leading to degradation of soil at places, depletion of groundwater, salinisation in irrigated areas, increased resistance to pests and weeds, pollution of soil, air and water and greenhouse gas (GHG) emissions (Aditya et al., 2020; Xie et al., 2019). Many experts are of the opinion that these negative externalities were caused primarily by the longstanding policies of subsidies for agriculture inputs (power and fertilisers, e.g.) and price support (MSP for paddy and wheat and fair and remunerative price (FRP) for sugarcane). These policies have also led to production choices becoming skewed towards water-intensive crops.

Figure 13 presents a recent assessment of the groundwater table in 6,584 units (blocks), across states in India, by the Central Ground Water Board (CGWB) in 2017. It revealed that 1034 units are 'over-exploited',[11] 253 are 'critical' and 681 are 'semi-critical' (CGWB, 2017). The over-exploited areas are mostly in three parts of the country, namely, north-western India, western India and southern peninsular India. The report also pointed out that the north-western region, which includes parts of Punjab, Haryana, Delhi and western Uttar Pradesh, has abundant replenishable sources, but experiences indiscriminate withdrawals of groundwater. On the

[10] According to the report, the value is calculated without including the imported palm oil.

[11] Over-exploited: annual groundwater extraction exceeds net availability and there is a significant long-term decline in groundwater levels either before or after the monsoon, or both. Critical: extraction is above 90% of net annual availability and there is a significant long-term decline in groundwater levels both before and after the monsoon. Semi-critical: extraction is above 70% and there is a significant long-term decline in groundwater levels either before or after the monsoon.

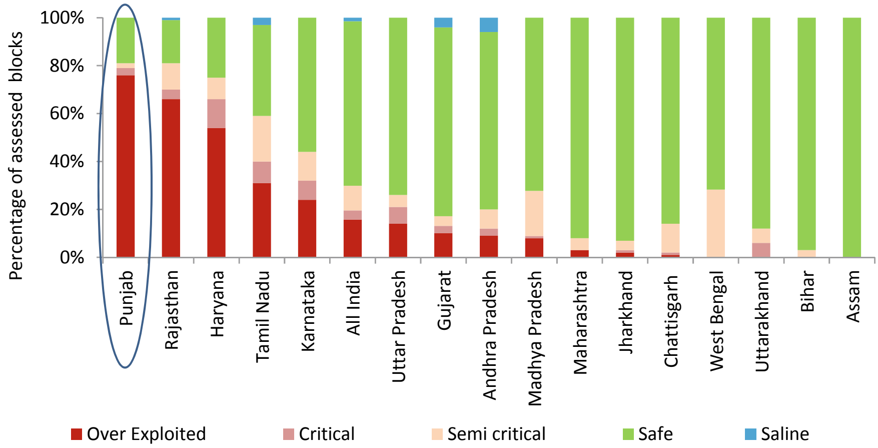


Fig. 13 Status of groundwater level in India, 2017. *Source* CGWB (2017)

other hand, in the western region, particularly in parts of Rajasthan and Gujarat, the arid climate limits groundwater replenishment. In the southern peninsular region, including parts of Karnataka, Andhra Pradesh, Telangana and Tamil Nadu, water replenishment is restricted by poor aquifer properties.

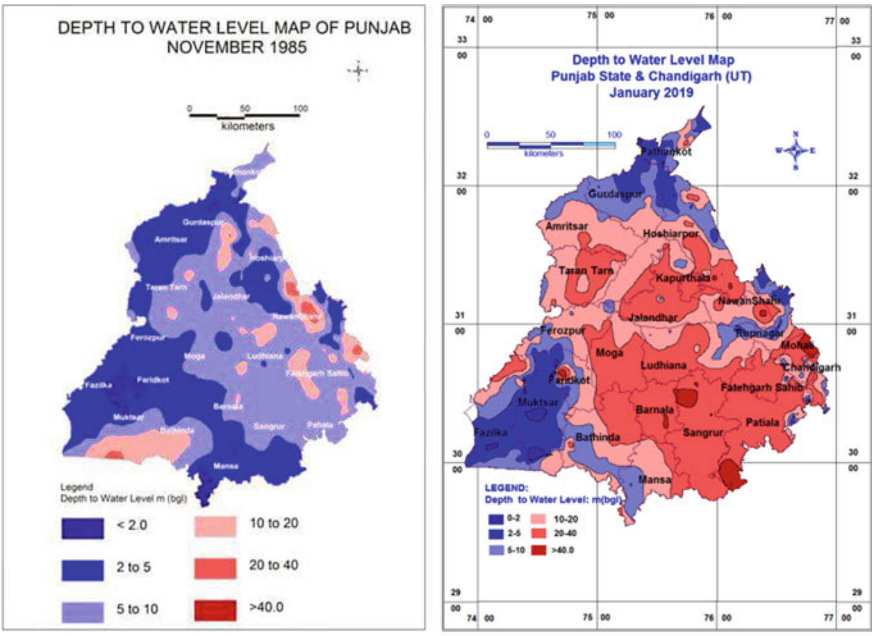


Fig. 14 Depth to water level status of Punjab. *Source* CGWB (2019)

Water Crisis in Punjab

In major parts of the state of Punjab, the depth to water level ranges between 10 and 20 m below ground level (mbgl) (Fig. 14). It is more than 20 mbgl around major cities like Jalandhar, Ludhiana, Moga, Amritsar, Patiala, Barnala, Mohali, Fatehgarh Sahib, Nawanshahar and Sangrur. Deeper water levels (more than 50 mbgl) occur in the plateau region of the Garshankar block of Hoshiarpur district. Overall, 78% (39,000 km^2) of Punjab's geographical area of 50,362 km^2 shows a decline in water levels over time, presenting an alarming state of Punjab's agriculture as we move ahead towards 2030 and beyond.

Further, the increasing use of fertilisers and pesticides has caused rapid accumulation of harmful chemicals in the soil and water, increased land degradation and soil erosion (Aditya et al., 2020). It is worth mentioning that the imbalanced use of fertilisers has created widespread deficiency of secondary and micro nutrients such as sulphur (41%), zinc (48%), iron (12%) and manganese (5%) in the soil. This is a matter of serious concern because deficiency of zinc in food, in particular, results in the stunted growth and impaired development of infants, which could lead to poor productivity of future generations.

India also faces increasing levels of GHG emissions and is the world's third largest emitter. The agricultural sector's share in these emissions is 18%, the second highest after the energy sector which accounts for 71% (CIMMYT, 2018; OECD/ICRIER, 2018). Of the total GHG emissions caused by agriculture, about 59% is generated through livestock rearing, followed by 21% from the excessive use of chemical fertilisers and their associated impact on soils. Some 18.3% GHG emission is generated from paddy cultivation and 1.7% from residue management practices (OECD/ICRIER, 2018). It has been estimated that in the years to come, India is likely to suffer significant impact of climate change, raising serious concerns that the toxic impact on the environment of the increase in emissions will only multiply.

In addition, India also suffers from increasing land degradation. According to estimates, 37% of the land area in the country (that is, about 120.4 mha) is affected by various types of degradation (OECD/ICRIER, 2018). Deforestation, poor irrigation and water management techniques, excessive and unbalanced use of fertilisers and pesticides, over-grazing and improper management of industrial wastes are some of the main reasons behind land degradation in the country. The states of Madhya Pradesh (west-central region), Kerala (south), Himachal Pradesh (north), Nagaland, Mizoram and Tripura (north-east) are the most affected, with 60% of their land experiencing degradation (OECD/ICRIER, 2018). This shows that the existing policy framework lacks a clear incentive structure for efficient and sustainable use of resources.

4.1 Remedial Measures for Sustainable Agricultural Intensification

With the demand for food expected to double and the issue of climate change projected to become severe in the near future, it is imperative to maintain biologically diverse landscapes for sustainable intensification of agriculture. In order to do so, the government needs to intervene and provide policy incentives that promote efficiency not only in agricultural production but also in input usage, with the ultimate goal of achieving overall food-feed-fibre security. Given that livestock is the biggest contributor of GHGs within the agriculture sector, improving the productivity per animal and reducing the population size is one of the important mitigation measures (Patra & Babu, 2017). At present, India has the world's largest livestock population and, consequent to the ban on cattle slaughter, unproductive male and female cattle compete with productive ones for feed and fodder. An innovative solution to tackle this problem is 'selective sex semen' technology, which facilitates the production of genetically improved high-milk-producing females at a faster rate (BAIF, 2015), and eliminates the redundant male cattle population.

After livestock rearing, rice cultivation is the next biggest source of GHG emissions, due to the metabolic activities of methanogen bacteria, which is quite effective in flooded conditions (Patra & Babu, 2017). In order to mitigate emissions from rice cultivation, it is imperative to improve productivity and plan cultivation in keeping with the climatic and biodiversity scenario across the country. Experts have recommended some specific mitigation measures:

1. The area under rice cultivation should be reduced by at least one million hectares in states like Punjab and Haryana, where 99% of rice fields are irrigated through flood irrigation methods, and that cultivation should be shifted to eastern India (Gulati & Gujral, 2012). This will also help to address the issue of groundwater depletion due to over-mining of water in these states.
2. Changing rice cultivation and irrigation practices, including the adoption of 'alternate wetting drying (AWD)' to reduce the consumption of irrigation water in rice fields without impacting the productivity (IRRI, 2019), can also cut emissions. One analysis undertaken to estimate the economics of this method found that the AWD technique can save up to 20–50% of water and can reduce GHG emissions by 30–50% (Kumar & Rajitha, 2019). Besides this, 'direct seeded rice (DSR)' is a much better practice than the conventional puddle rice cultivation because of its low-input demand. The technique has the potential to save 75% of water (Polycarpou, 2010), mitigate GHG emissions and also reduce the requirement of labour (Pathak et al., 2011).
3. Other water saving irrigation technologies like micro irrigation should be also looked at as the stepping stone for developing sustainable agricultural intensification. According to some studies, micro irrigation technology (drip and sprinkler) has an irrigation application efficiency of about 85–90% and can solve the issue of groundwater exploitation and GHG emissions to a large extent. However, a study by Birkenholtz (2017) found that while drip irrigation in

Rajasthan did improve crop productivity, it did not really save water. This is because farmers consider the water savings through this method as a resource that can be reallocated by bringing more land under cultivation. The study concludes that drip irrigation is a technically efficient innovation in terms of physical productivity, but it poses a serious challenge of groundwater overdraft in the absence of groundwater abstraction regulations (Birkenholtz, 2017).

Imbalance in the use of chemical fertilisers is another daunting challenge for agricultural intensification in India. Emissions from the use of chemical fertilisers have increased manifold in the 1980–2017 period. Absorption of all nitrogenous fertilisers applied to the soil or foliage of crops is quite difficult, and the surplus or unused amount of nitrogen pollutes water bodies or evaporates in the atmosphere in the form of nitrogen oxide, causing high levels of GHG emission (Patra & Babu, 2017). One of the commonly known mitigation practices is judicious use of chemical fertilisers based on soil health (after testing the soil) and the requirements of the crop/variety (Patra & Babu, 2017). Therefore, it makes sense for India to implement the soil health card scheme more seriously.[12] Subsidisation of soluble fertilisers instead of granules will be another step in the right direction. Optimally, the amount of fertiliser subsidy should be given directly to farmers in their bank accounts and the prices of N, P and K fertilisers freed up. Short of this direct cash transfer, in lieu of fertiliser subsidy, the nutrient-based subsidy scheme[13] needs to be extended to urea as well so that the unduly high subsidy on nitrogenous fertilisers is brought in line with the subsidy on P and K fertilisers.

Burning of crop residue also contributes to GHG emissions and climate change. This can be mitigated if farmers adopt other efficient ways to deal with crop residue, such as using it for biogas production. However, incentives should be provided for them to do that, especially in the Punjab-Haryana belt, where stubble burning of paddy has become an environmental menace.

In order to tackle the issue of rapid groundwater depletion below subsistence levels, Gujarat presents a successful model of decentralised rainwater harvesting that could be scaled up at the national level or at least be implemented in those states that are at risk. The technique includes building of check dams, village tanks and *bori-bund*s (built with gunny sacks stuffed with mud) for storing water. Government authorities in Gujarat, along with grass-roots organisations, built more than 100,000 check dams during the 1990s (Shah et al., 2009).

---

[12] The Government of India introduced the Soil Health Management (SHM) scheme under the National Mission for Sustainable Agriculture (NMSA) to promote Integrated Nutrient Management (INM) through the judicious use of chemical fertilisers (including secondary and micro nutrients) in conjunction with organic manures and bio-fertilisers for improving soil health and its productivity. The scheme includes strengthening of soil and fertiliser testing facilities to provide recommendations to farmers for improving soil fertility, ensuring quality control requirements of fertilisers, bio-fertilisers and organic fertilisers under the Fertiliser Control Order, 1985.

[13] Under the nutrient-based scheme for fertiliser, initiated by the Department of Fertilisers in 2010, a fixed amount of subsidy decided on an annual basis is provided on each grade of subsidised P&K fertilisers, except for urea, based on the nutrient content present in them.

5 The Way Forward: Pathways for Productive, Profitable and Sustainable Agriculture

Agriculture in India has witnessed an impressive growth trajectory, taking the country from a food deficit one during the 1960s to a marginally food surplus one. With food grain production at 292 MMT in 2019–20, India has not only emerged as the largest exporter of rice, but also a net exporter of agriculture produce. This breakthrough transformation has been the result of rapid development and adoption of modern technologies, investment, infrastructure (including irrigation, markets and roads) and institutions (land, water, mechanisation, extension services and agricultural credit). Notwithstanding the economic success, the sector today is at a crossroads, with numerous opportunities as well as concerns. On the one hand, the sector has grown and diversified, while, on the other, its contribution to the overall GDP has declined to 16.5% even as it still employs almost 42.3% of the total workforce. Moreover, despite India having achieved food sufficiency in agricultural production, there are still 176 million people living under poverty[14] and over 194.4 million undernourished. Furthermore, a growing population and the pressure of urbanisation is squeezing agricultural land for cultivation and affecting the quality of soil and air as well as quantity of water.

In order to meet these emerging challenges and mould food and agricultural policies, it is important to focus on the role of 3 'I's—Innovations, Incentives and Institutions that could help to produce more, diversified and nutritious food economically, and in an environmentally and financially sustainable way. Some of these potential innovations are already on the table, ready to be scaled up for higher efficiency, while others are unfolding.

5.1 *Innovations*

The major innovations in production technologies that can significantly impact overall productivity and production in India include:

Climate resilient seeds Indian agriculture, in particular, faces serious production risks due to climate change, as the country experiences "prolonged droughts in the Deccan plateau, states of the west and southern peninsula and floods in the Himalayan foothills from melting glaciers in the Himalayas" (Gulati et al., 2019). Farmers, hence, are always vulnerable to the risk of crop failure and income volatility. Therefore, the key to ensuring food sufficiency for a growing population is raising agricultural productivity through new strategic investments in climate resilient seeds with tolerance against droughts and floods, as well as sustainable farming practices. The Indian Council of Agricultural Research (ICAR) has introduced climate-smart rice varieties—CR Dhan 801 and 802 which were notified for official release by the

[14] At USD 1.90 a day, on 2011 purchasing power parity basis.

Government of India in February 2019 (ICAR-NRRI, 2019). These varieties, which have greater tolerance to submergence as well as drought, are a first for rice research and are unique globally. They are recommended for states like Andhra Pradesh, Telangana, Odisha, Uttar Pradesh and West Bengal. There is lot of ongoing research on seed varieties that are resistant to drought and submergence. Farmers just need to be incentivised to use such seeds and adopt climate-smart farming practices such as changing sowing and harvesting timings, cropping patterns and inter-cropping.

Nutritional security Despite being a food surplus nation, India is still lagging on a crucial target of Sustainable Development Goal (SDG) 2.2—that of eradicating all forms of malnutrition by 2030. Policies that were adopted in the early 1950s, and left largely unchanged since, have failed to eliminate hunger as well as to ensure adequate and appropriate nutrition for all of India's population. FAO's recent publication, *The State of Food Security and Nutrition in the World (2020)* estimates that about 14% of the Indian population is undernourished. More than 34.7% of Indian children aged below five years are stunted and 17.3% suffer from wasting, and 51.4% of women in the reproductive age group (15–49 years) suffer from anaemia (FAO et al., 2020). Inadequate access to food, inadequate care for children and women, inadequate education, insufficient health services and unhealthy environment are the underlying factors that contribute to this dismal situation. There is a need for immediate transformation of the food systems to reduce the cost of nutritious foods and increase the affordability of healthy diets (FAO et al., 2020). Thus, there is a need not only to ensure access to food, but also to nutritious foods.

According to the international nutrition community, one of the most cost-effective and sustainable solutions for alleviation of hidden hunger (or micronutrient deficiency) is the innovation of 'bio-fortification'. This is a technology through which staples (wheat and rice) are fortified with micronutrients like Vitamin A, zinc, iron and protein. This could be done by either breeding micronutrients into staple crops using agronomic practices, plant breeding, fertiliser applications or bioengineering to increase the density of micronutrients in the staple crop component of the diets (FAO et al., 2020). This technological innovation is particularly important in a smallholder rural economy like India where a majority of the population is yet unable to access a diversified healthy diet.

Globally, the HarvestPlus programme of the Consultative Group on International Agricultural Research (CGIAR) is already working in this direction, exploring opportunities to develop bio-fortified food crops. Globally, this programme has released more than 290 varieties of 12 staple food crops across 40 countries, benefitting over 48 million people. In India, they are working closely with scientists of ICAR, State Agricultural Universities, seed companies, farmer organisations, etc. for accelerating production of, and access to, iron-rich pearl millet and zinc-rich wheat to the poor. In addition, through independent research, the ICAR has so far developed 71 cultivars of cereals, millets, pulses, oilseeds, vegetables, fruits through plant breeding (ICAR, 2020). These biofortified crops have 1.5–3 times higher levels of protein, vitamins, minerals and amino acids than the traditional varieties. On the same lines, a research team at the National Agri-Food Biotechnology Institute (NABI) in Mohali has innovated bio-fortified coloured wheat (black, blue, purple) through crosses between high yielding Indian cultivars (PBW550, PBW621, HD2967) and coloured wheat from Japan and America. These varieties are rich in anthocyanins (antioxidants such those found in blueberries) and zinc (40 parts per million (ppm) compared to 5 ppm in white wheat). This seems to be the beginning of a new journey from food security to nutritional security. The best is yet to come.

Protected and sustainable agriculture Intensified agriculture with high input and high output has resulted in huge stresses on limited natural resources and the rural environment. In India, technologies to address this issue include micro-irrigation, solar pumps, *neem* coating of urea and soil health cards. *Neem* coating of urea, which is said to increase nutrient efficiency by 10%, has reduced the quantity of urea required by crops. In addition, unfolding innovations in farming practices such as soil-less farming systems—hydroponics, aeroponics, aquaponics and poly-house farming systems—need to be evaluated before being scaled up.

5.2 Incentives

Policies play key role in shaping the incentive structure for farmers. These incentives not only contribute to economic development but also encourage farmers to adopt new technology and augment production. Some innovative incentive policies include:

Direct income/cash transfer Given the extensive leakages and inefficiencies involved in input subsidies—along with their low impact on poverty alleviation and growth—it is important to shift the policy priority from subsidies to investment as well as supporting farmers in a more predictable and structured manner. This points to income support measures, which are less distorting and directly reach the actual beneficiaries. The governments of Jharkhand, Odisha, Telangana and West Bengal, as well as the Central government, have implemented income support schemes, but the sustainable implementation of these and scaling to a pan-India level is yet to happen.

Incentive for water and energy conservation Both the Central and state governments have introduced different incentives for farmers to save water and use solar technology. A crucial step in this direction has been the introduction of the *Pradhan Mantri Krishi Sinchai Yojana*[15] in 2015–16 and popularising micro-irrigation to ensure 'per drop, more crop'. The Government of Punjab has introduced the *paani bachao, paise kamao* (save water, earn money) scheme under which metres are installed on farmers' pumps to record the amount of water saved by them and farmers are paid a subsidy at the rate of INR 4 per unit for each unit saved. The amount is directly credited into their bank accounts. The scheme is a step in the right direction

[15] Prime Minister Irrigation Scheme.

towards promoting efficient water and electricity use. But whether it is scalable is a matter of further research.

5.3 Institutions

Institutions represent the ‘rules of the game’ that enable a given system to function. For innovations in technologies and incentives to be effective, a sector needs a supportive and enabling institutional environment. These institutions govern the access of key inputs and help in the development of a profitable and sustainable agriculture. The government plays an important role in setting up formal institutions, including agriculture-related laws and regulations, international trade agreements, food quality standards and land and water property rights. Innovation in institutions is required for farmers to better access and manage agricultural land, water, extension services and mechanisation at different stages of crop development and in a manner that is efficient, transparent, inclusive and sustainable.

There is an urgent need to reform land laws, free up the lease market and revoke all restrictions like ceilings on land holdings. This will encourage land consolidation and achieve viable size of holdings, which will also allow farmers to choose how to make the best possible use of their land. Liberalisation of this type will encourage long term investments in land and raise farmers’ productivity and incomes. However, the politico-environment is still opposed to the abolition of land ceilings, though it may be palatable to freeing up land lease markets.

In order to regulate the unsustainable extraction of water for irrigation, the government needs to create an institution that regulates spacing of tube wells, identification of aquifers, size of pumps and the overall rate of exploitation of this resource. This should be accompanied by institutional arrangements governing rights over water, land tenure, users’ relationships and financial incentives.

In the light of the need to produce more from limited cultivable land, the innovative idea of supplying farm machinery services to small and marginal farmers at an affordable cost through custom hire centres and ‘Uberisation’[16] platforms should be promoted more rigorously.

Last but not the least, the national network of agricultural extension plays a critical role in enabling a system of sharing knowledge, information, technology, policy and farm management practices all along the value chain, in order to enable farmers to realise a remunerative income on a sustainable basis (MoA&FW, 2018). As smallholders already face numerous and widely varying challenges, it is essential that they have access to timely, reliable and relevant information and advice. This requires an efficient agricultural extension system that goes beyond the theoretical scope of technology transfer, into the space of practical application and impact evaluation.

[16] Uberisation is an innovative on-demand business model that provides farm machinery and equipment (such as harvest combines and tractors) along with operator services to farmers at affordable costs.

Geo-tagging of farms, digitalisation of agri-value chains, big data analytics, Internet of Things, artificial intelligence in agriculture are the next frontiers of knowledge to drive agriculture into a new trajectory. Extension work has to be ready to take all these technologies from start-ups and pilots to farmers' fields for scaling up.

References

Aditya, V., Sumashini, P. S., Aravind, N. A., Ravikanth, G., Krishnappa, C., & Shaanker, R. U. (2020). Reconciling biodiversity conservation with agricultural intensification: Challenges and opportunities for India. *Cursos e Congresos Da Universidade De Santiago De Compostela, 118*(12), 1870–1873.

BAIF. (2015, January–March). *The BAIF Journal, 39*. The BAIF.

Birkenholtz, T. (2017). Assessing India's drip-irrigation boom: Efficiency, climate change and groundwater policy. *Water International*, 1941–1707.

CGWB. (2017). *Dynamic groundwater resources of India (As on March 31st, 2013).* Central Ground Water Board, Ministry of Water Resources, River Development & Ganga Rejuvenation.

CGWB. (2019). *Ground water year book (Punjab and Chandigarh): 2018–19.* Department of Water Resources, River Development and Ganga Rejuvenation. Ministry of Jal Shakti. Government of India.

CIMMYT Press Release. (2018). *India could cut nearly 18% of agricultural greenhouse gas emissions through cost-saving farming practices.*

DCD. (2017). *Status paper of Indian cotton.* Directorate of Cotton Development, Ministry of Agriculture and Farmers' Welfare, Government of India.

DES. (2017). *Land use statistics at a glance.* Retrieved March 23, 2020, from Directorate of Economics and Statistics: https://eands.dacnet.nic.in/LUS_1999_2004.htm. Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India.

Deshmukh, M. S., & Tanaji, V. S. (2017). Cropping intensity index and irrigation intensity index. *North Asian International Research Journal of Social Science and Humanities, 3*(2), 1–11.

DoAC&FW. (2019). *Agriculture census: 2015–16*. New Delhi, Agriculture Census Division, Department of Agriculture, Co-operation & Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India.

DoAHD&F. (2017). *Basic animal husbandry and fisheries statistics.* Ministry of Agriculture and Farmers' Welfare, Government of India.

DEA. (2019). *Economic survey: 2018–19.* Department of Economic Affairs, Ministry of Finance, Government of India.

FAO. (2016). *Promoting gender equality and women's empowerment in fisheries and aquaculture.* Food and Agriculture Organization.

FAO, IFAD, UNICEF, WFP and WHO. (2020). *The state of food security and nutrition in the world 2020*. FAO, IFAD, UNICEF, WFP and WHO.

Gulati, A. (2019, April 23). Will India become a big importer of food? *The Business Line.*

Gulati, A. (2021, November 22). From plate to plough—Repeal of farm laws: Tactical retreat or surrender? *The Financial Express.*

Gulati, A., & Gujral, J. (2012, September 5). India can cut agricultural emissions and subsidies by creating a market for farm offsets. *The Economic Times.*

Gulati, A., & Gupta, S. (2019, October 31). From plate to plough: Market incentives, direct income support for farmers are far more effective in increasing agricultural productivity. *The Indian Express.*

Gulati, A., & Juneja, R. (2018a, December 6). From plate to plough: Timidity and technology. *The Indian Express.*

Gulati, A., & Juneja, R. (2018b). Innovations and revolutions in Indian agriculture: A review. *Journal of Agricultural Science and Technology B, 8*(2018), 473–482.

Gulati, A., & Juneja, R. (2019, March 18). From plate to plough: Fielding the right incentives. *The Indian Express*.

Gulati, A., Kapur, D., & Bouton, M. M. (2019). *Reforming Indian agriculture*. Center for the Advanced Study of India, University of Pennsylvania.

Gulati, A., & Terway, P. (2018). 'Impact of investments and subsidies on agricultural growth and poverty reduction in India. In A. Gulati, M. Ferroni, & Y. Zhou, *Supporting Indian farms the smart way* (p. 456). Academic Foundation.

ICAR-NRRI. (2019). *CR Dhan 801 and CR Dhan 802: Climate-smart rice varieties of NRRI*. ICAR-National Rice Research Institute. http://climatechange.irri.org/projects/mitigation/mitigation-options-to-reduce-methane-emissions-in-paddy-rice

IRRI. (2019). *Mitigation options to reduce methane emissions in paddy rice*. International Rice Research Institute.

ICAR. (2020). *Bio-fortified varieties: Sustainable way to alleviate malnutrition*. Indian Council of Agricultural Research, Government of India.

Kathage, J., & Qaim, M. (2012, July 17). Economic impacts and impact dynamics of Bt (*Bacillus thuringiensis*) cotton in India. *PNAS, 109*(29), 11652–11656. Retrieved from https://www.pnas.org/content/109/29/11652

Kumar, K. A., & Rajitha, G. (2019). Alternate wetting and drying (AWD) irrigation—A smart water saving technology for rice: A review. *International Journal of Current Microbiology and Applied Sciences, 8*(3), 2561–2571.

Majhi, B., & Kumar, A. (2018). Changing cropping pattern in Indian agriculture. *Journal of Economic and Social Development, 14*(1), 37–45.

MoA&FW. (2018). *Report of the committee on doubling farmers' income*. Department of Agriculture, Co-operation and Farmers' Welfare, Ministry of Agriculture and Farmers' Welfare, Government of India.

NSSO. (2013). *Key indicators of household consumer expenditure in India, 2011–12 (July 2011–June 2012), Vol. KI of 68th Round*. National Sample Survey Office, Ministry of Statistics and Programme Implementation, Government of India.

NSO. (2019a). *Annual report: Periodic labour force survey (July 2018–June 2019).* National Statistical Office, Ministry of Statistics and Programme Implementation, Government of India.

NSO. (2019b). *National accounts statistics.* National Statistics Office, Ministry of Statistics and Programme Implementation, Government of India.

NITI Aayog. (2016). *Report of the expert committee on land leasing*. NITI Aayog, Government of India.

NITI Aayog. (2018). *Demand and supply projections towards 2030: The working group report*. NITI Aayog, Government of India.

OECD/FAO. (2019). *OECD-FAO agricultural outlook 2019–2028*. OECD Publishing.

OECD/ICRIER. (2018). *Agricultural policies in India.* OECD Food and Agricultural Reviews, OECD Publishing.

Pathak, H., Tewari, A., Sankhyan, S., Dubey, D., Mina, U., Singh, V. S., et al. (2011, November). Direct-seeded rice: Potential, performance and problems—A review. *Current Advances in Agricultural Sciences, 3*(2), 77–88.

Patra, N. K., & Babu, S. C. (2017). *Mapping Indian agricultural emissions: Lessons for food system transformation and policy support for climate-smart agriculture.* Washington, DC.: IFPRI Discussion Paper 01660.

Polycarpou, L. (2010, November 18). Direct seeding of rice—A simple solution to India's water crisis? *State of the Planet*. https://news.climate.columbia.edu/2010/11/18/direct-seeding-of-rice-%E2%80%93-a-simple-solution-to-india%E2%80%99s-water-crisis

Seetharaman, G. (2018, January 21). These two issues could put the brakes on the Bt cotton story. *The Economic Times*.

Shah, T. N., Gulati, A., Pullabhotla, H., & Shreedhar, G. (2009). Secret of Gujarat's agrarian miracle after 2000. *Economic and Political Weekly, 44*(52), 45–55.
Singh, S., Singh, R., & Singh, S. (2014). Farm power availability on Indian farms. *Agricultural Engineering Today, 38*, 48–52.
Subramanian, S. (2015). *Emerging trends and patterns of India's agricultural workforce: Evidence from the census*. Working Paper 347, Institute for Social and Economic Change.
USDA. (2019–20). Online Data available at https://apps.fas.usda.gov/psdonline/app/index.html#/app/downloads
World Bank. (2020). *National dairy support project*. The World Bank.
World Bank. (2019). *World development indicators*. The World Bank.
Xie, H., Huang, Y., Chen, Q., Zhang, Y., & Wu, Q. (2019). Prospects for agricultural sustainable intensification: A review of research. *MDPI, 8*(157), 1–27.

Dietary Diversity, Nutrition and Food Safety

S. Mahendra Dev and Vijay Laxmi Pandey

1 Introduction

India is faced with a triple burden of malnutrition, viz., under-nutrition, micronutrient deficiency and over-nutrition. In 2017, about 68.2% of the total death of children under-5, was due to malnutrition in India (LANCET, 2019). The prevalence of stunting among children under-5 was high at 34.7% during 2016–18 (MoHFW, 2019). The body mass index of 23% of women aged 14–49 was below normal in 2015–16 (NFHS, 2017). Moreover, two-thirds of India's population is estimated to be micronutrient deficient (Rao et al., 2018), which exists despite impressive economic growth (6% in 2018–19), a high level of food grain production and an increase in per capita net availability of food grains (GoI 2020). However, there has been a significant decline in the percentage of the population below the poverty line (Tendulkar method) from 37.2% in 2004–05 to 21.9% in 2011–12 (GoI, 2013).[1]

Along with undernutrition, overweight and obesity have emerged as severe public health problems leading to non-communicable diseases (NCD). In 2017, about 63% of deaths in India were attributable to NCDs (WHO, 2018). It is vital to address malnutrition challenges, especially in children and women, to ensure proper cognitive growth, overall health and productivity.

[1] The government has not released the latest 2017–18 consumer expenditure data due to comparison problems.

S. Mahendra Dev · V. L. Pandey (✉)
Indira Gandhi Institute of Development Research, Gen. Vaidya Marg, Goregaon (East), Mumbai 400065, India
e-mail: vijay@igidr.ac.in

S. Mahendra Dev
e-mail: profmahendra@igidr.ac.in

R. Chand et al. (eds.), *Indian Agriculture Towards 2030*,
India Studies in Business and Economics,
https://doi.org/10.1007/978-981-19-0763-0_3

Sustainable Development Goal (SDG)–2 aims to end hunger, achieve food security, improve nutrition and promote sustainable agriculture. Dietary patterns influence the production portfolio and sometime lead to environmental degradation. Food production is one of the major causes of global environmental change (Lancet, 2019). Therefore, interventions are needed to secure a sustainable diet that delivers food and nutrition security for all in a manner that does not compromise future generations' ability to ensure food and nutrition security (HLPE, 2014). The present paper aims to study dietary pattern and malnutrition trends, impact of different food and nutrition security interventions. The issues related to healthy diets and food safety are discussed and pathways for a safe and healthy diet to achieve nutritional security in India are suggested.

2 Changing Dietary Pattern

Consumption expenditure on different food groups and intake of calorie, protein and fat is studied using the National Sample Survey (NSS) 50th, 61th and 68th rounds.[2] National Family Health Survey second, third and fourth rounds (NFHS-2, NFHS-3 and NFHS-4) are used for understanding the trends in micronutrient consumption. Comprehensive National Nutritional Survey (CNNS) for the period 2016–18 (MoHFW, 2019), has also been referred for the latest available data on consumption pattern and nutritional status among the children and adolescents.

2.1 Consumption Expenditure on Food and Non-food Groups

The monthly per capita consumption expenditure (MPCE) has increased (in real terms) from INR 943 to INR 1287 in rural areas and from INR 1608 to INR 2477 in urban areas during 1993–94 to 2011–12. A steady decline in the percentage of food consumption expenditure in rural and urban areas was observed with steeper decline in urban areas than that in the rural areas (Fig. 1a, b). This decline is in line with Engel's Law, that the proportional share of food expenditure declines in the household budget with increase in income as shown in Fig. 2.

Over time, India's food basket has also got transformed. There are changes in the dietary pattern in rural and urban areas as per capita monthly consumption of edible oils, vegetables, egg, fish and meat has almost doubled from 1993–94 to 2011–12. Consumption of pulses remained nearly stagnant while of cereals reduced in the same period (Table 1). The dominance of cereals in total expenditure has also significantly decreased even among the poorest in rural and urban areas (Fig. 3a, b). A decline

[2] As National Statistical Office (NSO) has not released the 2017–18 consumer expenditure survey results, we could analyse consumption expenditure data only up to 2011–12. The uniform reporting period is being used from NSS reports of these rounds.

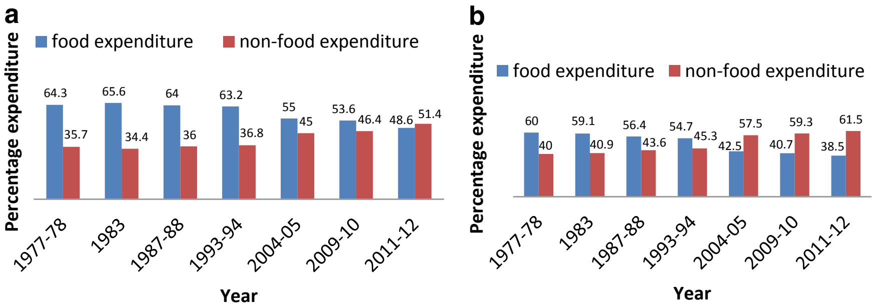


Fig. 1 **a** Food and non food expenditure: rural area (per cent). **b** Food and non food expenditure: urban area (per cent). *Source* NSSO (2013)

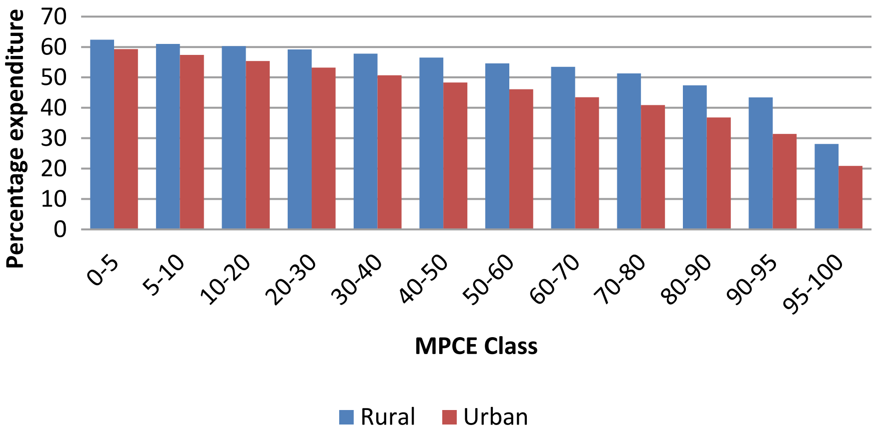


Fig. 2 Share of food in consumption expenditure (per cent) for different income class (2011–12). *Source* NSSO, 2013

Table 1 Per capita per month consumption of different food components

Year	Cereals (kg)	Pulses (kg)	Edible oils (kg)	Vegetables (kg)	Milk (litre)	Egg (No.)	Fish and meat (kg)
Rural areas							
1993–94	13.4	0.76	0.37	2.71	3.94	0.64	0.26
2004–05	12.12	0.71	0.48	2.92	3.87	1.01	0.30
2011–12	11.22	0.78	0.67	4.33	4.33	1.94	0.50
Urban areas							
1993–94	10.6	0.86	0.56	2.91	4.89	1.48	0.34
2004–05	9.94	0.82	0.66	3.17	5.11	1.72	0.37
2011–12	9.28	0.9	0.85	4.32	5.42	3.18	0.57

Source NSSO 1996, NSSO 2007, NSSO 2014

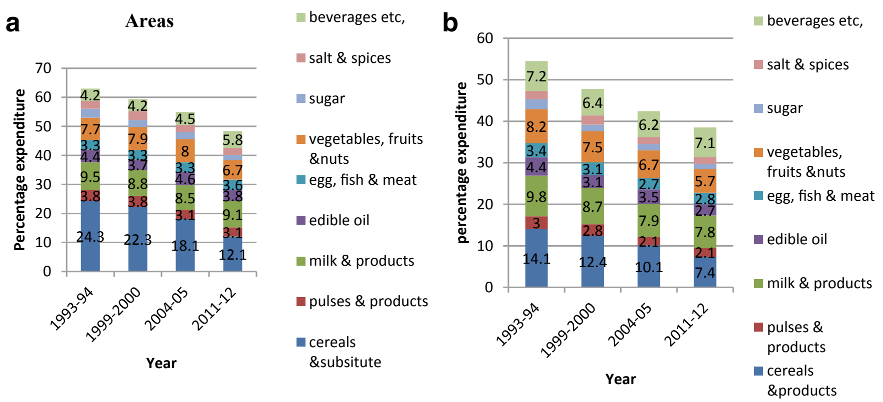


Fig. 3 **a** Percentage expenditure on different food components in rural areas. **b** Percentage expenditure on different food components in urban areas

in expenditure towards cereals reflects Bennett's Law, which suggests that with the increase in income, diets get more diversified and move away from staple grains. However, in the same period, share of expenditure on non-staples, pulses and pulses products, milk and milk products also decreased in both the areas. The spending on meat, egg and fish and beverages increased in the rural areas from 1993–94 to 2011–12 (Fig. 3a).

2.2 Calorie Intake Trends

A significant decline in the share of expenditure on cereals, main constituents and major energy source of Indian diet (Fig. 4a), in the food budget is observed, and evidence showed that it is possibly due to lifestyle changes, urbanization,

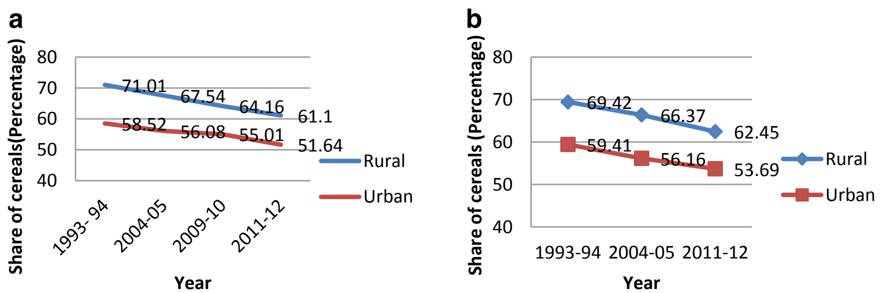


Fig. 4 **a** Share of cereals in total calorie intake. **b** Share of cereals in total protein intake

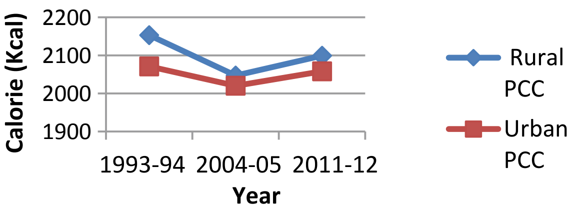


Fig. 5 Trend in calorie intake (Kcal) in rural and urban areas

mechanization, dietary diversification, etc. (Deaton & Dreze, 2009; Pingali et al., 2019).

The calorie intake was lower than the recommended guidelines of 2100 kcal in urban and 2400 kcal in rural areas in 1993–94, and it further declined by 2011–12 (Fig. 5). The calorie intake improved in both the areas in 2011–12, compared with 2004–05 due to better coverage of the public distribution system (Srivastava & Chand, 2017) and increased income. Recommended calorie intake guidelines were revised and lowered to 2090 kcal per person per day in urban areas and 2155 kcal per person per day in rural areas by Indian Council of Medical Research. Even with the revised guidelines, average calorie consumption was below the norms in rural and urban areas. However, it was above the revised norms in the highest 50 and 60% of the MPCE classes in rural and urban areas, respectively (Fig. 6a, b).

The average calorie consumption of the poorest and the richest class in rural and urban areas is significantly different, though, the gap has narrowed in both rural and urban areas (Fig. 6a, b). The Gini coefficients of inequality in calorie intake reduced from 0.16 to 0.13 in rural areas and 0.18 to 0.14 in urban areas (Srivastava & Chand, 2017). This improvement might be attributable to better food access because of increased income and better coverage of government food subsidy programme. In the higher decile classes (5th decile class and above), calorie intake reduced in both the areas, and the highest decline is in the richest decile. According to Deaton and Dreze (2009), the calorie *Engel* curve's downward shift is due to lower calorie

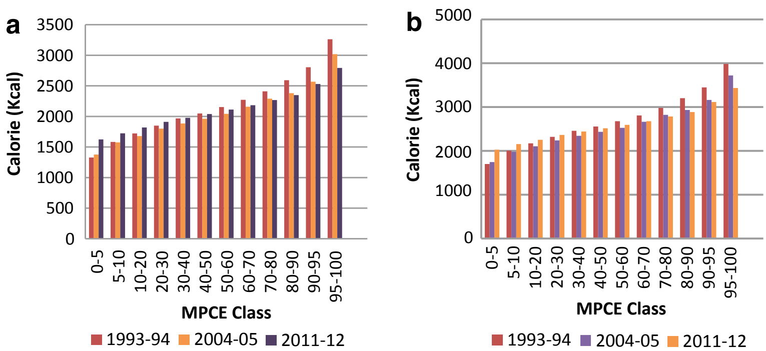


Fig. 6 **a** Per capita per day intake of calorie (Kcal) in rural areas in different MPCE class. **b** Per capita per day intake of calorie (Kcal) in urban area in different MPCE class

Table 2 Average number of meals consumed by the households outside the house in last 30 days

Year	Free meals		Meals on payment	
	Rural	Urban	Rural	Urban
1993–94	6	7	1	4
2004–05	11	8	1	3
2011–12	13.7	8.05	1.44	5.45

Source NSS reports

requirements, mainly associated with better health and lower activity levels. The calorie consumption decreases even when there is undernutrition. However, number of meals taken outside the house is increasing (Table 2), and calorie consumption calculations ignore these consumed calories.

The share of cereals in total energy intake is highest for lowest decile class in 2011–12 (Fig. 7a, b). This indicates poor diet quality of households in lower decile classes than the higher decile classes. According to dietary guidelines, balanced diet should have 50–60% of total calories from carbohydrates, about 10–15% from proteins and 20–30% from fats (NIN, 2011). EAT-LANCET norms suggest that total calories from cereals should be about 32.44% for a healthy diet (Willett et al., 2019). These evidence clearly show that Indian diets are unhealthy across all the income classes as contribution of cereals in calorie intake is quite high.

The highest contribution in calorie intake after cereals was oil and fats, with 9.01% in rural areas and 12.2% in urban areas in 2011–12 (Table 3). The increase in the share of oils and fats from 1993–94 to 2011–12 was 3.7% point in rural areas and a 3.4% point in urban areas. However, the share of vegetables and fruits in total calorie intake has declined despite their increased consumption, both in rural and

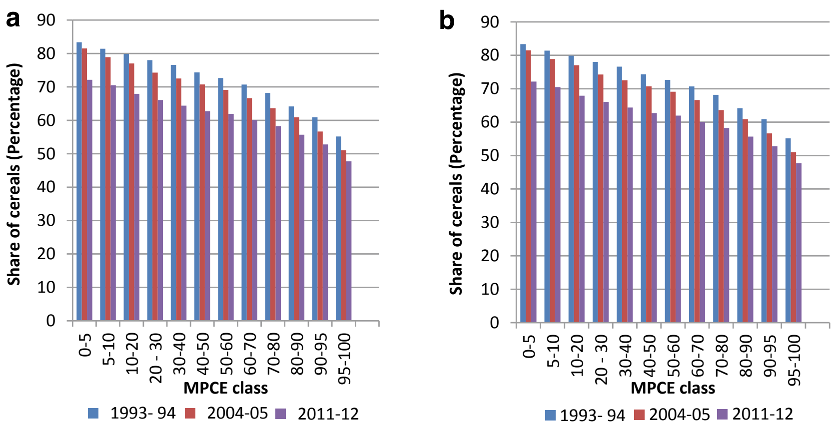


Fig. 7 **a** Share of cereals in total calorie intake (Rural). **b** Share of cereals in total calorie intake (Urban)

Table 3 Percentage of calorie consumption from food groups other than cereals

	Roots & tubers	Sugar & honey	Pulses, nuts & oilseeds	Veg & fruits	Meat, eggs & fish	Milk & milk products	Oils & fats	Misc food, food products & beverages
Rural								
1993–94	2.65	4.8	4.92	2.02	0.68	6.15	5.34	2.41
2004–05	2.95	4.78	4.98	2.23	0.76	6.42	7.36	2.98
2011–12	3.01	4.9	5.2	1.85	0.82	7.07	9.01	7.04
Change (1993–94 to 2011–12)	0.36	0.10	0.28	-0.17	0.14	0.92	3.67	4.63
Urban								
1993–94	2.54	6.21	6.05	3.26	1.02	8	8.79	5.6
2004–05	2.82	5.69	6.68	3.17	1.05	8.61	10.58	5.32
2011–12	2.73	5.62	6.41	2.62	1.13	9.07	12.17	8.61
Change (1993–94 to 2011–12)	0.19	-0.59	0.36	-0.64	0.11	1.07	3.38	3.01

Source NSS reports

urban areas. The highest percentage point increase was observed in miscellaneous food category, mostly fast food, processed food, sugary beverages etc. (Table 3). This diversion of calorie sources towards unhealthy foods might be one of the causes of increasing overweight in India.

2.3 Protein Intake Trends

The average consumption of protein declined in rural and urban areas (Fig. 8) in

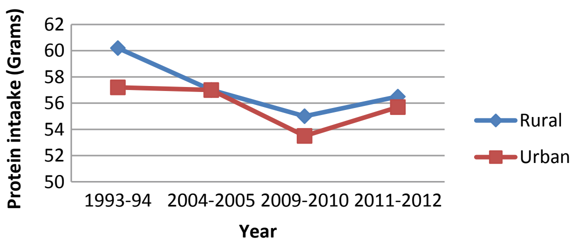


Fig. 8 Per person per day intake of protein

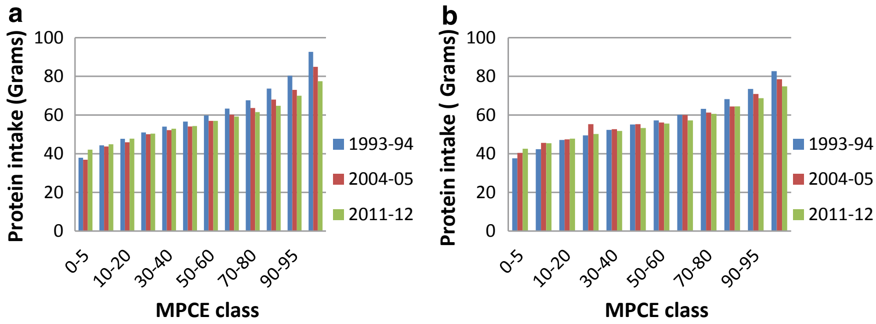


Fig. 9 **a** Protein intake in different MPCE class in rural areas (Grams). **b** Protein intake in different MPCE class in urban areas (Grams)

2011–12 compared to 1993–94. The average intake of protein is above the norms in both rural and urban areas. The recommended dietary allowance (RDA) norms for protein consumption are 48 g and 50 g per person per day in urban and rural areas, respectively (GoI, 2014). However, there is a vast gap in protein intake among the MPCE classes. Wealthier households consume higher than RDA norms. The average consumption of the poorest households is below the RDA norms in rural and urban areas (Fig. 9a, b). Though protein consumption in the lowest decile classes (first and second) has improved from 1993–94 to 2011–12, still there is a need to increase the protein intake by the poor households.

Cereals are also the primary source of protein in the Indian diet (Fig. 4b), followed by pulses, milk and milk products and egg, fish, meat and other miscellaneous foods (Table 4). Though cereals are a moderate source of protein (NIN, 2017), they become the major source of protein due to their large quantity of consumption. The percentage point increase for other food products covering fast food, processed food, etc., is highest (3.34%) in rural areas. Protein-rich foods such as milk and milk products and egg, fish and meat have recorded a modest increase in the share of total protein intake.

2.4 Fat Intake Trends

The per capita per day consumption of fat increased significantly by 32.5 and 25% in rural and urban areas, respectively, during 1993–94 to 2011–12 (Fig. 10). The intake is much higher, in urban areas (52.5 g), than the RDA norms of 26 g (RDA for rural areas is 28 g).

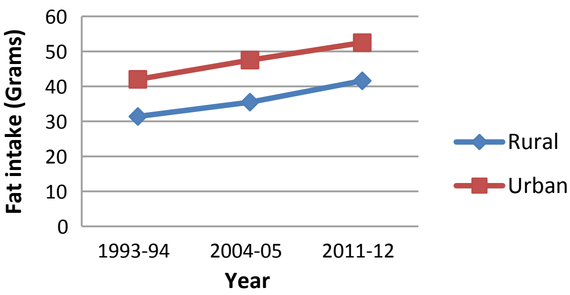
There is a considerable gap in fat intake among the MPCE classes. The average consumption of the poorest households is below the RDA in rural areas (Fig. 11a, b). However, fat consumption in the urban areas is above the RDA (25 g) across all the MPCE classes.

Table 4 Percentage of protein intake from different food groups

	Cereals	Pulses	Milk & milk products	Egg, fish & meat	Other food
Rural					
1993–94	69.42	9.76	8.81	3.66	8.35
2004–05	66.37	9.47	9.28	3.98	10.84
2011–12	62.45	10.57	10.56	4.73	11.69
Change (1993–94 to 2012)	-6.97	0.81	1.75	1.07	3.34
Urban					
1993–94	59.41	11.54	11.66	5.29	12.1
2004–05	56.16	11	12.33	5.47	14.98
2011–12	53.69	12.41	13.57	6.39	13.94
Change (1993–94 to 2011–12)	-5.72	0.87	1.91	1.10	1.84

Source NSS reports

Fig. 10 Per person per day consumption of fat



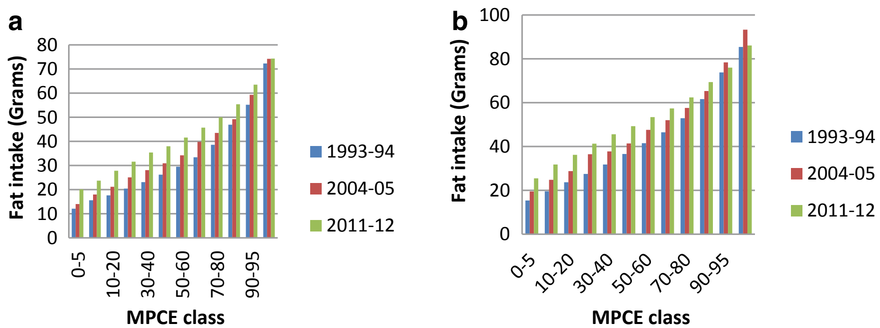


Fig. 11 **a** Intake of fat for different MPCE class in rural areas (Grams). **b** Intake of fat for different MPCE class in urban areas (Grams)

2.5 Micronutrients Intake

An adequate amount of micronutrient intake is necessary for sound health. The problem of chronic micronutrient deficiency (hidden hunger) is relatively severe (George & McKay, 2019). Milk and milk products, dark and green leafy vegetables, fruits, pulses, fish, egg and meat, are rich sources of micronutrients but its content in each food is different; therefore, various foods are required to get sufficient vitamins and minerals. The NFHS-4 data (NFHS-4, 2017) show that only 45 and 38% of women between the age 15–49 years consumed pulses and dark and green leafy vegetables, respectively, at least once a week in 2015–16. The data showed an increase in the percentage of women in the age group 15–49 years consuming milk and curd, pulses, egg, fish and fruits at least once a week but decreases for leafy vegetables, from 1998–99 to 2015–16 (Fig. 12). There is a significant difference in the consumption of milk, curd and fruits between rich and poor households (Fig. 13).

Recent Comprehensive National Nutritional Survey 2016–18 (CNNS) shows that among school-age children (5–9 years) and adolescents (10–19 years), consumption of dairy products was less frequent (61% among school-age children and 60% among

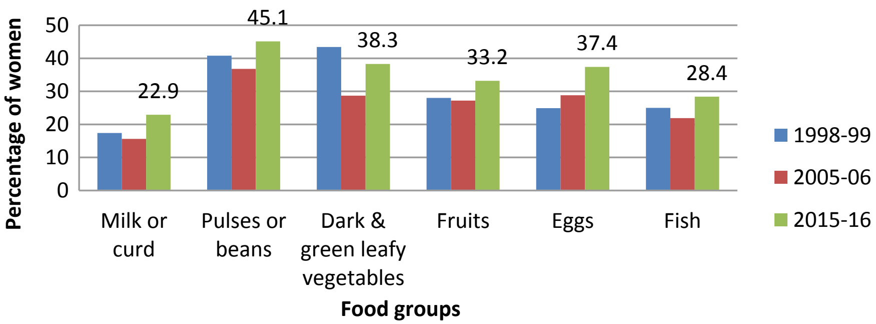


Fig. 12 Consumption of different food by women between 15–49 years at least once a week. *Source* NFHS-2 (2000), NFHS-3 (2007), NFHS-4 (2017)

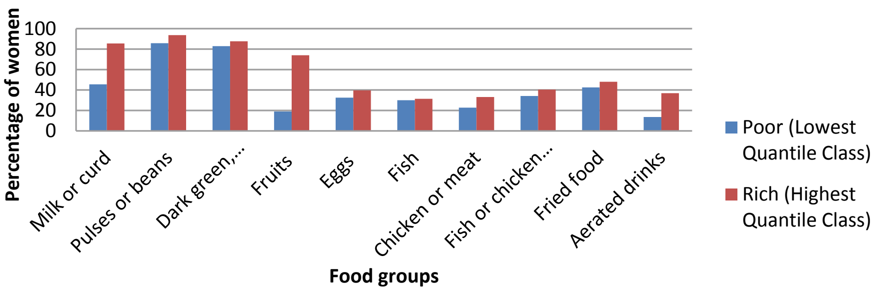


Fig. 13 Consumption of different foods at least once in a week by women aged 15–49 years in poor and rich households (2015–16). *Source* NFHS-4 (2017)

adolescents) and of fruits, eggs and fish or chicken or meat was even less regular. The report shows that mothers' education and household wealth significantly impact the consumption of these food groups as well as of unhealthy foods such as fried food and aerated drinks (Fig. 14a, b; Fig. 15a, b).

The mean level of consumption of various micronutrients among the adult women (≥ 18 years of age and involved in sedentary work) show a decline in intake of almost all the micronutrients except for thiamine and niacin, between 1996–97 and 2011–12 in the rural areas (Table 5). The intake of calcium, vitamin A and vitamin C is much below the RDA. The gap from RDA in iron intake may be the primary cause of anaemia in women of reproductive age. According to CNNS, in 2016–18, about 28 and 22% of adolescents had anaemia and iron deficiency, respectively. Iron deficiency was much higher in adolescent women (31%) than men adolescents (12%). The CNNS also reported that children and adolescents in urban areas had a higher prevalence of iron deficiency than their rural counterparts. Prevalence of deficiency of vitamin A (16%) and vitamin zinc (32%) was also considerably high

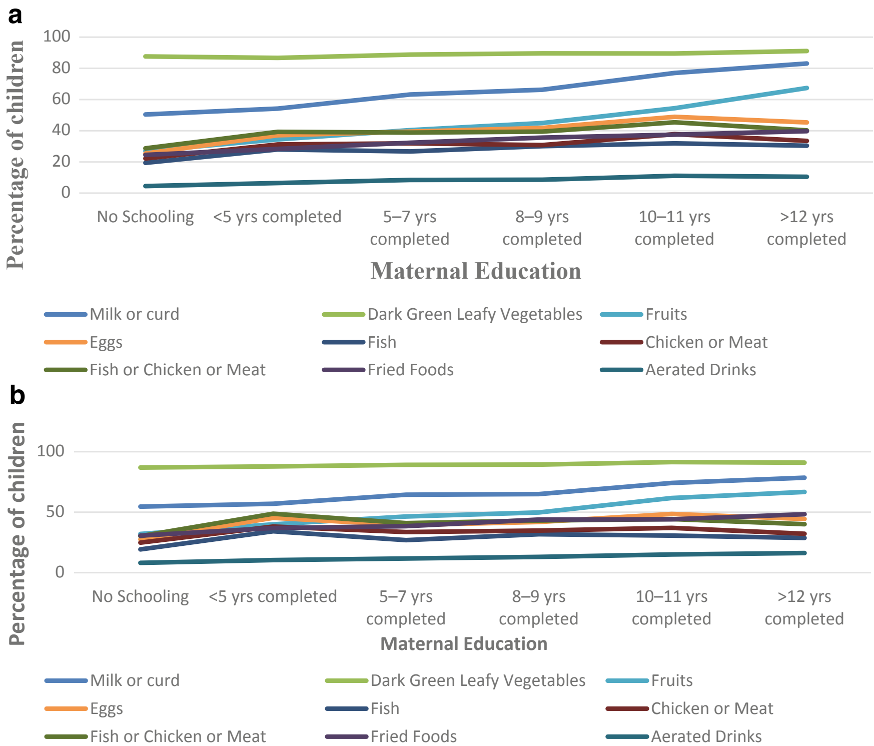


Fig. 14 **a** Consumption of food groups by children of ages 5–9 years at least once per week (Percentage). *Source* MoHFW 2019. **b** Consumption of food groups by children of ages 10–19 years at least once per week (Percentage). *Source* MoHFW 2019

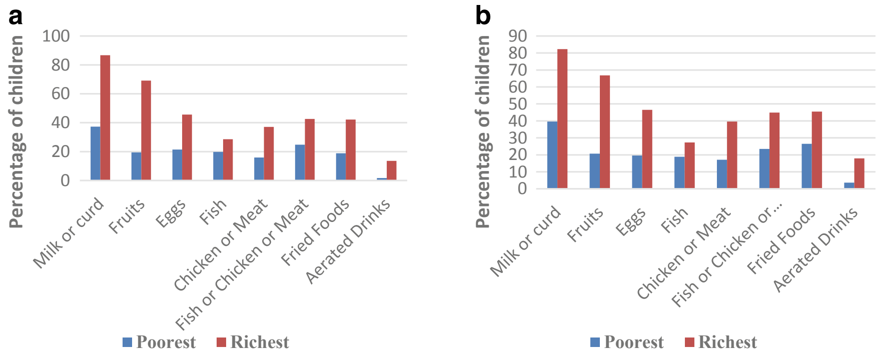


Fig. 15 **a** Consumption of food groups by children of age 5–9 years at least once per week. **b** Consumption of food groups by children of age 10–19 years at least once per week

Table 5 Mean intake of micronutrients (per day) among adult women (≥ 18 years of age) for sedentary worker

Non-pregnant non-lactating women							
Micronutrients	Calcium (mg)	Iron (mg)	Vitamin A (μg)	Thiamine (mg)	Riboflavin (mg)	Niacin (mg)	Vitamin C (mg)
1996–97	593	24.1	311	1.1	1	12	44
2005–06	443	13.8	254	1.1	0.6	14.2	47
2011–12	372	14.4	251	1.3	0.8	14	39
RDA	600	21	600	1.1	1.3	14	40
Pregnant women							
	Calcium	Iron	Vit A	Thiamin	Riboflavin	Niacin	Vit.-C
	(mg)	(mg)	(μg)	(mg)	(mg)	(mg)	(mg)
1996–97	575	24.3	269	1.1	0.9	12	39
2005–06	456	14	261	1.1	0.6	13.7	42
2011–12	418	13.7	291	1.3	0.8	13.8	43
RDA	1200	35	800	1.2	1.4	14	60
Lactating women							
	Calcium	Iron	Vit A	Thiamin	Riboflavin	Niacin	Vit.-C
	(mg)	(mg)	(μg)	(mg)	(mg)	(mg)	(mg)
1996–97	553	26.7	277	1.3	1	14	40
2005–06	447	14.7	249	1.2	0.6	15.5	46
2011–12	411	15.8	304	1.4	0.8	15.5	47
RDA	1200	21	950	1.2	1.45	15.5	80

Source NNMB 2006, NNMB 2012

among adolescents (MoHFW 2019). There is a need to give more focus on the nutritional status of adolescent women.

There is a structural shift in the dietary pattern and it points towards India's nutrition transition (Drewnowski & Popkin, 1997). A dietary shift towards high-value food commodities such as vegetables and animal-sourced foods would significantly impact the agricultural production system and environment. The intake of calorie and protein has reduced, and the intake of micronutrients is still very low. The average consumption of protein is above the RDA but below it in the poorest households. The contribution of non-cereals items in calories and proteins is increasing in both rural and urban areas. At the same time, the consumption of unhealthy foods such as processed and fast foods, beverages, etc., increased (Table 3). However, these trends are based on quite old data sets, and to make meaningful policy suggestions the recent shift in dietary pattern needs to be understood.

In India, rising income, demographic transition and the spread of retail chains have transformed households' dietary habits (Pingali et al., 2019; Shetty, 2002). Food expenditure elasticities have also changed over time, contributing to nutrition transition. Kumar et al. (2016) showed that consumers spend additional income on spices and beverages, followed by animal products. Cereals are losing their importance in Indian diets, and their demand has become more income inelastic and price elastic suggesting that cereals are a substitute rather than a complement to animal products in a diet (Law et al., 2019). Both price and non-price factors were responsible for changes in consumption patterns.

3 Malnutrition Trends

Malnourished children and adolescents are at increased risk of impaired growth, poor cognitive development, low immunity and mortality (Black & Dewey, 2014). In India, stunting among children under five declined from 48% in 2005–06 to 38.4% in 2015–16 at an average rate of 1% per year (Table 6). Underweight among children under-5 also declined from 42.5% to 35.7%, a 0.7% decline per year during this period. According to CNNS, stunting and underweight among children under-5 was even lower at 35% and 33%, respectively, during 2016–18. On the other hand, wasting has slightly increased (19.8 to 21% during 2005–06 to 2015–16) as per NFHS-4 (2017) data; however, CNNS shows that wasting was 17% during 2016–18. Malnutrition and anaemia for children and women is higher in rural than that in urban areas (MoHFW, 2019). Although anaemia decreased for children and women, and BMI improved for women, the levels are still not satisfactory. Around 58% of children and 53% of women were anaemic in 2015–16 (Table 6).

Malnutrition is 51% in the lowest wealth quintile in 2015–16. It is very high and nearly 2.5 times of malnutrition levels than the highest quintile (Table 7). Scheduled castes and Scheduled tribes have 10% points higher malnutrition than other castes. No education category has 20% points higher malnutrition than the category with secondary or more (Table 7). Maternal education influences nutrient intake and

Table 6 Nutritional status of children under five years and women (15–49): all India, per cent

	Total (Rural + Urban)		2015–16 (NFHS-4)	
Children under 5 years	2005–06 (NFHS-3)	2015–16 (NFHS-4)	Rural	Urban
Stunting (height for age)	48.0	38.4	41.2	31.0
Underweight (weight for age)	42.5	35.7	38.3	29.1
Wasting (weight for height)	19.8	21.0	21.5	20.0
Anaemia among children	69.4	58.4	59.4	55.9
Women (15–49 years)				
Anaemia among women	55.3	53.0	54.2	50.8
BMI below normal (women)	35.5	22.9	26.7	15.5

Sources NFHS-3 (2007) and NFHS-4 (2017)

Table 7 Nutrition status of children under five years, stunting (height for age): all India, 2015–16

Wealth Quintile	Stunting (per cent)	Social groups	Stunting (per cent)	Education	Stunting (per cent)
Lowest	51	Scheduled Caste	43	No education	51
Second	44	Scheduled Tribe	44	Primary complete	44
Middle	36	Other Backward Class	39	Secondary or more complete	31
Fourth	29	None of them	31		
Highest	22				

Source NFHS-4 (2017)

reduces malnutrition in children under-5 (Figs. 14a, 16, Jose et al., 2020; Pandey et al., 2016).

However, the decline in malnutrition is much higher during 2005–06 to 2015–16 compared to 1998–99 to 2005–06. Despite the non-improvement of diet quality in terms of protein and quantity of micronutrients at the aggregate level, the nutritional outcomes are getting better. The decline in malnutrition depends on several

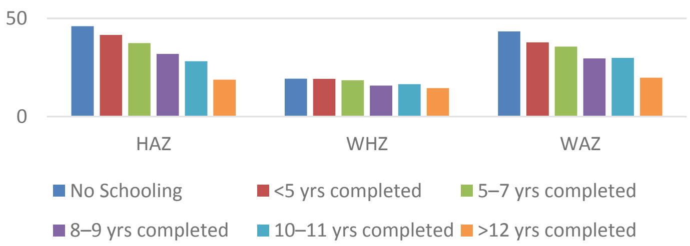


Fig. 16 Maternal education and anthropometry of children (0–4 years). *Source* MoHFW 2019

multidimensional factors—(i) increased protein intake in the lowest 20% of the MPCE class, (ii) expansion and improvement of several programmes targeting a mix of direct and indirect causes of undernutrition, (iii) increasing efficiency in these programmes' delivery systems and (iv) improvements in drinking water, sanitation, hygiene (WASH) and women's literacy rate. Studies showed that hygiene and sanitation are strongly associated with nutritional status, especially for children (Jose et al., 2020; Shively, 2015).

The NFHS-5 fact sheets of key indicators were released in December 2020 for 22 States and UTs. Table 8 presents comparison of NFHS-5 with NFHS-4 for six major states and shows an increase in: (i) children's dietary adequacy, drinking water, sanitation facilities, clean cooking fuels, women's education and women's empowerment, (ii) stunting in children under-5 in Gujarat, Maharashtra and West Bengal (WB), (iii) proportion of severely wasted under-5 children in all the states except Karnataka, (iv) diarrhoea in children in all the five states except Gujarat, (v) underweight children under-5 in Gujarat, Maharashtra and WB, (vi) percentage of overweight children in all six states. The overweight children are 2% more than wasted children. Anaemia among the children between age 6–59 months increased in all the states, and among women aged 15–49 years it increased in all the states except Andhra Pradesh (Table 8). The worsening of nutritional status despite improvement in WASH, maternal education and programme coverage could be due to decline in household income, poor maintenance of sanitation facility, increase in environmental pollution, etc., but it has to be explored further once full data is made available.

India is also suffering from increase in overweight and obesity in the population (8.1% point (12.6–20.7%) among the women during 2005–06 to 2015–16) that poses more significant risks for NCDs (MoHFS, 2019). It increased by 9.3% points (9.3–18.6%) among the men during the same period. Undernutrition in utero and early childhood can affect individuals to become overweight and develop NCD in adulthood (WHO, 2018). According to 2019 CNNS, overall, 2% of children under-5 were overweight or obese during 2016–18. In the well-nourished population, it is normal. But in India, as almost 20% of under-5 children were wasted, with the mean weight-for-length/height z-score (WHZ score) for the population being -1.0, the prevalence of overweight or obese at 2% was considered significantly higher and could indicate rise of overweight and obesity in the country (MoHFW, 2019).

4 Different Interventions and Impact

Policies related to social protection are important as they would directly deliver support to the needy. Research showed that risk and vulnerability justification should be added since the poor do not have formal instruments for risk mitigation and coping (Devereux, 2006).

In order to alleviate poverty and achieving food security, India adopted a two-fold strategy of letting the economy grow fast and attacking poverty directly through

Table 8 Comparing status of child feeding, nutritional outcome and prevalence of diseases in children under-5 ([FHS -5 (2019–20) and NFHS-4 (2015–16)]

	AP		Bihar		Gujarat		Karnataka		Maharashtra		WB	
Characteristics	NFHS-5	NFHS-4	NFHS-5	NFHS-4	NFHS-5	NFHS-4	NFHS-5	NFHS-4	NFHS-5	NFHS-4	NFHS-5	NFHS-4
Women with 10 or more years of schooling (%)	39.6	34.3	28.8	22.8	33.8	33	50.2	45.5	50.4	42	32.9	26.5
Population with an improved drinking-water source (%)	96.7	95.6	99.2	98.4	97.2	95.9	95.3	95.3	93.5	92.5	97.5	97.2
Population that use an improved sanitation facility (%)	77.3	54.4	49.4	26.5	74	63.6	74.8	57.8	72	52.3	68	52.8
Households using clean cooking fuel (%)	83.6	62	37.8	17.8	66.9	52.6	79.7	54.7	79.7	59.9	40.2	27.8
Child feeding												
Children under age 6 months exclusively breastfed (%)	68	70.2	58.9	53.4	65	55.8	61	54.2	71	56.6	53.3	52.3
Children age 6–23 months receiving an adequate diet (%)	9.3	7.6	10.9	7.5	5.9	5.2	12.8	8.2	9	6.5	23.4	19.6
Nutritional status and diahorrea among children under-5												
Stunted (%)	31.2	31.4	42.9	48.3	39	38.5	35.4	36.2	35.2	34.4	33.8	32.5
Wasted (%)	16.1	17.2	22.9	20.8	25.1	26.4	19.5	26.1	25.6	25.6	20.3	20.3
Severely wasted (below-3 standard deviations)	6	4.5	8.8	7	10.6	9.5	8.4	10.5	10.9	9.4	7.1	6.5
Underweight	29.6	31.9	41	43.9	39.7	39.3	32.9	35.2	36.1	36	32.2	31.6
Overweight	2.7	1.2	2.4	1.2	3.9	1.9	3.2	2.6	4.1	1.9	4.3	2.1
Prevalence of diarrhoea in the 2 weeks preceding the survey (%)	7.2	6.6	13.7	10.4	8.2	8.4	5.3	4.5	8.9	8.5	6.5	5.9

(continued)

Table 8 (continued)

	AP		Bihar		Gujarat		Karnataka		Maharashtra		WB	
Characteristics	NFHS-5	NFHS-4	NFHS-5	NFHS-4	NFHS-5	NFHS-4	NFHS-5	NFHS-4	NFHS-5	NFHS-4	NFHS-5	NFHS-4
Prevalence of symptoms of acute respiratory infection in the 2 weeks preceding the survey (%)	2.4	0.5	3.5	2.5	1	1.4	1.5	1.2	3.2	2.4	2.8	3.3
Anaemia among children and adults												
Children age 6–59 months who are anaemic (< 11.0 g/dl) (%)	63.2	58.6	69.4	63.5	79.7	62.6	65.5	60.9	68.9	53.8	69	54.2
Non-pregnant women age 15–49 years who are anaemic (< 12.0 g/dl) (%)	59	60.2	63.6	60.4	65.1	55.1	47.8	44.8	54.5	47.9	71.7	62.8
Pregnant women age 15–49 years who are anaemic (< 11.0 g/dl)(%)	53.7	52.9	63.1	58.3	62.6	51.3	45.7	45.4	45.7	49.3	62.3	53.6
All women age 15–49 years who are anaemic (%)	58.8	60	63.5	60.3	65	54.9	47.8	44.8	54.2	48	71.4	62.5

Source NFHS-4 (2017) and NFHS-5 (2021) poverty alleviation programmes. We first examine here the trends in poverty and the role of direct social protection programmes before going to the individual schemes.

4.1 Poverty Trends

Based on NSS Consumer Expenditure data there are two conclusions on the trends in poverty. (i) Datt et al. (2016) showed that poverty declined by 1.36% points per annum in post-1991 compared to that of 0.44% points per annum prior to 1991. This study also showed that among other things, urban growth is the most important contributor to the rapid reduction in poverty even in rural areas in post-1991 period. Second conclusion is that within the post-reform period, poverty declined faster in 2000s than in 1990s. The official estimates based on the Tendulkar poverty lines showed that poverty declined much faster during 2004–05 to 2011–12 as compared to the period 1993–94 to 2004–05. In fact, the number of poor came down by 137 million during 2004–05 to 2011–12 while it increased by 3.4 million during 1993–94 to 2004–05. According to the Rangarajan Committee methodology, the decline from 2009–10 to 2011–12 is 92 million.[3]

Faster reduction in poverty is true even on the basis of multidimensional poverty index (MPI). According to the Report of the Global MPI, 2019 (Oxford and UNDP, 2019), India has made momentous progress in reducing multidimensional poverty. The incidence of multidimensional poverty was almost halved between 2005–06 and 2015–16, climbing down to 27.5%. Thus, from consumption based poverty or MPI point of view, poverty declined faster during the high growth period; GDP growth was 8.5% per annum during 2004–05 to 2011–12 as compared to 6.3% per annum during 1993–94 to 2004–05. During the period 2004–05 to 2011–12, several poverty alleviation programmes, like MGNREGA (Mahatma Gandhi National Rural Employment Guarantee Act) and NFSA (National Food Security Act), were introduced. These programmes were responsible for faster decline in poverty in India. Data after 2011–12 is not available.

The importance of individual programmes in reducing poverty and improving nutrition has been examined here.

4.2 MGNREGA

In India, the provision of employment has been extensively used as a tool of entitlement protection from many centuries. After independence in 1947, central government sponsored many schemes, beginning with the Rural Manpower programme in 1960. However, the most important programme at the state level is the Maharashtra Employment Guarantee Scheme (EGS), introduced in 1972.

[3] Rangarajan Committee estimates only for the years 2009–10 and 2011–12.

The National Rural Employment Guarantee Act (NREGA) was notified in September 2005. It is now called Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA). Its objective is to enhance livelihood security in rural areas by providing at least 100 days of guaranteed wage employment in a financial year to every household. MGNREGA has been subject to much scrutiny, and assessment in terms of its effectiveness as a social protection intervention.[4] These assessments have yielded mixed findings, in terms of the effectiveness of the programme's design and objectives, its impact on the socially disadvantaged, especially children and women.

Several pathways lead to better outcomes in nutrition, health and education of children due to social protection programme like MGNREGA. These can be grouped into three heads (i) indirect effects of reduction in risks and vulnerabilities and increase in livelihoods and incomes of households, (ii) women's well-being and intra-household decisions and (iii) direct effects of childcare facilities and linkages with school education and ICDS.

Dev (2011), while examining the impact of MGNREGA on the well-being of children and the impact of the scheme on women, reported positive impact of MGNREGA on child well-being[5] as well as on household incomes, empowerment and well-being of women, in improving nutrition, health and education of children and reducing child labour.[6] Related to the issue of children in agriculture, especially girls, is the gender aspect of recognizing women as producers and farmers and linking to household food security. Strengthening extension training curriculum on gender and child protection issues in agriculture can help in reducing child labour.

Narayanan and Gerber (2017) and Narayanan (2020) also showed positive impact of MGNREGA on women and children. MGNREGA benefits the poor and the marginalized, who generally are more undernourished and have poor health.[7] MGNREGA can have links to nutrition and health at the micro level in two ways: (i) through rise in earnings and expenditures that seem to have a positive impact on calories, proteins and micronutrient intake in Andhra Pradesh, Rajasthan and Maharashtra[8]; (ii) through the assets created under MGNREGA (Narayanan & Gerber, 2017). Narayanan et al. (2014) studied the assets created in Maharashtra under MGNREGA, and revealed that 87% of works exist and function and over 75% of these are directly or indirectly related to agriculture.

MGNREGA is the most important social protection programme in India. Apart from direct benefits, it has secondary benefits such as creation of assets for agriculture and rural development; more participation of women (more than 50% of workers

[4] For example, see Dreze and Khera (2009), Khera (2008), Dev (2011), Narayanan and Gerber (2017), Narayanan (2020).

[5] Child well-being indicators are child labour, nutrition and education.

[6] Studies showed a positive relationship between MGNREGA and child nutrition indicators. Also it is shown that access to food also increased for the households including children.

[7] MGNREGA provided employment to 55 million rural households in 2019–20. Majority of them belong to poorer households as they are self-selected for doing manual unskilled work.

[8] This is based on Jha et al. (2011).

Table 9 Allocation and offtake under NFSA, 2019–20 (in million tonnes)

	TPDS	ICDS	MDMS	Total
Allocation	52.2	2.2	2.5	56.9
Offtake	50.1	1.2	2.1	53.4

Source Food Bulletin, Department of Food and Public Distribution System (GoI)

are females); helping marginalized sections like SCs and STs; reducing distress migration; involvement of panchayats, etc.[9] The programme demonstrated varying degrees of success across the country. The achievements are still short of potential, which can be harnessed to strengthen the right to employment enhancing the rights of women and children.

4.3 NFSA

The Indian Public Distribution System (PDS) is one of the instruments for improving food security at the household level. The PDS ensures availability of essential commodities like rice, wheat, edible oils and kerosene to the consumers through a network of outlets or fair price shops. These are supplied at below market prices to consumers. The National Food Security Act (NFSA) 2013 aims to provide subsidized food grains to approximately two-thirds of India. It includes the Midday Meal Scheme (MDMS), Integrated Child Development Services scheme (ICDS) and Targeted Public Distribution System (TPDS). Further, the NFSA 2013 recognizes maternity entitlements. The MDMS and the ICDS are universal in nature whereas the TPDS reaches about two-thirds of the population (75% in rural areas and 50% in urban areas).

Under the provisions of the Act, beneficiaries of the PDS are entitled to 5 kg per person per month of cereals at INR 3 per kg of rice, INR 2 per kg of wheat and INR 1 per kg of coarse grains (millets). Pregnant women, lactating mothers and certain categories of children are eligible for daily free cereals. In 2019–20, the offtake under TPDS was 50 million tonnes while it was 1.2 million tonnes and 2.1 million tonnes for ICDS and MDMS, respectively (Table 9).

4.3.1 The Impact of PDS on Food and Nutrition Security

In general, the poor and the vulnerable groups benefited from the PDS although the impact varies across states. Narayanan and Gerber (2017) showed a range of limited to modest positive impact on calorie intake.[10] The study also indicated that most of the studies are limited to assessing the intermediary outcomes than on undernutrition.

[9] On benefits of employment guarantee schemes, see Dev (1995) and Dev (2011).

[10] This is based on literature survey by Narayanan and Gerber (2017).

Krishnamurthy et al. (2014) revealed an increase in consumption of protein, calcium and iron due to the PDS (12.9%, 26.4% and 14.2% respectively).

Himanshu and Sen (2013) estimated that the value of PDS transfer was 2.4% of MPCE for the total population, and 5.2% of MPCE for the bottom 40%. In other words, poor benefited more than others due to these in-kind food transfers. Their study showed that in 2009–10, total poverty ratio (Tendulkar methodology) was 30.68% with PDS transfers, while it was 33.85% without transfers in 2009–10.

One issue of NFSA is its adverse impact on diversification of cropping pattern. The policies in India support rice and wheat due to minimum support prices, buffer stock and PDS. These policies provide incentives for farmers to produce more of rice and wheat which are water intensive. They act as disincentives to undertake diversified farming.

Related criticism is that NFSA is not going to solve the problem of malnutrition as they give mainly calories. It is possible that savings from subsidized food items indirectly helps in consuming protein and micronutrient related foods. It is true that the poor and vulnerable spend more on cereals. It is known that health is determined by calorie, proteins, micronutrients, sanitation, safe drinking water, etc. NFSA mainly provides rice, wheat and coarse cereals. It, however, has some provision for nutritious food for women and children.

4.4 Child Nutrition Schemes

4.4.1 ICDS

The Integrated Child Development Services (ICDS), launched in 1975, aims at the holistic development of children up to 6 years of age with a special focus on children up to 2 years, besides expectant and nursing mothers. This is done through a service package—health check-ups, immunization, referral services, supplementary feeding, non-formal pre-school education and advice on health and nutrition.

The scheme has to focus more on 0–3 year children as malnutrition sets in *in utero* and is likely to intensify during the 0–3 year period, if not addressed. A child malnourished during 0–3 years will be marred physically and mentally for life. The scheme is designed to address this problem frontally.

Mother's malnutrition has knock-on effects on child malnutrition. Exclusive breastfeeding for six months is necessary to avoid unnecessary infections to the baby, develop the baby's immunity and ensure growth. The baby must begin to receive solid, mushy food at 6 months (i.e. together with breastfeeds) for the baby to continue to grow in the way nature intended it to grow. The ICDS scheme accordingly needs to be restructured in a manner that addresses some of the weaknesses that have emerged and is suitable for universalization. The programme must effectively integrate the different elements that affect nutrition and reflect the different needs of children in different age groups (GoI, 2008).

Apart from the above, preliminary findings of FOCUS (Focus on children under-6) survey conducted in May–June 2004 in six states brought out some of the problems and regional disparities in the working of ICDS (Dreze, 2006). This study showed that Tamil Nadu scores over Northern states in infrastructure, quality of pre-school education, immunization rates, mother's perceptions and quality of anganwadi workers.

Saxena (2008) informed that ICDS reached only 12.5% of children in the age group 6 months to 6 years. The aim of the 11th Five Year Plan document was to halve the incidence of malnutrition by the end of the Plan period, and reduce anaemia among pregnant women and children to under 10%. It stated that to achieve these objectives, ICDS has to be restructured with higher allocations of funds and effective implementation.

The above studies were done more than a decade back. Jain (2015), using NFHS 2005–06, showed that the supplementary feeding component of ICDS had sizable positive effects on heights of 0–2 year olds in 2005–06; girls who received ICDS food daily were at least 1 cm taller than those who did not. It also indicated that the supplementary nutrition could potentially bridge the height gap between the richest and poorest girls by at least 28% and for boys by 19% at adulthood. However, the study warned that one can have all these benefits only if the programme is targeted towards 0–2-year-old children. ICDS was restructured in recent years including focus on supplementary feeding on children below 3-years of age and pregnant and lactating mothers. Apart from other factors, ICDS restructuring helped in decline in stunting in recent years.

A study by Chudasama et al. (2016) evaluates ICDS programme during 2012–2015. Some of the findings are mentioned here.

(a) A majority of pregnant women (94.7%) and lactating mothers (74.4%), and adolescent girls (86.6%) were availing ICDS services. (b) Two-thirds (66.2%) children were covered by supplementary nutrition (SN). (c) Only 14.6% of the AWCs (Anganwadi Centres) reported 100% preschool education (PSE) coverage among children. (d) More than half (55.4%) of the AWCs reported an interruption in supply during the last 6 months. (e) Various issues were reported by AWWs (Anganwadi Workers) related to the ICDS. The study reported gaps in terms of infrastructure facility, different trainings, coverage, supply and provision of SN, status of PSE activities in AWCs and provision of different services to the beneficiaries. These gaps have to be addressed to improve the impact of ICDS on nutrition. One has to examine the working of ICDS more thoroughly and find out the reasons for less take off in this scheme as compared to schemes like PDS and mid-day meal scheme.

4.4.2 Mid-day Meals Scheme

The MDMS in India is a programme covering primary school children to improve nutrition as well as increase educational enrolment, retention and attendance. Using Young Lives project data, Porter et al. (2010) examine the effect of the scheme on children's nutrition and their learning. Among the children surveyed by Young Lives in Andhra Pradesh, the scheme delivered significant nutritional benefits for children aged 4–5 years with respect to better height-for-age and weight-for-age than would otherwise be expected, suggesting that MDMS helps reduce malnutrition. For older children (aged 11–12 years) there is evidence of significant positive impacts on children's learning, although it is not clear if these effects are generated by less hunger or by improved school attendance. The school meals have most impact in areas affected by drought. For younger children, there are large and significant gains in height-for-age and weight-for-age, which more than compensate for the negative effects of the drought. The success of Tamil Nadu MDMS on nutrition and education is well known.

4.5 Cash Transfers

Some argue unconditional cash transfers (CTs) to reduce poverty and undernutrition. It is advocated that the system should move towards direct benefits transfer in place of present social protection programmes. There has been a lot of discussion on universal basic income (UBI) in both developed and developing countries. Rangarajan and Dev (2017) say introducing UBI is unrealistic. In fact, the concept of basic income must be turned essentially into a supplemental income.

A study on Bangladesh (Ahmed et al., 2019) showed positive relationship between cash transfers and nutrition. They implemented randomized control trials in rural Bangladesh, with two treatments: (a) cash transfers, a food ration or a mixed food and cash transfer and (b) cash and nutrition behaviour change communication (BCC) or food and nutrition with BCC. The study revealed only cash plus nutrition BCC had a significant impact on nutritional status, but its effect on height-for-age was large. Improved diets—including increased intake of animal source foods – along with reductions in illness in the cash plus BCC treatment were responsible for improvement in children's nutrition.

4.6 COVID-19 and Safety Net Programmes

COVID-19 created health and economic crisis in India similar to many other countries. The complete shutdown of all economic activities except essential services created an economic crisis and misery for the poor, with massive job losses and rising food insecurity.

The central and state governments and the RBI recognized the economic crisis and responded using fiscal and monetary policies. The Central government announced *Atmanirbhar package* with INR 21 trillion (around 10% of GDP). But most of the package relates to liquidity measures. The real fiscal stimulus seems to be around 2% of GDP. It also includes food transfers and cash transfers for the informal poor workers including migrants. Government allocated more funds for MGNREGA.

India has nearly 56 million tonnes of excess stock of grains and cereals compared to the usual norms. In March 2020, the government declared 5 kg free rations in addition to the present entitlement of buying 5 kg at subsidized prices. In June 2020, the Prime Minister announced extension of the Pradhan Mantri Garib Kalyan Anna Yojana (PMGKAY), a programme to provide free ration for over 80 crore people, mostly poor, for five more months till November end. It was to help the informal sector workers in both rural and urban areas. However, government has to make sure that no one is excluded as there are still exclusion errors in the PDS. State governments have also announced free basic and enhanced rations. The Central government also announced 'One Nation-One Ration Card'. The nutritional levels of informal workers and unemployed poor were low even before the crisis. It will decline further due to lack of jobs and incomes during lockdown and beyond. Therefore, there is a need to have pulses, oils, etc. in the provision to ensure a diversified diet for them. Anganwadis and schools can provide rations at home. Eggs can be added to improve nutrition for children and women. Government has to make sure that the prices of essential food items are under control. Otherwise high prices would have adverse impact on the food and nutrition security of the poor.

4.6.1 Minimum Basic Income for the Poor in Post-COVID-19 period

Universal Basic Income (UBI) was discussed in detail during pandemic times. It is true that a universal scheme is easy to implement. Feasibility of such a scheme is the critical question. Targeted programme is another option but its main problem is of identification. Narrowly targeted programmes will run into complex problems of identification and give rise to exclusion and inclusion errors.

Rangarajan and Dev (2020) suggested three proposals to avoid the identification problem and help in providing minimum basic income to poor and vulnerable groups in both rural and urban areas. These are:

(a) give cash transfer to all women—above the age of 20 years—in both rural and urban areas;
(b) expand the number of days provided under MGNREGA; and
(c) launch National Employment Guarantee Scheme in urban areas.

In all the three proposals, there is no problem of identification. A combination of cash transfer and an expanded MGNREGA can provide minimum basic income.

a. *Total cost of the three proposals*

The proposal of providing cash transfers to women above 20 years costs INR 1.72 lakh crore (0.84% of GDP). The total cost of the expenditure on MGNREGA for providing 150 days employment and 150 days for urban employment guarantee scheme would cost INR 3.21 lakh crore in a year (1.58% of GDP). The total cost of the three proposals would be INR 4.9 lakh crores or 2.4% of GDP. A person working in MGNREGA and urban programme can get an additional INR 30,000 if 150 days are provided.

It may be noted, however, that the total expenditure of the proposals could be lower due to two reasons. First, the number of days availed of by the employment guarantee programmes could be lower as it is a demand based programme. This is happening even now. Second, on cash transfers, some women particularly from richer classes may voluntarily drop out of the scheme or alternatively a declaration may be obtained from those receiving cash transfer that their total monthly income is less than INR 6000 per month. In addition it may be noted that the government is already incurring a total expenditure of INR 67,873 crore on MGNREGA.

In the post-COVID-19 situation, we need to institute schemes to provide minimum income for the poor and vulnerable groups. For this purpose, it is proposed to offer cash transfers for women, increase MGNREGA from the present 100 days to 150 days of work in rural areas and introduce 150 days of work as an urban employment guarantee scheme. This will cost around 2% of GDP and will help the poor, informal workers including migrant workers and poverty and food and nutritional insecurity can be reduced significantly.

5 Food Safety Concerns

Food safety refers to ways to prevent food-borne diseases (FBD) due to food contamination in the entire food system—production, processing, storage, transport, food distribution and at the household level. It also refers to the prevailing standards and controls to protect consumers from unsafe foods. The Food Safety and Standards Authority of India (FSSAI) finalizes science-based quality and safety standards for food and regulate the manufacturing, storage, distribution, sale and import to ensure safe and healthy food (Food Safety and Standards Act, 2006). However, several shortcomings in FSSAI functioning are also reported (Siruguri & Bhat, 2018). Food safety, security and nutrition (FSN) are closely linked, with unsafe food creating a vicious circle of diseases and malnutrition, affecting the more vulnerable groups (WHO, 2015). Nutritional and food safety objectives generally contradict, as the most nutritious foods are usually the riskiest ones (FAO, 2016).

Economic growth, improved literacy rates, rising incomes, urbanization and liberalization have influenced Indians' dietary pattern and have made them more aware of food safety. Food safety is determined by—how food is produced, delivered and also by how consumers procure, handle, cook, store and consume food. Access to safe water, toilets and washing hands with soap is required for proper utilization of the consumed food.

Food contaminations also affect the export of fresh and processed food commodities. In January 2020, the USA rejected 112 consignments of food and beverages from India. Major Indian products rejected by USFDA include spices, shrimps and prawns, vitamins and proteins, honey, sweets, biscuits and flavoured snacks (USFDA Rejection Data). In 2009–10 European Union (EU) rejected around 1200 of total 3400 Indian containers of grape consignments, citing the presence of pesticide residue on the fruit. The EU banned the import of Indian mangoes in 2014 because they were infected with pests that could harm indigenous crops, which was lifted in 2015. EU has also banned eggplant, bitter gourd and snake gourd after consignments of these items were found infested with fruit flies. The Indian basmati rice was also subjected to import restrictions because London's Pesticide Safety Directorate stated that it contained a high level of fumigants.

Spain, Italy and Germany detained the import of Indian spices owing to the presence of aflatoxin and pesticide residue. Aflatoxins are produced by fungi that infect crops and are highly toxic and cancer-causing. Indian marine products were also banned by the EU because antibiotic residues were more than the prescribed level. Likewise, shrimp import by Japan was restricted on the ground of non-freshness, foreign bodies and unhygienic practices.

Kohli and Garg (2015) reported that the FBD are infrequent and often not reported in India and referred to a study conducted in 2006 that showed only 13.2% of households reported FBD. The FBD outbreaks, together with acute diarrhoeal diseases and measles, constitute a majority of all reported outbreaks of diseases in India (GoI, 2020). To increase the productivity, farmers use a range of fertilizers and pesticides. These agrochemicals are often found in trace quantities in the final product and enter the food chain adversely affecting human health. Similarly, in animal farming, veterinary drugs/antibiotics are commonly used, and which, by entering the food chain, become injurious to human health. It is estimated that FBD costs stood at around 0.5% of the country's GDP in 2011 (Kristkova et al., 2017); they projected that there would be a higher consumption of food, mainly fruits, vegetables and meat, between the period 2011 and 2030, resulting in a significant increase of FBD cases to 150–177 million in 2030 compared to 100 million in 2011.

Most cases of FBD illnesses are preventable by following food protection principles. WHO promotes five keys to food safety measures viz., keep clean; separate raw and cooked; cook thoroughly; keep food at safe temperatures; use safe water and raw materials. There is a need to have food safety literacy at the household level, especially for the women, as they are generally custodians of food preparation and handling. In India, diverse food habits, cultural practices and the changes brought in by globalization and scarcity of resources, especially clean water, money, appliances, etc., at the household level, make food safety promotion a difficult task (Subbarao, 2019). According to the World Water State in 2018, around 19.33% of the population do not have access to clean water in India, which has implications for food safety.

Clean water, sanitation and hygiene (WASH) are essential for reducing malnutrition and mortality rates (Headey & Palloni, 2019). The inadequate WASH leads to diarrhoea, undernutrition, helminthiases and vector-borne diseases. Interventions to address water and sanitation simultaneously have positively affected child health (Checkley et al., 2004; Duflo et al., 2015; WHO, 2008). Spears (2013) studied India's Total Sanitation Campaign and reported a decrease in infant mortality by 4 per 1000 and an increase in children's height by 0.2 standard deviations at the mean programme intensity. The NFHS-4 (2017) reports that handwashing places with soap and water availability are present in 78.4% of households. Around 3.31% of households have handwashing places with no water or soap arrangements in India's urban areas, and it is even worse in rural areas. Under such circumstances, food safety issues at the household level become crucial for good health, and require interventions focusing on improved practices at the point of consumption.

Proper cooking is needed, as inadequate cooking or not thoroughly reheating leads to food safety risks. But in situations where cooking fuel is difficult to get or inconvenient to use, households may try to save energy, effort, or time and may not thoroughly reheat before consumption. Therefore, WASH (water, sanitation and hygiene) and access to clean and convenient cooking fuel are necessary for food safety. However, as mentioned earlier, the recent fact sheets of NFHS-5 for 22 States and UTs showed, that despite improvements in WASH and access to clean fuels for cooking, children and women's nutritional status has worsened in most of the states. There is a need to explore further the factors behind the worsening of the nutritional status.

6 Sustainability in Consumption

Presently, India is self-sufficient in addressing calorie intake requirements by producing staple crops (rice and wheat). Based on the review of 11 studies projecting the consumption of foods in India up to 2050, Alae-Carew et al. (2019) reported an increase in per capita consumption of meat, vegetables, fruits and dairy products and consumption of cereals and pulses to remain constant. Kumar et al. (2016) projecting the demand for 2030 reveals that demand for all the cereals is likely to be met with domestic production in India. However, pulses, edible oils, sugar, vegetables and fruits would be short in supply (Annexure 1). Though the production of fruits and vegetables is sufficient to meet the demand, supply reduces due to very high post-harvest losses. Therefore, the issue is to target hidden hunger by using micronutrient-rich products for food and nutrition security and sustainable food systems.

India's dietary patterns are changing, and this trend is likely to continue (Alae-Carew et al. 2019). These changes in dietary habits, together with a growing population, will have consequences on food systems. They might have potential implications for environmental sustainability through GHG emissions, ground- and surface- water depletion, soil pollution, etc. (Foley et al., 2005) and subsequently, lead to unsustainable agricultural production. Green et al. (2018) quantified GHG emissions, associated with five distinct dietary patterns, based on the life cycle assessment approach. The results showed substantial variability in the environmental impact between diets. The rice-based dietary patterns had higher associated GHG emissions and green water (precipitation) footprints (WFs), but wheat-based diets had lower GHG and higher blue (irrigation) WFs. The rice and meat patterns had the highest environmental impacts. Thus, the increased consumption of animal-sourced foods would significantly increase GHG emissions from Indian agriculture; this is a fact, which has to be kept in mind while adopting animal diet.

Aleksandrowicz et al. (2019) using NSSO 2011–12 data calculated the potential changes in GHG emissions, blue and green WFs and land use (LU) that would result from shifting current national food consumption patterns in India to healthy diets that meet dietary guidelines (RDA) and also moving to diets currently consumed by the wealthiest quartile of the population. They modelled the changes in consumption of 34 food groups necessary to meet Indian dietary guidelines. The analysis showed that shifting to healthy guidelines at the national level will require increased dietary energy by 3%, fruit intake by 18% and vegetable intake by 72% in the year 2011–12. Meeting healthy guidelines would slightly increase environmental footprints (3–5%). However, shifting to healthy diets among those with dietary energy intake below RDA would increase 28% in GHG emissions, 18 and 34% in blue and green WFs, respectively, and 41% in LU. Decreased environmental impacts were shown for those who currently consume above RDA energy (−6 to −16% across footprints).

Thus, in India widespread adoption of healthy diets may lead to small increases in the environmental impact relative to the current status. For attaining healthy diets and the sustainability of the food production system, it is required to improve resource use efficiency in food production and reduce postharvest losses.

6.1 Reducing Postharvest Losses

Postharvest losses (PHL) add to food insecurity, wastage of natural resources and wastage of labour and energy used to produce the food (UNEP 2016). A reduction in food waste will affect the total demand for food production while simultaneously reducing pressure on natural resources and the environment (FAO, 2019). In India, PHL are as high as around 40% in fruits and vegetables produced every year (NAAS, 2019). The Ministry of Food Processing Industries estimated losses of 23 million tonnes of grains, 12 million tonnes of fruits and 21 million tonnes of vegetables for a total approximate value of 4.4 billion USD in 2018–19. This is happening due to absence of rural infrastructure for food processing. According to Fan et al. (2008), rural infrastructure is one of the three most effective public-spending items for promoting agricultural growth and reducing poverty. Therefore, proper transportation and storage facilities are must for reducing PHL.

Food processing and packaging can preserve the available nutrients and even enhance the shelf life and nutrient content of foods. Thus, proper processing and packaging can help make nutritious foods to reach those vulnerable groups who cannot access or afford fresh products. If unhealthy ingredients are present in the food, product reformulation can be carried out, e.g. reducing sodium and trans-fats (HLPE, 2017).

There is also a need to regulate and monitor food processing by setting standards and labelling processed food products. Enforcement of standards is required to ensure food safety and reduce FBD. Thus, it is necessary to make the functioning of FSSAI more effective by removing the shortcomings (Siruguri & Bhat, 2018).

7 Fortification and Bio-fortification

Dietary diversity can help tackle malnutrition, but implementing it may not always be feasible among poor households. The diet that meets all the recommended nutrient requirements in vulnerable populations of Uttar Pradesh was over twice more expensive than the diet that meets only the calorie requirements. A nutritious diet was unaffordable by 75% of the households in 2018 (Kachwaha et al., 2019). Agricultural research has focused on increasing the production and productivity of calorie-dense staple crops. The prices of nutrient-dense non-staple foods have increased because of high demand and relatively low supply (Bouis & Saltzman, 2017). The effectiveness of dietary diversity may also be impacted by seasonality of crops and low bioavailability of specific micronutrients. Nutrient deficiency in food can be tackled either by providing supplements or by food fortification such as iron and folate-fortified flour, iodized salts, etc. There was an increased focus on food fortification in the Union Budget 2019–20. However, these approaches may not be sustainable because they rely on a robust distribution, good infrastructure and consumer compliance (Yadava et al., 2018). Generally, fortification is done with synthetic minerals, which are lower in bio-availability than bio-fortification (Mitra-Ganguli et al., 2019). Therefore, bio-fortification may be one of the more cost-effective solutions to provide the desired levels of nutrients, e.g. rice bio-fortified with zinc, iron-rich pearl millet, etc. (Pfeiffer & McClafferty, 2007).

Studies demonstrated the positive effects of bio-fortified crops on human health. Meenakshi et al. (2010) reported that the bio-fortification of staples may be more cost-effective in reducing the burden of diseases than fortification and supplementation. Stein et al. (2007) estimated that zinc bio-fortification of rice and wheat might reduce loss of Disability Adjusted Life Years (DALYs) burden by 20–51% and save 0.6–1.4 million DALYs each year. Scott et al. (2018) showed that consumption of bio-fortified pearl millet twice daily for six months by 12–16-year-olds from economically-disadvantaged classes had significantly improved their cognitive skills in Maharashtra, India.

Distribution of bio-fortified cereals through PDS will ensure its reach to nutrition-deficient groups at a subsidized price. The incorporation of bio-fortified staples in welfare schemes, such as ICDS and MDMS, might reduce children's malnutrition levels. There is a need to intensify efforts by public sector institutions for the adoption and acceptance of bio-fortified crops. To popularize the bio-fortified varieties, the seeds' genetic purity and vigour need to be retained (Yadava et al., 2018). Farmers should be encouraged and given incentives to grow bio-fortified crops with assured markets and minimum support prices for bio-fortified crops. Effective extension services are needed to increase the awareness of the production and consumption of bio-fortified crops.

For the successful adoption of bio-fortified crops by the consumer, food industry participation is also vital to bring bio-fortified crops into the food system for Indian consumers. The food industry can participate via food product development and innovations that fit into the consumers' growing demand due to increasing concerns for plant-based protein, reduced food additives, lower genetically modified ingredients and more natural foods (Walton, 2019).

For this purpose, the identification of sustainable routes to market is required (Mitra-Ganguly et al., 2019). A HarvestPlus workshop to discuss ways to increase the scale, reach and impact of bio-fortified foods in India highlighted a significant demand from the food industry but lack of awareness is a major barrier (Mitra-Ganguly et al., 2019).

8 Pathways for Safe and Healthy Diets for Nutritional Security

The pathways for safe and healthy diets that ensure nutritional security require meeting food demand for 18.1% of the world population whose share in total global DALYs attributable to the child and maternal malnutrition was 25.4% in 2017 (Lancet, 2020). India's population is projected to reach 1.5 billion by 2030, peaking at 1.6 billion by 2048 (Lancet, 2020). This will require sustainable food systems that cater to nutritional requirements by increasing the production efficiency of agricultural systems that is faced with small landholdings, fragmentation of farmland, climate change impacts and degradation of natural resources. However, for making meaningful suggestions it is necessary to have recent and integrated data on food consumption patterns and agricultural production systems.

The pathways for safe and healthy diets for nutritional security in India consist of: (a) improving dietary diversity, (b) reducing postharvest losses, (c) bio-fortification of staples, (d) empowerment of women, (e) enforcing standards of foods safety, packaging and labelling, (f) improving WASH, (g) food safety awareness and nutrition education, (h) implementation of food safety and nutrition programmes and (i) use of ICT.

8.1 Improving Dietary Diversity

Availability and access to adequate amounts of diverse food groups are required to address undernutrition and micronutrient deficiency. The household dietary diversity can be improved by increasing crop diversity and having access to kitchen gardens, including diverse food groups in the safety net programmes such as PDS, MDMS and THR (take-home ration).

The Government of India has programmes for diversifying the cropping system such as Crop Diversification Programme (CDP), National Horticulture Mission, National Food Security Mission - Pulses. There is a need to improve the coverage of these programmes and increase the production of fruits and vegetables rich in micronutrients. It is required to integrate these programmes with resource conservation technologies like micro-irrigation, precision agriculture, postharvest management infrastructure and marketing infrastructure (Manjunatha et al., 2017).

The studies showed that home production of diverse food increases affordability and accessibility of nutritious diet. Improving access to kitchen garden (own or community) results in a strong association with household dietary diversity and child nutrition (Dev et al., 2020). The local food and nutrition security can check the adverse effects of food supply shocks and food price volatility (Galhena et al., 2013), which can immediately impact children's nutritional status and persist in their adult lives (Hoddinott et al., 2013). Many such non-government and government initiatives of kitchen gardens have helped people accessing nutritious foods. Few such initiatives are discussed here.

An initiative 'Gardens of Hope—Emergency Kitchen Gardens' by Utthan, a Gujarat based NGO, helps vulnerable rural communities in four districts of Gujarat to grow their own chemical-free vegetables at home. Despite the financial crunch during the COVID-19 induced lockdown and the consequent livelihood crisis, the beneficiaries' nutritional needs were met. There is a unique sharing mechanism under which each family growing vegetables share the produce with three other families who do not have land, water resources, or currently not growing vegetables. It has been estimated that each person will get nutritional security of around 700 g/day from these kitchen gardens (Karelia, 2020).

A community-based malnutrition management programme by Vikas Samvad, a non-profit organization, in Madhya Pradesh, developed kitchen gardens in the backyards of 232 families across six districts. This initiative gave people self-sustenance and helped them during the COVID-19 lockdown when the anganwadis were closed. Under this initiative, a network was created through which around 37 quintals of vegetables grown were shared among 425 families. The beneficiaries included 217 malnourished children, 140 pregnant and lactating mothers and 68 elderly persons (Sushma, 2020).

The School Nutrition (Kitchen) Garden (SNG) scheme of Government of India aims to address the malnutrition and micronutrient deficiencies and enhance the knowledge of children for nutritional traits of vegetables. It has been reported that after the introduction of SNG, consumption of fresh vegetables in the daily diet among the children increased in fourteen selected schools of Raichur and Bagalkot districts of Karnataka (Kammar et al., 2017). Many state governments have also taken the initiative to promote the kitchen gardens. Odisha Livelihood Mission, as part of the farm livelihood/promotion of Nutrition-sensitive Agriculture, is promoting kitchen gardens. The Karnataka Horticulture Department, with funds from MGNREGA is developing kitchen gardens called 'Akshara Kaitoota' in government schools. The vegetable gardens already exist in many schools to promote the consumption of vegetables and fruits. In Chhattisgarh, kitchen gardens are encouraged to secure livelihood for rural households by converging MGNREGA with the Panchayat and Rural development departments. To create awareness of the significance of vegetables and fruits, Tamil Nadu Horticulture Department has tied up with the School Education Department to establish roof gardens. Maharashtra, in a joint initiative of Rajmata Jijau Nutrition Mission under the Department of Women and Child Development and Reliance Foundation, has developed kitchen gardens at anganwadi centres to grow fruits and vegetables (Suri, 2020).

Thus, households should be encouraged to have their own or community kitchen gardens with more diverse vegetables and fruits to take seasonality into account for a better dietary diversity. Perennial vegetables and fruits and wild edible vegetables and fruits depending on the agro-climatic conditions, should be encouraged. The role played by information and communication technologies (ICT) is very important in providing information regarding new crop varieties, seeds, fertilizers, weather, raising awareness about nutrition, etc.

8.2 Reducing Postharvest Losses

Another important pathway for ensuring food and nutrition security is to reduce PHL. India is the second-largest producer of food next to China. However, in India, only 2.2% of the farm produce is processed against around 23% in China. A high level of PHL in India is unacceptable when a large section of the population is undernourished. These high levels of losses are mostly due to improper handling, inadequate transportation and packaging, low storage and poor postharvest management.

Boss and Pradhan (2020) reported that use of postharvest technologies like storage bags and drums and the application of postharvest loss management practices have positive outcomes on farmers' price realization. New and innovative methods are required to reduce the PHL. At Tamil Nadu Agricultural University, researchers developed a method to control losses in package houses, transportation and retail shops by spraying Enhanced Freshness Formulation (EFF) on trees before the harvest. The method slows down ripening and controls losses at the farm level (ToI, 2018). Such technologies should be encouraged after assessment of environmental and health impacts.

Strong farm-firm linkages might also reduce PHL by providing assured markets. These institutional services and reducing PHL can also help smallholders raise their farm productivity and income and mitigate the risks involved in participating in the markets for high-value crops, livestock and fishery products. However, achieving these goals will require new institutions and innovations to develop supply chains and facilitate linkages between farmers, wholesalers, processors and retailers. These institutions and innovations may include various contract farming models, including those by farmer groups and private-sector resource intermediation (Gulati et al., 2008).

Thus, a holistic approach engaging proper postharvest storage and management technologies, institutions for efficient marketing of the products and food processing and packaging technologies is required to reach end consumer with its original nutritional value, intact or enhanced.

8.3 Bio-fortification of Staples and Improving Awareness

Bio-fortification may be one of the more cost-effective solutions to provide the desired levels of nutrients. Indian diets are shifting towards high-value foods, therefore, require more emphasis to bio-fortifying vegetables and fruits along with staples in India. The initiative of distributing bio-fortified staples through PDS will help in reducing hidden hunger. There is a need to develop the supply chain for bio-fortified crops. ICT initiatives of both public and private sectors can improve awareness among the farmers to adopt bio-fortified crops and among consumers for safe and natural nutrient-rich primary and processed produce. The involvement of food business firms is required along the supply chain for broader adoption by the consumers. However, food businesses require guidance for food product development and marketing of bio-fortified food products (Walton, 2019).

8.4 Empowerment of Women

Empowering women positively impacts dietary diversity (Dev et al., 2017; Malapit et al., 2015; Pandey et al., 2016). As discussed in Sect. 2.5, mother's education has a significant role in improving children's dietary diversity and nutritional status. Hence, there is a need for targeted policies to increase women's education and empower them for a healthy diet.

According to NSSO, India's female literacy rate was 70.3% in 2017–18, which has improved from 65.5% in 2011 (Census 2011). GoI has taken many initiatives to empower women. The Right to Education Act (RTE) came into force in 2010 for free and compulsory education for children between 6 and 14. The central government introduced the Beti Bachao Beti Padhao (BBBP) campaign (translates to 'save the girl child, educate the girl child') in 2015 to address the declining sex ratio and improve girls' education level. The Samagra Shiksha scheme was launched in 2018–19 to make good quality education accessible and affordable to all. This scheme subsumes the three Schemes of Sarva Shiksha Abhiyan, Rashtriya Madhyamik Shiksha Abhiyan and Teacher Education. To empower the adolescent 'SABLA' scheme was launched in 2010 to improve their nutritional and health status and promote awareness about health, hygiene and nutrition.

The role of women in Indian agriculture is increasing. Nearly 77% of the total rural women workforce is employed in this sector (Labour Bureau, 2014). However, around 83% of agricultural land in India is inherited by male members of the family (Mehta, 2018). Land ownership rights to women is critical for their empowerment. Conditions under which women are engaged (for example, prolonged exposure to fertilizers, pesticides, long working hours) and the support systems to strengthen women's capacity to care for themselves and their children are of utmost importance. Easy access to maternity entitlements (JSY, THR), optimum quality day-care facilities for children within the community and at the place of work are vital to strengthen caring capacity and translate to higher incomes.

A greater emphasis on women's collectives[11] based on primary surveys, Agarwal (2018) examined the impact of group farming by women on productivity and profitability in Kerala and Telangana. The farms of women's groups under Kudumbashree (also called joint liability groups) in Kerala performed much better than the predominantly male-managed individual farms in their annual value of output per hectare and annual net returns per farm. In the case of Telangana (Samatha Dharani Groups) and Kerala group farms perform much better in commercial crops than in traditional food grains (Agarwal, 2018). The study demonstrated that group farming can provide an effective alternative, subject to specified conditions and adjustment of the model to the local context.

8.5 Enforcing Standards of Foods Safety, Packaging and Labelling

Food safety has become a serious issue with its public health implications. FSSAI is revising Food Safety and Standards (Packaging and Labelling) Regulations 2011, with having three different regulations dealing with packaging, labelling and advertisement and claims requirements.

Food processing and packaging can preserve the available nutrients and even enhance the shelf life and nutrient content of foods. Thus, proper processing and packaging can help make nutritious foods to reach those vulnerable groups who cannot access or afford fresh products. The micronutrients can be added to less nutrient-dense foods by food fortification during food processing. However, fortifications have some limitations, as discussed in Sect. 7. Product reformulation can be carried out, e.g. reducing sodium and trans-fats, for taking care of unhealthy ingredients present in the food (HLPE, 2017).

There is also a need to regulate and monitor the labelling of processed food products. The processed foods can contain high amounts of certain ingredients that are not healthy, such as "hidden" salt, which consumers may not be aware of and maybe desensitize to those amounts (HLPE, 2017). The evidence shows that food label information of quality and nutrition, production and storage process, influences informed decision-making by the consumers (Ali & Kapoor, 2009). A study in the village of South Delhi by Bhilwar et al. (2018) reported that about 64.1% of the consumers read food labels. Still, a majority of them (86%) only check for the manufacture and expiry dates. Generating awareness would be required to improve this behaviour. The factors that influence reading labels are associated with the study participants' educational status, socioeconomic status and body mass index (Bhilwar

[11] Has shown positive results. The NGO Deccan Development Society (DDS), for example, enables women from landless families to access various government programmes to establish land claims, through purchase and lease.

et al., 2018). Therefore, in the areas with lower education levels, regulatory policies need to be followed strongly for promoting and marketing healthy foods.

FSSAI is overhauling the labelling regulations for packaged food products. The draft regulations propose colour-coded front-of-pack nutrition labelling to enable consumers to identify high fat, salt and sugar products. Accordingly, the product will have a red colour if the total amounts of calories, fats, trans fats, sugar and sodium per serving exceed the recommendations. However, there are some concerns from people and food industries related to the proposed labelling regulation, such as it is intended for individuals who are literate and nutritionally aware, the colour red is a danger sign and might deter consumers from the products, etc. (Pande et al., 2020).

A food traceability system is an essential tool for managing food quality and safety risks and developing effective supply chain management. The traceability techniques used in India are radio-frequency identification (RFID) tags to track inventories, Holograms, Barcode, Nuclear techniques and other tracking media to monitor the production process. Dandage et al. (2017) have reported that the development of an effective food traceability system is adversely affected by factors like restrictive government marketing standardization and unstable actions for food safety. Inefficient infrastructure in the market area and inadequate agricultural practices with many small and medium players further make the system difficult to work.

Indian food regulation lays more emphasis on food adulteration due to it being an important issue. However, there is a need to focus on other food safety issues, together with food adulteration. Sudershan et al. (2008) reported about limited knowledge of basic food microbiology of the food regulators in South India. These regulators were not equipped to check newer adulterations. Therefore, to improve the effectiveness of FSSAI in ensuring the availability of safe and nutritious food, along with enforcing its standards and regulations there is need to increase and upgrade technical manpower, strengthen food safety infrastructure and surveillance system (Parliamentary Standing Committee, 2018).

8.6 Improving WASH

Access to adequate WASH and clean cooking fuel is crucial for nutritional security, as discussed in Sect. 5. GoI has taken many initiatives towards improving WASH, such as Jal Jeevan Mission (JJM) and Swachh Bharat Mission (SBM) (Clean India Mission). JJM aims to provide Functional Household Tap Connection to every rural household by 2024. Under SBM, around 10.28 crore of toilets were built, and the coverage of rural sanitation increased from 34% in 2014 to 100% in 2019. The usage of these toilets is reported to be around 95% (GoI, 2019). SBM is now moving towards Phase II of SBM-Grameen to ensure that the open defecation free behaviours are sustained, no one is left behind, and that solid and liquid waste management facilities are accessible. These programmes will help in reducing FBD.

8.7 Implementation of Programmes

Pathways for a sustainable diet that is safe and healthy need sustainable food systems and require better implementation and synergy between different policies and programmes. To achieve SDG 2 of reducing hunger and malnutrition by 2030, effective implementation of programmes can contribute significantly in attaining the targets. The MGNREGA positively impacted child and woman well-being. It positively impacted household income, empowerment and well-being of women and improved children's nutrition and health and education and reduced child labour. Apart from its direct benefits, it has secondary benefits such as creating assets for agriculture and rural development, more women's participation, helping marginalized sections like SCs and STs reducing distress migration and involvement of panchayats, etc.

The Public Distribution System (PDS) is a critical instrument towards improving food security at the household level in India. The impact of ICDS on child nutrition and protecting children's rights is quite limited. There is a need to increase its coverage to ensure rapid universalization, change the design and restructure it with higher allocations of funds and effective implementation. The ICDS programme must effectively integrate the various elements that affect nutrition and reflect children's different needs in different age groups. The midday meal has helped reduce serious malnutrition, and for older children (aged 11–12), there is evidence of significant positive impacts on children's learning. Supplemental income can be started with old age populations by enhancing the amount of old-age pensions scheme and making it nearly universal.

8.8 Nutrition Education and Food Safety Awareness

Education, especially for women, is found associated with a reduction in the mortality rate, dietary diversity and improved nutrition (Alderman & Headey, 2017; Gillespie & Haddad, 2003; Gulati et al., 2012; Spears, 2013). There is a need to make nutrition education and nutrition information part of the education system and be integrated with other community programmes for behavioural change and to improve the intake of nutritious food in a safe and hygienic manner. Banerji et al. (2016) reported that when nutrition information is provided, consumer acceptance and willingness to pay increases for healthy food.

8.9 Use of ICT

ICT can play a vital role in providing useful information such as nutrition-sensitive messages, healthy meal menus, recipes, etc. and educating people about lifestyle recommendations. ICT can also be used for real-time monitoring, data management and convergence of schemes. Radio broadcasting can be a medium for comprehensive coverage in a less expensive manner related to food safety measures, labelling, etc (Bilali & Allahyari, 2018). Penetration of mobile phones has rapidly increased in India. It can be used to disseminate different information related to food safety, food handling, processing, etc. The information can be sent in the local language and can also engage symbols and digital pictures, as smartphone users have increased.

Thus, for achieving food and nutrition security, sustainable food systems are required through multi-pronged strategies with better targeting and coordination between different policies and programmes. However, it is necessary to have recent data on food consumption for making meaningful suggestions. In India, these strategies need to focus on improving dietary diversity, kitchen gardens, reducing postharvest losses, bio-fortification of staples with their inclusion in safety net programmes, women's empowerment, enforcement of standards and regulations, improving WASH, nutrition education and behavioural change and effective use of digital technology in more innovative ways in food systems. The recent fact sheets of NFHF-5 indicated that besides WASH, women's empowerment and education status, other factors like household income, personal hygiene, health information and nutrition knowledge might be critical for sustainability in improving nutritional outcomes. In the future, food and nutrition security initiatives will have to be tuned in keeping with changing demographic structure, livelihood patterns, climate change and health-specific needs. These also have to be linked with the overall development activities of the country.

Acknowledgements The authors thank the reviewers for useful comments on an earlier draft.

Annexure

Demand–supply projections and gaps (Million tonnes).

Commodities	Year	Supply projection	Demand projection	Demand-supply gap
Rice	2020	108.1	111.8	− 3.7
	2030	122.1	122.4	− 0.3
Wheat	2010	104.2	98.3	5.9
	2030	128.8	114.6	14.2
Coarse cereals	2020	50.4	42.5	7.9
	2030	64.2	47.2	17.0
Total cereals	2020	262.6	252.6	10.0
	2030	315.1	284.2	30.9
Pulses	2020	20.7	21.9	− 1.3

(continued)

(continued)

Commodities	Year	Supply projection	Demand projection	Demand-supply gap
	2030	26.4	26.6	− 0.2
Food grains	2020	281.2	274.4	6.8
	2030	338.8	310.8	28.0
Edible oils	2020	12.5	17.0	− 4.5
	2030	19.1	21.3	− 2.1
Sugar	2020	33.4	33.1	0.3
	2030	40.3	39.2	1.1
Vegetables	2020	186.4	155	− 13.1 (Post harvest losses (PHL) 23.99%)
	2030	210	192	− 32.0
Fruits	2020	97.7	81	− 2.7 (PHL 20%)
	2030	116.4	103	− 9.9
Milk	2020	156.6	138	10.4 (PHL 5.03%)
	2030	188.7	170	8.8
Eggs	2020	4.7	4.4	0.1 (PHL 5.02%)
	2030	6.2	5.8	0.1

Source Kumar et al. (2016)

References

Agarwal, B. (2018). Can group farms outperform individual family farms? Empirical insights from India. *World Development, 108*, 57–73.

Ahmed, A., Hoddinott, J., & Roy, S. (2019). Food transfers, cash transfers, behavior change communication and child nutrition evidence from Bangladesh. IFPRI Discussion paper no. 01868, Washington DC.

Alae-Carew, C., Bird Frances, A., Chudhury, S., Harris, F., et al. (2019). Future diets in India: A systematic review of food consumption projection studies. *Global Food Security, 23*, 182–190.

Aleksandrowicz, L., Green, R., Joy, E. J. M., Harris, F., Hiller, J., Vetter, S. H., Smith, P., et al. (2019). Environmental impacts of dietary shifts in India: A modelling study using nationally-representative data. *Environment International, 126*, 207–215.

Alderman, H., Headey, D. D. (2017). How important is parental education for child nutrition? *World Development, 94*, 448–464. Available at https://doi.org/10.1016/j.worlddev.2017.02.007 (accessed on November 28, 2020).

Ali, J., & Kapoor, S. (2009). Understanding consumers' perspectives on food labelling in India. *International Journal of Consumer Studies, 33*, 724–734.

Banerji, A., Birol, E., Karandikar, B., & Rampal, J. (2016). Information, branding, certification, and consumer willingness to pay for high-iron pearl millet: Evidence from experimental auctions in Maharashtra, India. *Food Policy, 62*, 133–141.

Bhilwar, M., Tiwari, P., Saha, S. K., Sharma, P., & Parija, P. P. (2018). Use of information on pre-packaged foods among residents of an urban village of South Delhi, India. *The National Medical Journal of India, 31*, 211–214.

Bilali, H. E., & Allahyari, M. S. (2018). Transition towards sustainability in agriculture and food systems: Role of information and communication technologies. *Information Processing in Agriculture, 5*, 456–464.

Black, M. M., & Dewey, K. G. (2014). Promoting equity through integrated early child development and nutrition interventions. *Annals of the New York Academy of Sciences, 1308*(1), 1–10.

Boss, R., & Pradhan, M. (2020). Post-harvest management and farm outcomes. *Economic and Political Weekly, 55*(16).

Bouis, H. E., & Saltzman, A. (2017). Improving nutrition through biofortification: A review of evidence from HarvestPlus, 2003 through 2016. *Global Food Security, 12*, March, 49–58.

Checkley, W., Gilman, R. H., Black, R. E., Epstein, L. D., Cabrera, L., Sterling, C. R., & Moulton, L. H. (2004). Effect of water and sanitation on childhood health in a poor Peruvian peri-urban community. *Lancet, 363*(9403), 112–118 Available at https://pubmed.ncbi.nlm.nih.gov/14726164/ (accessed December 2, 2020)

Chudasama, R. K., Patel, U. V., Kadri, A. M., Mitra, A., Thakkar, D., & Oza, J. (2016). Evaluation of integrated Child Development Services program in Gujarat, India for the years 2012 to 2015. *Indian Journal of Public Health, 60*, 124–130.

Dandage, K., Badia-Melis, R., & Ruiz-García, L. (2017). Indian perspective in food traceability: A review. *Food Control, 71*, 217–227.

Datt, G., Ravallion, M., & Murgai, R. (2016). *Growth, urbanization and poverty reduction in India.* NBER working paper No. 21983, USA.

Deaton, A., & Dreze, J. (2009). Food and nutrition in India: Facts and interpretations. *Economic and Political Weekly, 47*(7), 42–65, https://doi.org/10.2307/40278509

Dev, S. M. (1995). India's (Maharashtra) employment guarantee scheme: Lessons from long experience. In J. von Braun (Ed.), *Employment for poverty reduction and food security*, pp. 108–143.

Dev, S. M. (2011). "*NREGS and Child Well Being*", Working Paper No. 4, Indira Gandhi Institute of Development Research, Mumbai.

Dev, S. M., Pandey, V. L., & Suganthi, D. (2017). Women's empowerment in agriculture: Implications on Nutrition in India. In S. M. Dev (Ed.), *India development report*. Oxford University Press (Ch 6).

Dev, S. M., Suganthi, D., & Pandey, V. L. (2020). Agricultural diversity and child diet diversity in the rural areas of Bihar and Odisha. In S. M. Dev (Ed.), *India development report*. Oxford University Press (in press).

Devereux, S. (2006, May). Looking at social protection through a livelihood Lens. IDS IN FOCUS, Issue 01 Social Protection.

Drewnowski, A., & Popkin, B. M. (1997). The nutrition transition: New trends in the global diet. *Nutrition Reviews, 55*, 31–43.

Dreze, J. (2006). Universalisation with quality: ICDS in a rights perspective. *Economic and Political Weekly, 41*(34).

Dreze, J., & Khera, R. (2009). The battle for employment guarantee. *Frontline, 26*(1), Jan 3–16.

Duflo, E., Greenstone, M., Guiteras, R., & Clasen, T. (2015). *Toilets can work: Short and medium run health impacts of addressing complementarities and externalities in water and sanitation.* National Bureau of Economics, Working Paper No. 21521. Available at https://www.nber.org/papers/w21521 (accessed on November 12, 2020).

Fan, S., Gulati, A., & Thorat, S. (2008). Investment, subsidies, and pro-poor growth in rural India. *Agricultural Economics, 39*, 163–170.

FAO. (2016). *Influencing food environments for healthy diets.* Food and Agriculture Organisation of the United Nations, Rome.

FAO. (2019). *The state of food and agriculture: In brief*. Food and Agriculture Organization of the United Nations, Rome.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., & Carpenter, S. R. et al. (2005). Global consequences of land use. *Science, 309* (5734), 570–574. https://doi.org/10.1126/science.1111772.

Galhena, D. H., Freed, R., & Maredia , K. M. (2013). Home gardens: A promising approach to enhance household food security and wellbeing. *Agriculture and Food Security, 2*, 1–13.
George, N., & McKay, F. (2019). The public distribution system and food security in India. *International Journal of Environmental Research and Public Health, 16*, 3221.
Gillespie, S., & Haddad, L. (2003). *The double burden of malnutrition in Asia: Causes, consequences and solutions*. International Food Policy Research Institute.
GoI. (2008). "*Draft 11th five year plan*". Planning Commission, Government of India.
GoI. (2013). *Press note on poverty estimates, 2011–12*. Planning Commission, Government of India.
GoI. (2014). *Expert group on poverty measurement*. Planning Commission, Government of India.
GoI. (2019). Food and nutrition security analysis, India (2019) Ministry of Statistics and Programme Implementation and The World Food Programme, Government of India.
GoI. (2020). Agricultural statistics at glance 2019. Ministry of Agriculture and Farmers Welfare, Department of Agriculture, Cooperation and Farmers Welfare Directorate of Economics and Statistics, Government of India, p. 165.
Green, R. F., Joy, E. J. M., Harris, F., Agrawal, S., Alksandrowicz, L., Hillier, J., Macdiarmid, J. I., Milner, J., Vetter, S. H., Haines, A., Smith, P., & Dangour, A. D. (2018). Greenhouse gas emissions and water footprints of typical dietary patterns in India. *Science of the Total Environment, 643*, 1411–1418.
Gulati, A., Joshi, P. K., & Landes, M. (2008). *Contract farming in India: An introduction International Food Policy Research Institute*. National Centre for Agricultural Economics and Policy Research and Economic Research Service, US Department of Agriculture.
Gulati, A., Ganesh-Kumar, A., Shreedhar, G., & Nandakumar, T. (2012). Agriculture and malnutrition in India. *Food and Nutrition Bulletin, 33*(1), 74–86.
Headey, D., & Palloni, G. (2019). Water, sanitation, and child health: Evidence from sub-national panel data in 59 Countries. *Demography* (56), 729–752. Available at https://doi.org/10.1007/s13524-019-00760-y (accessed June 14, 2020).
Himanshu, & Sen, A. (2013). In-kind transfers: Impact on poverty. *Economic and Political Weekly, 48*(45–46).
HLPE. (2014). *Food losses and waste in the context of sustainable food systems A report by the high level panel of experts on food security and nutrition of the committee on world food security Rome*. http://www.fao.org/3/a-i3901epdf
HLPE. (2017). Nutrition and food systems. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome.
Hoddinott, J., Rosegrant, M., & Torero, M. (2013). Investments to reduce hunger and undernutrition In: B. Lomborg (Ed.), *Copenhagen consensus, 2012*. Cambridge University Press.
Jain, M. (2015). India's struggle against malnutrition—Is the ICDS program the answer? *World Development, 67*, 72–89.
Jha, R., Bhattacharyya, B., & Gaiha, R. (2011). Social safety nets and nutrient deprivation: An analysis of the National Rural Employment Guarantee Program and the Public Distribution System in India, *Journal of Asian Economics, 22*, 189–201.
Jose, S., Gulati, A., & Khurana, K. (2020). *Achieving nutritional security in India: Vision 2030*. NABARD research study-9, NABARD and ICRIER, New Delhi.
Kachwaha, S., Nguyen, P. H., Defreese, M., Cyriac, S., Girard, A. W., Rasmi, A., & Menon, P. (2019). Assessing the economic feasibility of assuring nutritionally adequate diets for vulnerable populations in Uttar Pradesh, India: Key findings from 'cost of the diet' analysis (OR21-05-19). *Current Developments in Nutrition, 3*(Supplement 1), 749. https://doi.org/10.1093/cdn/nzz034.OR21-05-19
Kammar, M., Biradar, A. P., Angadi, S. C., & Vidyavathi, G. Y. (2017). Impact of school nutrition garden on the nutrient intake of children. *Asian Journal of Agricultural Extension, Economics & Sociology, 18*(2), 1–6.
Karelia, G. (2020). *Unique kitchen garden model helps 2000 families in rural Gujarat feed 7500 others the better India*. Available at https://www.thebetterindiacom/237638/gujarat-

lockdown-organic-kitchen-garden-coronavirus-natural-vegetables-save-money-families-share-india-gop94/ (Accessed on December 10, 2020).
Khera, R. (2008). Empowerment guarantee act. *Economic and Political Weekly, l43*(35), 8–10.
Kohli, C., & Garg, S. (2015). Food safety in India: An unfinished agenda. *MAMC Journal of Medical Sciences, 1*(3), 131–135.
Krishnamurthy, P., Pahania, V. S., & Tandon, S. (2014). *Food price subsidies and nutrition: Evidence from state reforms in India's public distribution system in India*. Public Law Research Paper.
Kristkova, Z. S., Grace, D., & Kuiper, K. (2017). The economics of food safety in India—A rapid assessment. Wageningen University & Research [Available at https://cgspace.cgiar.org/bitstream/handle/10568/89203/Economicspercent20foodpercent20safetypercent20Indiapdf (accessed on June 12, 2020)].
Kumar, P., Joshi, P. K., & Mittal, S. (2016). Demand versus supply of food in India—Futuristic projection. *Proceeding of the Indian National Science Academy, 82*(5), 1579–1586.
Labour Bureau. (2014). Statistical profile on women labour 2012–2013. Ministry of Labour and Employment, Government of India. Available at http://labourbureaunew.gov.in/UserContent/Statistical_Profile_2012_13.pdf.
Lancet. (2019). The burden of child and maternal malnutrition and trends in its indicators in the states of India: The global burden of disease study 1990–2017. *The Lancet Child & Adolescent Health, 3*(12), 855–870 (Available at https://doi.org/10.1016/S2352-4642(19)30273-1).
Lancet. (2020). Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017–2100: A forecasting analysis for the global burden of disease study (Available at https://doi.org/10.1016/S0140-6736(20)30677-2 [accessed on 27 July 27, 2020)].
Law, C., Fraser, I., & Piracha, M. (2019). Nutrition transition and changing food preferences in India. *Journal of Agricultural Economics, 71*(1).
Malapit, H. J. L., Kadiyala, S., Quisumbing, A. R., Cunningham, K., & Tyagi, P. (2015). Women's empowerment mitigates the negative effects of low production diversity on maternal and child nutrition in Nepal. *Journal of Development Studies, 51*, 1097–1123.
Manjunatha, A. V., Ramappa, K. B., Maruthi, I., & Kumar, P. (2017). *Impact evaluation of National Horticulture Mission (NHM) and Horticulture Mission for North East and Himalayan States (HMNEH)*. ADRT Centre, Institute for Social and Economic Change, Bengaluru, Karnataka.
Meenakshi, J. V., Johnson, N., Manyong, V. M., De Groote, H., Javelosa, J., Yanggen, D., Naher, F., Gonzalez, C., Garcia, J., & Meng, E. (2010). How cost-effective is biofortification in combating micronutrient malnutrition? An ex ante assessment. *World Development, 38*(1), 64–75.
Mehta, A. (2018). Gender gap in land ownership: Legislation and gender-based agri land allotment would help. *Business Standard*, April 17, 2018.
Ministry of Health and Family Welfare (MoHFW) 2019, Government of India, UNICEF and Population Council. (2019). *Comprehensive National Nutrition Survey (CNNS)*. National Report New Delhi.
Mitra-Ganguli, T., Boyd, K., Uchitelle-Pierce, B., & Walton, J. (2019). Proceedings of the workshop 'Biofortified food—Working together to get more nutritious food to the table in India'. *Journal of Nutrition & Intermediary Metabolism, 18*, 1–9 [Available at https://wwwsciencedirect.com/science/article/pii/S2352385919300180 (accessed on July 2, 2020)].
NAAS. (2019). Saving the harvest: Reducing the food loss and waste. *Policy Brief No. 5*, National Academy of Agricultural Sciences, New Delhi.
Narayanan, S. (2020). The continuing relevance of MGNREGA. *The India Forum*, April 3, 2020.
Narayanan, S., Ranaware, K., Das, U., & Kulkarni, A. (2014). *MGNREGA works and their impact: A rapid assessment in Maharashtra*, IGIDR working paper, 2014-042.
Narayanan, S., & Gerber, N. (2017). *Social safety nets for food and nutrition security in India Global Food Security* (Available online May 17, 2017. ISSN 2211-9124. https://doi.org/10.1016/j.gfs.2017.05.001)
NFHS-2. (2000). *National family health survey 1998–99 IIPS*. Mumbai.
NFHS-3. (2007). *National family health survey 2005–06 IIPS*. Mumbai.
NFHS-4. (2017). *National family health survey 2015–16 IIPS*. Mumbai.

NFHS-5. (2021). *National family health survey 2019–20 IIPS*. Mumbai.

NIN. (2011). *Dietary Guidelines for Indians-A manual*. National Institute of Nutrition, Government of India, Hyderabad. Available at https://www.nin.res.in/downloads/DietaryGuidelinesforNINwebsite.pdf (accessed 4 July, 2020).

NIN. (2017). *Nutrition Atlas*. National Institute of Nutrition, Government of India, Hyderabad.

NNMB (National Nutrition Monitoring Bureau). (2006). *Diet and nutritional status of population and prevalence of hypertension among adults in rural areas*. NNMB Technical Report No. 24. National Institute of Nutrition.

NNMB (National Nutrition Monitoring Bureau). (2012). *Diet and nutritional status of rural population, prevalence of hypertension and diabetes among adults and infants and young child feeding practices*. Report of Third Repeat Survey National Institute of Nutrition, Hyderabad. (Available at http://nnmbindia.org/1_NNMB_Third_Repeat_Rural_Survey___Technicl_Report_26.pdf. Accessed May 24, 2020).

NSSO. (1996). *Nutritional intake in India 1993–94*. NSS report No. 405 National Sample Survey Office (NSSO), Ministry of Statistics and Programme Implementation, Government of India.

NSSO. (2007). *Nutritional intake in India 2004–05*. NSS report No. 513, NSSO, Ministry of Statistics and Programme Implementation, Government of India.

NSSO. (2013). *Key Indicators of Household Consumer Expenditure in India 2011–12*. NSSO, Ministry of Statistics and Programme Implementation, Government of India.

NSSO. (2014). *Nutritional intake in India 2011–12*. NSS report No. 560. National Sample Survey Office (NSSO), Ministry of Statistics and Programme Implementation, Government of India.

Oxford & UNDP. (2019). Global Multidimensional Poverty Index 2019: Illuminating Inequalities. Available at https://hdr.undp.org/sites/default/files/mpi_2019_publication.pdf (accessed on 9 November 2020)

Pande, R., Rao, S., Gavaravarapu, M., Kulkarni, B. (2020). Front-of-pack nutrition labelling in India. *The Lancet Public Health, 5*(4), e195 [Available at https://www.sciencedirect.com/science/article/pii/S2468266720300311?via%3Dihub (accessed on December 11, 2020)]

Pandey, V. L., Dev, S. M., & Jaychandran, U. (2016). Impact of agricultural interventions on the nutritional status in South Asia: A review. *Food Policy, 62*, 28–40.

Parliamentary Standing Committee. (2018). *One hundred tenth report on functioning of Food Safety and Standards Authority of India*. Ministry of Health and Family Welfare, Government of India.

Pfeiffer, W. H., & McClafferty, B. (2007). HarvestPlus: Breeding crops for better nutrition. *Crop Science, 47*, S88-105.

Pingali, P., Aiyar, A., Abraham, M., & Rahman, A. (2019). *Transforming food systems for a rising India*. Palgrave Studies in Agricultural Economics and Food Policy Published by Palgrave Macmillan.

Porter, C., Sinha, A., & Singh, A. (2010). *The impact of mid-day meal scheme on nutrition and learning*. University of Oxford (Available on https://www.younglives.org.uk/content/impact-midday-meal-scheme-nutrition-and-learning)

Rangarajan, C., & Dev, S. M. (2017). Let's talk about supplemental income. *The Hindu*, August 7, 2017.

Rangarajan, C., & Dev, S. M. (2020) A safety net: Post-COVID. *Indian Express*, July 3, 2020.

Rao, N. D., Min, J., DeFries, R., Ghosh-Jerath, S., Valin, H., & Fanzo, J. (2018). Healthy, affordable and climate-friendly diets in India. *Global Environmental Change, 49*, 154–165.

Saxena, N. C. (2008). *Hunger, undernutrition and food security in India*. mimeo

Scott, S. P., Murray-Kolb, L. E., Wenger, M. J., Udipi, S. A., Ghugre, P. S., Boy, E., & Hass, J. D. (2018). Cognitive performance in Indian school-going adolescents is positively affected by consumption of iron-bio-fortified pearl millet: A 6-month randomized controlled efficacy trial. *Journal of Nutrition, 148*(9), 1462–1471.

Shetty, P. S. (2002). Nutrition transition in India. *Public Health Nutrition, 5*(1A), 175–182.

Shively, G., & Sununtnasuk, C. (2015). Agricultural diversity and child stunting in Nepal. *Journal of Development Studies, 51*, 1078–1096 (available on https://doi.org/10.1080/00220388.2015.1018900).

Siruguri, V., & Bhat, R. V. (2018). Management of food safety risks in India. *Proceeding of the Indian National Science Academy, 84*(4): 937–943 (available on https://doi.org/10.16943/ptinsa/2018/49439).

Spears, D. (2013). Policy lessons from the implementation of India's total sanitation campaign. *India Policy Forum, National Council of Applied Economic Research, 9*(1), 63–104.

Srivastava, S., & Chand, R. (2017). Tracking transition in calorie-intake among Indian households: Insights and policy implications. *Agricultural Economics Research Review, 30*, 23–35.

Stein, A. J., Nestel, P., Meenakshi, J. V., Qaim, M., Sachdev, H. P. S., & Bhutta, Z. A. (2007). Plant breeding to control zinc deficiency in India: How cost-effective is bio-fortification? *Public Health Nutrition, 10*(5), 492–501.

Subbarao, G. M. (2019). Nutrition communication-Rhetoric and reality. *Indian Journal of Medical Research, 149*(3), 333–344.

Sudershan, R. V., Subbarao, G. M., Rao, P., Rao, M. V. V., & Polasa, K. (2008). Knowledge and practices of food safety regulators in Southern India. *Nutrition & Food Science, 38*(2), 110–120.

Suri, S. (2020). *Nutrition gardens: A sustainable model for food security and diversity ORF Issue Brief No. 369*, June 2020, Observer Research Foundation.

Sushma, M. (2020). *National nutrition week: How kitchen gardens are saving villagers from malnourishment Down to Earth.* https://www.downtoearthorgin/news/health/national-nutrition-week-how-kitchen-gardens-are-saving-villagers-from-malnourishment-73248

ToI. (2018). *Reducing post-harvest losses, the main challenge: Researchers ToI*. March 22, 2018 (available on https://timesofindia.indiatimescom/city/coimbatore/reducing-post-harvest-losses-the-main-challenge-researchers/articleshowprint/63405223cms).

UNEP. (2016). *UNEP Frontiers 2016 report: Emerging issues of environmental concern.* United Nations Environment Programme.

WHO. (2006). *Five keys to safer food manual* [Available on https://www.who.int/foodsafety/publications/consumer/manual_keys.pdf?ua=1 (accessed on May 15, 2020)].

WHO. (2008). Poor sanitation threatens public health Joint News Release WHO/UNICEF [Available at https://www.who.int/mediacentre/news/releases/2008/pr08/en/ (accessed on December 9, 2020)].

WHO. (2015). *Healthy diet fact sheet No. 394 WHO media centre Geneva, Switzerland*. [Available at http://www.who.int/mediacentre/factsheets/fs394/en/ (accessed on June 5, 2020)].

WHO. (2018). *Noncommunicable Diseases (NCD) country profile* [Available at https://www.who.int/nmh/countries/ind_en.pdf?ua=1, (accessed on August 5, 2020)]

Walton, J. (2019). Working with the food industry to expand biofortification's reach Harvest-Plus [Available at https://www.harvestplusorg/knowledge-market/in-the-news/working-food-industry-expand-biofortifications-reach (accessed on December 10, 2020)].

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S. et al. (2019). Food in the Anthropocene: The EAT–Lancet commission on healthy diets from sustainable food systems. *Lancet, 6736*, 3–49 [Available at: https://www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736(18)31788-4.pdf?utm_campaign=tleat19&utm_source=HubPage (accessed on June 15, 2020)].

Yadava, D. K., Hossain, F., & Mohapatra, T. (2018). Nutritional security through crop biofortification in India: Status and future prospects. *Indian Journal of Medical Research, 148*(5), 621–631 [Available at https://doi.org/10.4103/ijmr.IJMR_1893_18 (accessed on May 27, 2020)].

Managing Climatic Risks in Agriculture

Pramod Aggarwal, Joyashree Roy, Himanshu Pathak, S. Naresh Kumar, B. Venkateswarlu, Anupa Ghosh and Duke Ghosh

1 Introduction

The contribution of agriculture in India's national gross value added (GVA) is only about 17%. However, its role in human wellbeing is vital considering its critical contribution in food, employment and livelihood security for 1350 million people.

P. Aggarwal (✉)
Borlaug Institute for South Asia - CIMMYT, New Delhi 110012, India
e-mail: p.k.aggarwal@cgiar.org

J. Roy
School of Energy, Resource and Development, Asian Institute of Technology, Pathum Thani 12120, Khlong Luang, Thailand
e-mail: joyashree@ait.asia; joyashreeju@gmail.com

Jadavpur University (on lien), Kolkata, India

H. Pathak
ICAR-National Institute of Abiotic Stress Management, Baramati, Pune, Maharashtra 413115, India
e-mail: hpathak.iari@gmail.com

S. Naresh Kumar
Centre for Environment Science and Climate Resilient Agriculture, ICAR-Indian Agricultural Research Institute, New Delhi 110012, India
e-mail: soora.nareshkumar@icar.gov.in

B. Venkateswarlu
Vasant Rao Naik Maratwada Krishi Vidya Peeth, Parbhani 431402, India
e-mail: bandi9501@gmail.com

A. Ghosh
The Bhawanipur Education Society College, 20 L.L.R. Sarani, Kolkata 700020, India
e-mail: anupa.ghosh@thebges.edu.in

D. Ghosh
Global Change Research, 69/10 B.B. Sengupta Road, Kolkata 700034, India
e-mail: duke.ghosh@globalchangeresearch.in

R. Chand et al. (eds.), *Indian Agriculture Towards 2030*,
India Studies in Business and Economics,
https://doi.org/10.1007/978-981-19-0763-0_4

Agricultural production of India has been continuously rising and has reached almost 290 million tonnes in 2019; but India continues to have an undernourished population of approximately 14% (von Grebmer et al., 2020). Absolute quantity of food grains demand will continue to increase with rising population and income. The pace of food production must be accelerated to achieve food and nutritional security, which is imperative for India to achieve the zero-hunger goal by 2030. A systemic approach is necessary for increasing food production, and improving its distribution and service delivery mechanisms in view of the rapidly changing climatic conditions, continued population growth, urbanisation, changes in diets and depletion of natural resources that are exerting unprecedented pressure on food systems (FAO, 2018). Broader context of managing risk in Indian agriculture needs to be the basic need for securing human well-being.

The immense influence of climatic stressors, particularly the spatial and temporal rainfall variability, continues to keep the seasonal and annual yield from Indian agriculture uncertain. Climate change is projected to cause significant adverse impacts on the agriculture of tropical regions including India. Combined with increased competition for land, water and labour from non-food sectors, climate change and associated increase in climatic variability will exacerbate seasonal/annual fluctuations in food production. As all agricultural commodities are climate-sensitive, hence, even the current climate and weather patterns—the droughts, floods, tropical cyclones, heavy precipitation events, hot extremes, heat waves, cold waves, frost events and hailstorms– are impacting agricultural production and farmers' livelihoods. For instance, loss of farm revenue due to extreme temperatures and rainfall shocks is estimated to be ~12% for monsoon (*kharif*) and ~6% for winter (*rabi*) crops with more impacts on unirrigated systems. Similarly, extreme temperatures caused a farm revenue loss of 4% during *kharif* and 5% during *rabi* (The Economic Survey, 2018). Negative anomalies of monsoon seasonal precipitation and number of rainy days during 1966–2010 are highly correlated with negative anomalies of *kharif* and *rabi* food grain yield (Prasanna, 2014).

Climate change is causing significant shifts in weather patterns throughout the world, and climate change is expected to alter the agricultural production systems across the world, posing major challenges to the livelihoods and food security of millions of people (IPCC, 2014). South Asia, along with Africa, is likely to be the most impacted in future. Increased temperatures, changed rainfall patterns and more frequent and intense floods and droughts will impact the food production (Lobell et al., 2012; Rosenzweig et al., 2014). The impacts of climate change on crop yields indicate that yield losses may be up to 60% by the end of the century depending on crop, location and future climate scenario (Rosenzweig et al., 2014; Challinor et al., 2014). Increasing climatic variability may further complicate agricultural production and food security as almost one-third of yield variability is related to climatic variability (Ray and Chowdhury, 2015).

Risk management in agriculture sector is getting complicated due to rising market uncertainty. As mentioned above it is becoming clear that production, distribution and delivery mechanisms need to be managed systematically in Indian context. Production uncertainty leads to income uncertainty and price volatility. Attention, therefore, needs to be given for both commercial and home gardens and minimising pest attacks and livestock related diseases. This also impacts accessibility and affordability and market opportunity for various social groups in different ways leading to indebtedness to meet basic and decent living standards. There are many options to mitigate the negative impacts of climate change, to minimise risks to agricultural systems and make the latter resilient to climate change and help reduce emissions (Some et al., 2019). Options range from change in crop management, such as sowing time, stress resistance varieties, change in cropping systems and land use, to adjust to new climates (Porter et al., 2014). This chapter will provide a summary of the probable impacts of climate change and the options available to India for managing its negative impacts.

2 Climate Change in India

Climate change projections, derived from the bias corrected probabilistic ensemble of 33 global climate models, indicated that rise in minimum temperature is likely to be more than the rise in maximum temperature in India. It will be more during *rabi* (October–April) than that during *kharif* (June–September). An increase in minimum temperature by 0.946–4.067 °C in 2020–2080 over baseline (1976–2005 period) in *kharif*; and by 1.096–4.652 °*C* in *rabi*, is projected. Similarly, an increase in maximum temperature by 0.741–3.533 °*C* (2020–2080) during *kharif* and by 0.882–4.01 °*C* is projected for *rabi*. Rise in temperatures is projected to be more in northern parts of India than that in southern parts. Variability in minimum and maximum temperatures is projected to be significantly more during *rabi* than that during *kharif*. Increase in rainfall by 2.3–3.3% (2020), 4.9–10.1% (2050) during *kharif*, and by 12% (2020), 12–17% (2050) *rabi* with increased variability as compared to baseline period (1976–2005) are projected (Naresh Kumar et al., 2019).

These changes will increase occurrence of extreme events including unseasonal rainfall, droughts and floods throughout the country. The sea-surface temperature has already risen by almost 1 degree over the last century and is expected to rise in the coming years (Krishnan et al., 2020). This will lead to a projected sea-level rise of 300 mm in the Indian ocean by the end of the century relative to 1986–2005 values. There has been an increase in both the spatial and temporal frequency of droughts since 1950s. Some of these droughts showed an increased severity over the last few decades and are projected to increase in frequency and magnitude. Increase in severe tropical cyclones along the coastline of India is also anticipated.

Agriculture also contributes about 16% to total greenhouse gas (GHG) emissions in India. The Indian agriculture emits 417.2 Mt CO_2e of total GHG emissions that comes from—enteric fermentation, 54%; agricultural soils, 19%; rice cultivation, 18%; manure management, 7%; and field burning and agricultural residue, 2% (MoEFCC, 2018).

3 Projected Impacts of Climate Change on Indian Agriculture

3.1 Crops

Studies indicated different values of impact on crop yields depending upon the method and climate change scenario used for impact assessment. Most studies indicated a decrease in yield with time. Studies conducted at the Indian Agricultural Research Institute and elsewhere indicated a yield loss in wheat up to ~9%, irrigated rice ~12%, maize ~18%, mustard ~12% and potato ~13% by 2040 under RCP 4.5 scenarios without adaptation as compared to the mean yield between 2000–2007 despite CO_2 fertilisation effects (Naresh Kumar et al., 2013, 2014a, b, 2015, 2019). In addition, negative impacts of ~2.5% on rainfed sorghum yield by 2040 are projected as compared to the mean yield of 2000–2007 (Srivastava et al., 2010; Naresh Kumar et al., 2012) even with rise in atmospheric CO_2 concentration in future climates. Increase in minimum temperatures is affecting maize yields in the Telangana region (Guntukula and Goyari, 2020). *Rabi* maize is projected to have increased yield in the range of 8.4–18.2% in 2020 scenario in Bihar (Haris et al., 2013). Pearl millet yields are projected to reduce in parts of Maharashtra while they may improve in Haryana in future scenarios of 2030 and 2050 (Piara Singh et al., 2017). On an all-India basis, yields of groundnut, soybean (Naresh Kumar et al., 2012) and cotton are projected to improve due to climate change. Similarly, chickpea yield is projected to improve (by 17–25%) in Haryana and central Madhya Pradesh but is projected to decrease (by 7–16%) in southern Andhra Pradesh in 2050 scenario (Piara Singh et al., 2014). However, regression analysis indicated a plausible decrease in pigeon pea yield by ~ -3.2 to -10.1% in 2035 scenario, without considering CO_2 fertilisation effects. The decrease in yield may be even up to ~18% in 2065 scenario (Birthal et al., 2014). Coconut plantations are projected to gain in western coast while significant yield loss is projected for eastern regions of the country (Naresh Kumar & Aggarwal, 2013). Shift in apple belt to higher elevations from 1250 to 2500 mamsl is reported from Himachal Pradesh and Kashmir. Changes in rainfall pattern and shift in seasons are significantly affecting Assam tea yields (Nowogrodzki, 2019). Arabica coffee plantations in India are projected to lose yield and may shift to higher altitudes (Merga & Alemayehu, 2019). The Indo-Gangetic plains of Uttar Pradesh, Bihar and West Bengal exhibited high sensitivity of crop yields to climatic variables (Rao et al., 2016). Severity of droughts and intensity of floods in various parts of India are likely to increase (Pathak et al., 2014).

Climate change is projected to affect grain quality as well. Grain protein is projected to reduce by about 1.1% in high CO_2 and low N input conditions in wheat. In addition to protein, the concentration of minerals such as Zn and Fe is also likely to reduce in many crops (Porter et al., 2014). Similarly, the quality of horticultural crops is reported to be affected due to temperature stress, heavy rainfall events and high CO_2 (Table 1; Naresh Kumar, 2009).

Table 1 Effect of elevated CO_2 (550 ppm), temperature and rainfall on the quality of produce of some horticultural crops

Crop	Parameter
Apple	Exposure to direct sunlight and high temperatures causes accumulation of sugars; high temperatures increase tartaric acid in fruits, affects fruit firmness; causes sunburn, loss of texture and development of water core in fruits. In ripening apples, anthocyanins are synthesised at temperatures <10 °C. High temperatures affect biosynthesis of anthocyanin pigment and cause poor red peel
Strawberry	Warmer day (25 °C) and night (18–22 °C) increase antioxidant components such as flavonoids. Fruits develop darker red colour
Vine grape	High variation (15–20 °C) in day/night temperature promotes anthocyanin development
Sweet potato	Elevated CO_2 increases starch, carotene and glucose
Coconut	Increase in storage temperature reduces keeping quality of oil
Arecanut	Storage temperature >28 °C reduces myristic acid
Cashew	High rainfall coinciding nut development causes nut germination, blackening of nuts
Black pepper	Increased temperatures may increase b-caryophyllene and lower limonene, sabinene and myrcene
Onion	High CO_2—decreases flavonoids, temperature above 40 °C reduces the bulb size in onion
Tomato	High CO_2 increases lycopene and carotenoid content; increases vitamin C, sugars and acids
Capsicum	Temperature >27 °C inhibits red colour development

(*Source* Naresh Kumar, 2019)

3.2 Pests and Diseases

Climate variability and change impact the interactions between crops, insect pests and their natural predators. Pests are projected to cause more damage to crop owing to excessive feeding on foliage that has high C:N ratio. In addition, alterations in synchrony of crops and pest phenological events, reproductive behaviour of pests, etc., affect the pest load on crops and alter pest species dominance. In the last 20 years, several insect pests such as Asian fruit fly, American tomato moth, blackfly, desert locust, fall armyworm and mango fruit borer have been reported as invasive species along with others across various regions in India (Chakravarthy et al., 2013; Vennila et al., 2018).

The recent 2020 desert locust attack on crops in north-western India is reported to be highly damaging vis-à-vis earlier attacks since 1993. The locust swarm came from Africa and Middle East triggered by climatic risks in the region. The 2020 outbreak affected cumin, rapeseed and mustard, particularly in Rajasthan and Gujarat. According to the Locust Warning Organization, Jodhpur, so far 19 events of locust plagues have occurred between 1964 and 2020. Before the recent event, the last major outbreak was in 2010. The prolonged monsoon is suggested to have helped its outbreak. In India, fall armyworm affected maize crop in about 170 thousand ha mainly in Karnataka, spreading to western Maharashtra and Gujarat and eastern states in 2018 and 2019. While advancing fast, it also damaged paddy, sugarcane and sweet corn. Yield loss due to fall armyworm is estimated to be 33% in an isolated study from a single district of Telangana (Balla et al., 2019). Long dry spells coupled with overcast sky made maize susceptible to attacks of pest. Adverse impact on biodiversity in home gardens owing to climate change through changing pests is becoming common in South Asia (Marambe et al., 2018) and in dry zones of West Bengal (Jana et al., 2014, Jana & Roy, 2019), where home gardens are substantial supplementary nutrition security providers.

Simulation studies indicated additional generations drive higher incidence of *Spodoptera litura* and *Aphis craccivora* on groundnut (Rao et al., 2014); *Bactrocera dorsalis* on mango (Choudary et al., 2017) and *Tuta absoluta* on tomato (Kanle Satishchandra et al., 2018) in climate change scenarios. Similarly, diseases such as powdery mildew of wheat, are likely to be restricted to the western zone only, except a slight change in the eastern plains. A marginal increase in leaf blast pattern in boro rice grown during December to March in the eastern part of the India is projected (Viswanath et al., 2017).

The devastating effect of plant pests impacts mainly the food-insecure populations. In India, estimated crop loss due to insect pests increased from about 7.2% in 1960s to 16.8% in 2010s (Dhaliwal et al., 2015). Hence, these pest and disease incidences and outbreaks should be effectively controlled by starting online plant clinics like online human health clinics in COVID-19 pandemic.

3.3 Livestock

The livestock sector is also projected to be significantly affected by climate change. Risks to plants and animals in home gardens in dry districts of West Bengal are becoming more visible (Jana & Roy, 2020). The thermal stress affects the quantity and quality of milk and reduces body weight of goats (Pragna et al., 2018). It is estimated that this will reduce milk yield by 1.6 million tonnes in 2020 and >15 million tonnes in 2050 (Naresh Kumar et al., 2012). Crossbreeds are more affected than that of local breeds. In addition, heat and cold waves cause short- and long-term cumulative effects on health and milk production in cattle and buffaloes. Climatic stress related loss of milk yield in Trans and Upper Gangetic plains of India is projected to cause a loss of INR 12 billion per year in this decade (up to 2029), which may double in the next decade (Choudhary, 2017). Poultry is also projected to face heat stress causing a reduction in yield of meat and egg; temperatures beyond 42 °C cause bird mortality. Increase in temperature from 31.6 to 37.9 °C decreases feed consumption by 36% and egg production by 7.5% in broiler breeds. In commercial layers decline in egg production was 6.4% (Naresh Kumar et al., 2012).

3.4 Fisheries

Climate change is projected to impact fisheries by altering abundance and distribution of marine fish species and their breeding and migration patterns. Extension of abundance of oil sardine species from southern latitudes to northern latitudes along the Indian coast is linked to increasing sea surface temperatures (Vivekanandan and Jeyabaskaran, 2010). The freshwater fish species are also affected due to increased breeding cycles and higher growth rates. The climatic change is projected to exacerbate more negative impacts than earlier thought owing to changes in zoo- and phytoplankton, sea surface temperatures, precipitation changes, sea water acidification, sea surface salinity and oxygen deficiency.

Despite the climatic challenges, marine fish landings increased from about 0.53 million tonnes/year in 1950–51 to ~3.81 million tonnes/year in 2017. The assessments project a production potential of ~5 million tonnes/year in Indian exclusive economic zone (EEZ). Further, marine culture options including open sea cage farming, seaweed farming, integrated multi-tropic farming, mussel and oyster culture, ornamental fish production, pearl culture, seaweed farming along Indian coasts can augment marine food and other marine production (Gopalakrishnan et al., 2017).

3.5 Food Supply and Prices

In India, a lot of spatial and social variations exist with respect to exposure to climatic stresses. Demand-supply inequalities and availability, accessibility and affordability due to market price volatility of food are markedly high in areas prone to climatic stresses such as droughts and floods (Ghosh and Roy, 2006; Roy et al., 2005). Livelihoods and annual income reduced by 60% in drought affected villages of Jalna district, Maharashtra (Vedeld et al., 2014). Long-term malnutrition in children was observed to be associated with frequent floods in Jagatsinghpur district of Odisha (Rodriguez-Llanes et al., 2011). Moreover, migration of many landless and marginal farmers to cope with climate variability is commonly seen in India and elsewhere (Bhatta et al., 2015), and is considered as an adaptation strategy to cope with climate change (Jahn et al., 2018).

Field level socio-economic studies across India showed that increasing frequency of extreme climatic events are leading to growing uncertainty in farmers' income and price volatility in agricultural product markets affecting access, affordability and nutrition at the household level. Nelson et al., (2009) projected an increase in the prices of wheat, rice and maize in the range of 121–194% by 2050 because of climatic change. Thus, the multi-factorial effects on food production and supply systems will significantly impact the food and nutritional security of vulnerable populations. With increasing risks in production and markets because of climate change, there exists a high volatility of operating cash flow and profit from agricultural activities. As a result, farmers face constraints in scaling up agricultural activities, and volatile profits further restrain them from reinvesting in farm related activities. And some farmers leave the agricultural sector, which was evident from reports from states Punjab, Madhya Pradesh and Tamil Nadu (ADB, 2011). Some farmers resort to borrowing from formal or informal sources with constraints of repayment (Kumar et al., 2017).

4 Technological Options

Several existing technologies can be suitably used to manage climatic risks. Certain such potential technologies are discussed here and assessed in terms of adaptation benefits, mitigation co-benefits, productivity and income, their ease of implementation, no-regret options and friendliness to small-holding farmers (Table 2). In addition, farmers' decision to adopt a technology is influenced by several other factors such as their socio-economic characteristics, age, gender and land-holding size (Khatri-Chhetri et al., 2017). Therefore, a suitable policy response is required for finding an optimal balance between preference and prioritisation by different stakeholders for promoting a technology.

4.1 Field and Horticultural Crops

4.1.1 Multiple Stress Tolerant Varieties

Developing varieties tolerant to multiple abiotic and biotic stresses using stress-tolerant QTLs, genes and alleles in elite cultivars, is an efficient way of achieving climate resilience with easy access to farmers. ICAR developed crop varieties such as CR Dhan 801 and CR Dhan 802 for rice and several others for different crops, which are tolerant to multiple stresses i.e. submergence, salinity, drought, heat, pests and diseases (Pathak et al., 2018).

4.1.2 Inter-Specific Grafting of Crops

This strategy was successful for flood-tolerance in tomato, where grafting of tomato plants was done onto brinjal rootstocks. Grafted tomato plants exhibited better survival and improved fruit yield over self-grafted and un-grafted plants under flooding (Bahadur et al., 2015).

Table 2 Technological options with their potential benefits for climate-smart agriculture

Strategy	Technology	Adaptation benefit	Mitigation benefit	Productivity gain	Income gain	Ease of implementation	No regret character	Small farmer friendly	Average
1. Food and horticultural crops	1. Multiple stress tolerant varieties	5	1	4	4	5	4	5	4.0
	2. Inter-specific grafting of vegetable crops	5	1	4	4	2	3	5	3.4
	3. Diversification to stress-tolerant and new crops	5	2	4	4	2	2	2	3.0
2. Livestock and poultry	4. Stress-tolerant breeds	4	1	4	4	3	3	2	3.0
	5. Feed and housing management	4	4	4	3	3	4	2	3.4
	6. Livestock health care for emerging diseases	3	1	4	3	3	4	3	3.0
	7. Small ruminants in drought-prone areas	4	3	2	2	3	2	4	2.9
3. Fisheries	8. Composite and drought-escaping fish culture	4	1	4	4	4	3	3	3.3
	9 Diversification of fish species	4	1	4	4	3	2	3	3.0

(continued)

Table 2 (continued)

Strategy	Technology	Adaptation benefit	Mitigation benefit	Productivity gain	Income gain	Ease of implementation	No regret character	Small farmer friendly	Average
	10 Pen/cage culture of fish	5	1	5	4	2	2	1	2.9
	11 Wastewater aquaculture	3	2	3	4	2	2	2	2.6
4. Water management	12 Dry direct-seeded rice	4	4	3	4	3	2	4	3.4
	13 Micro-irrigation (drip, sprinkler)	5	5	4	3	3	2	2	3.4
	14 Rainwater harvesting and drainage	5	3	4	3	2	3	2	3.1
5. Energy management	15 Solar energy-based machineries	2	5	2	4	3	3	2	3.0
	16 Zero/minimum tillage	2	3	2	4	3	3	2	2.7
	17 Energy plantation	2	4	2	3	2	2	2	2.4
	18 Protected cultivation and vertical farming	5	1	5	5	2	2	1	3.0

(continued)

Table 2 (continued)

Strategy	Technology	Adaptation benefit	Mitigation benefit	Productivity gain	Income gain	Ease of implementation	No regret character	Small farmer friendly	Average
6. Nutrient management	19 Site-specific nutrient management	2	3	4	4	4	4	4	3.6
	20. Microbial technologies and bio-fertiliser	2	4	3	4	3	4	4	3.4
	21. Integrated nutrient management	3	3	3	4	4	4	4	3.6
	22. Nitrification and urease inhibitor	2	4	4	4	3	4	4	3.6
7. Management of soil carbon	23. Conservation agriculture	3	4	3	4	3	3	3	3.3
	24. Agro-forestry	3	5	2	3	2	2	2	2.7
	25. Residue management	2	3	2	3	2	3	3	2.6
8. Weather forecasting and services	26. Weather forecasting and early warning	4	1	3	3	3	3	3	2.9
	27. Contingency plan for abiotic stresses	4	1	3	3	2	4	3	2.9
	28. Insurance	5	1	4	5	3	4	3	3.6

(continued)

Table 2 (continued)

Strategy	Technology	Adaptation benefit	Mitigation benefit	Productivity gain	Income gain	Ease of implementation	No regret character	Small farmer friendly	Average
9. Institutional arrangement	29. Custom-hiring centres	3	1	3	4	2	3	5	3.0
	30. Seed and fodder bank	4	1	3	3	2	3	5	3.0
	31. Community nursery	4	2	4	4	3	3	5	3.6

Note The parameters have been evaluated using rapid expert judgement on a scale of 1–5—where the lowest gain is 1, and the highest 5. Suitable climate-smart technologies were short-listed from a list of reported technologies and prioritised using multi-criteria decision analysis

4.1.3 Diversification to Stress-Tolerant and New Crops

Crop diversification should focus in promoting climate-smart, hardy crops like millets; and more remunerative fruit crops such as dragon fruit and pomegranate in drought prone areas. Dragon fruit, a new crop, has high potential for increasing farmers' income, particularly in climate stressed areas. Diversification, however, should be based on the climate resilience of the crops, availability of water and other resources of the region and market demand. These factors will in turn decide the risks and returns from the diversified system and their adoption by the farmers.

4.2 Livestock

4.2.1 Stress-Tolerant Breeds

Selection and promotion of stress tolerant breeds is paramount for climate resilience. In high stressful environments and for less resourceful farmers, indigenous breeds will be more suitable compared to exotic breeds (TIFAC, 2019). Indigenous breeds however have limitations of low productivity. Therefore, a decision at local level has to be made between stress-tolerance and maintenance cost in one hand and the productivity on the other to decide the profitability and adoption of the breeds.

4.2.2 Feed and Housing Management

To ensure climate resilient livestock production, providing heat-stress-resilient housing, sufficient good quality feed with supplements such as vitamin C for poultry, improving feeding strategy and extending financial and risk mitigation services will be of immense use. Establishment of cattle camps to ensure feeding and housing in adverse years was adopted as a successful strategy for climate resilience in Maharashtra, India.

4.2.3 Small Ruminants in Drought-Prone Areas

Small ruminants, generally not requiring costly housing and feed, make husbandry easier; adjustment to hardy climatic conditions should be promoted in drought-prone areas. This effort can help millions of farmers with minimal incentives from the government (TIFAC, 2019).

4.2.4 Livestock Healthcare for Emerging Pests and Diseases

Climate change is causing the emergence and spread of new pest and diseases. To address this, awareness and number of diagnostic centres should be increased, and their infrastructure and services strengthened for early and better diagnosis (TIFAC, 2019).

4.3 Fisheries

4.3.1 Composite and Drought-Escaping Fish Culture

In composite fish culture, more than one type of compatible fish such as grass carp, common carp, big head carp and amur carp are cultured together. Amur carp (modified variety of common carp) has more growth and tolerance to varying temperature regimes compared to common carp (Medhi et al., 2018).

4.3.2 Drought-Escaping Fish Culture

In this, fishes are grown in smaller ponds that retain water for 2–4 months, and fish species such as *Pangasius* sp., *Puntius javanicus*, *Pygocentrus nattereri* and *Oreochromis niloticus* are cultured.

4.3.3 Diversification of Fish Species

Culturing brackishwater fish in freshwater and low salinity tolerant freshwater fish in brackishwater is a reality (Trivedi et al., 2015). Several stress-tolerant species such as *Pangasianodon hypophthalmus*, *Anabas testudineus* and *Channa stiatus* were identified for stress conditions to provide flexibility and resilience in fish culture.

4.4 Natural Resource Management

4.4.1 Water Management

To conserve, store and enhance water use efficiency, pressurised, low cost and demand-driven irrigation methods are being promoted. Technologies such as alternate wetting and drying in rice, dry direct-seeded rice (Pathak et al., 2018), rainwater harvesting and groundwater recharge have substantial adaptation benefits. A successful technology for drought-prone and low rainfall areas is Jalkund i.e., low-cost rainwater harvesting structures, for harvesting rainwater during the rainy season and its subsequent use during the dry periods (Prasad et al., 2014).

4.4.2 Nutrient Management

Efficient management of nutrients can help in climate change adaptation by enhancing root growth and early vigour of plant and improving soil microbial activities that lead to adequate supply of plant nutrients under climate-stress conditions. Soil test-based, balanced fertiliser application, use of efficient fertilisers, site-specific real time N application and integrated nutrient management are some options of efficient nutrient management practices. Use of neem-coated urea, soil health card and leaf colour chart for enhancing fertiliser use efficiency were successfully utilised in India. Integrating all these options will further improve the efficiency of applied fertilisers (Pathak et al., 2019). Microbe-based technologies for nitrogen fixation, nutrient recycling, bio-residue management and alleviation of abiotic and biotic stress will be very useful in the changing climate scenario.

4.4.3 Conservation Agriculture

Conservation agriculture helps (i) reduce the carbon footprint of the production system, (ii) improve productivity and (iii) enhance adaptability, by modulating soil moisture and temperature regimes (Somasundaram et al., 2020). Such practices are followed by farmers on a large scale in the Indo-Gangetic Plains. However, refinement and promotion are required to extend the technology in climatic stressed, dry land areas.

4.4.4 Mechanisation in Agriculture with Renewable Energy Sources

Solar-powered machineries such as water pumps, sprayers and weeders are better alternatives to diesel-powered machines in India. Such machines are economical, help in timely field operation at low cost, affordable to small farmers and do not release greenhouse gases. Individual farmers, panchayats, cooperatives, farmer producer organisations can install solar power plants for which government is providing incentives.

4.4.5 Protected Cultivation and Vertical Farming

Protected cultivation and vertical farming practices such as plastic low tunnel, hydroponics, trench underground greenhouse, fogponics, aeroponics, vertically stacked layers, vertically inclined surfaces and/or integrated in other structures have advantages of flexibility of location and are well-adopted in adverse climatic conditions (TIFAC, 2019).

5 Institutional and Policy Options for Adapting to Climate Risks

Climate resilient technologies undoubtedly play an important role in climate change adaptation in agriculture. However, strong institutional support is necessary to apply and scale up these technologies for successful adoption and societal embedding. This support may include correcting market distortions, strengthening implementation machinery at different levels, better linkages and prudent financial allocation.

5.1 Mainstreaming Climate Adaptation in Development Planning

Climate change has largely remained a subject dealt by the national government under eight Missions of the National Action Plan on Climate Change (NAPCC). However, agriculture being a state subject, more active involvement of states is needed so that state specific problems can be addressed effectively. Most state governments have prepared State Action Plans (SAPs) covering different sectors including agriculture but are weakly formulated around CSA without adequate financial allocations and provisions for adequately trained climate service providers. Agriculture being a state subject greater attention and better coordination are required among concerned departments at the state level. Singh et al., (2019) found that many schemes of the Government of India have strong implications for climate change adaptation. A systemic comprehensive effort might help in accelerating strategic actions. Multiple experimental or small-scale uncoordinated actions in project mode are happening through NABARD and other agencies but review and strengthening of efforts towards scale up need specific attention. These require institutional mechanism for multi-level collaboration and governance. Vertical integration of national-subnational-local scales and horizontal integration among various private sector players, framers and financial institutions would be very useful.

5.2 Leveraging Watershed Programmes and MGNREGA

India has long experience of implementing watershed development programme in rainfed areas and command area development in irrigated regions. Several institutions like Water Users Associations (WUA), Watershed Committees (WC), Watershed Development Teams (WDT), Project Implementing Agencies (PIA), etc., are functioning at the village/watershed level for many years. The National Rainfed Area Authority (NRAA) is currently revising common guidelines of the Watershed Development Programme. It provides an opportunity to integrate climate change adaptation objectives as many NRM interventions in watersheds also help in climate resilient agriculture. MGNREGA (Mahatma Gandhi National Rural Employment Guarantee Act) provides legal status to right to work and social security through enhanced livelihood security in rural areas. It provides at least 100 days of wage employment in a financial year to every household for adult members ready to volunteer for unskilled manual work. The list of work covers – water conservation and water harvesting; drought proofing including afforestation; irrigation works; restoration of traditional water bodies; land development; flood control; rural connectivity and works notified by the government. All these activities are closely linked to adaptation options for climate change. It is already operating with an institutional structure, on digital platform and financial allocations. Though it is primarily designed as a rural job creation programme to provide income security, yet it provides a vehicle to achieve climate change response objectives as well. Women are the most vulnerable section to climate change, yet they contribute significantly to adaptation actions in Agriculture. India has a very strong institutional setup of women Self Help Groups (SHGs) at village level and their federations at block level. These are playing a stellar role in natural resource management, crop and livestock production and fisheries. It is pertinent to make effective use of this institutional mechanism for achieving the goals of CSA.

5.3 Contingency Crop Planning and Agro Advisory Services

While climate change will have long term impacts on the farm sector, inter-annual climate variability triggers no lesser risks. ICAR prepared district-wise contingency crop plans for all rural districts in India for coping with monsoon aberrations (www.agricoop.nic.in). However, owing to lack of a systemic approach, no institutional mechanism exists to implement these plans at the subnational level. The key challenges are—production, storage and supply of seeds of short duration contingent crops and varieties at a short notice. It is recommended that states develop a special seed production programme of contingent crops and varieties, build infrastructure and logistics for storage and supply of such seeds at short notice. One or two such hubs can be built in each state and operated under private-public-partnership mode or through new innovative business model solutions. If the monsoon is normal, the seed can be disposed as grain and the cost difference can be absorbed by participating parties.

Over time, India's established institutional structure of AGROMET advisory services of IMD have expanded and now each district has a District Agro Met Unit (DAMUs) involving IMD, Krishi Vigyan Kendras (KVK) and State Agricultural Universities for dissemination of short and medium range forecasts and crop advisories under the Grameen Krishi Mausam Seva (GKMS). However, considering large spatial and temporal climatic variability, weather information with higher spatial resolution of a block or panchayat is required. This needs better high-resolution forecasting models, international collaboration, investments in infrastructure and large number of appropriately trained manpower (Mehajan et al., 2019). Considering the importance of this function, serious consideration needs to be given to whether a separate dedicated organisation can be created through new legislation in parliament or an existing organisation can be re-mandated. At the ground level under global adaptation projects in India climate service providers are emerging, but all these experiments need an institutional mechanism to get mainstreamed in agricultural extension service or agricultural enterprise level. New enabling conditions will help in enhancing social acceptance of new practices and technologies and better management of natural capital like soil quality, water quality and quantity and watershed. Many of these come under new public service categories. Additional services to reduce information asymmetry and market access and provision of security at various subsystem levels in agricultural sector can be categorised under broader public service categories.

5.4 Insurance, Credit and Risk Management

Insurance can be one of the key instruments for managing short-term climatic risks in Indian agriculture. India has one of the largest agricultural insurance programmes in the world covering more than 30 million farmers. It is a comprehensive scheme covering many crops, hazard types and low premium contribution by farmers but bottlenecks in implementation and delay in claim settlements remain. Another major criticism of the scheme is the time-consuming nature of Crop Cutting Experiment (CCE), which is often contested both by the farmers and insurance companies. Use of new technologies and tools like remote sensing and drones, simulation modelling, blockchain technology and artificial intelligence could possibly make the scheme more efficient and transparent (Aggarwal et al., 2016). Considering that almost the entire premium is paid by the central and state governments, it will be useful to examine if the scheme could be modified to run as a social welfare scheme with insurance principles for management; various possibilities need to be scientifically weighed. The additional budget could be made available by merging a few disaster management schemes into this scheme. Moreover, insurance cannot be a stand-alone solution to climate change. In the farm sector, it shall form part of a comprehensive risk mitigation strategy, illustrated in Fig. 1, encompassing investments in infrastruc-

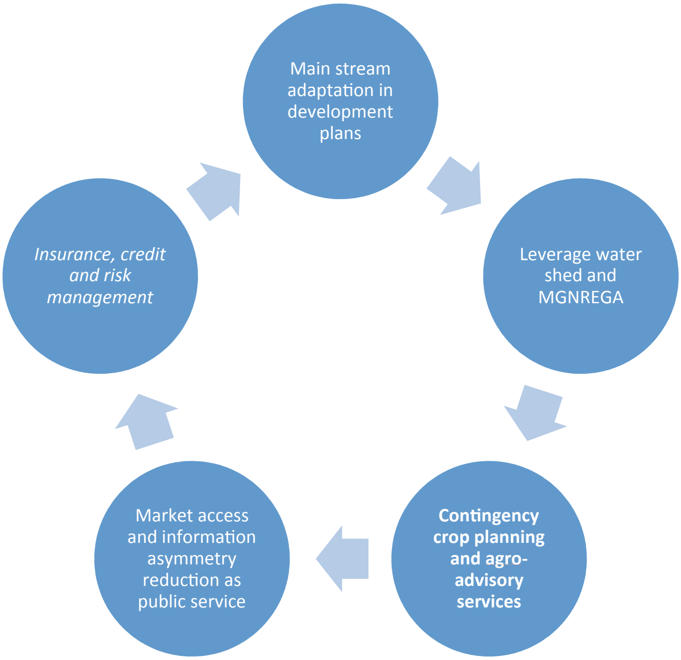


Fig. 1 Illustrating the various components required for building a comprehensive climatic risk management strategy in agriculture

ture and adoption of climate smart practices at the farm level (Koerner and Loboguerrero, 2019) to reduce likely loss and damage related to climate change and disasters by enhancing resilience through climate proofing of production, distribution and access.

The eNAM – a pan-India online trading platform for agricultural commodities by the GoI – was opened to improve market access and reduce information asymmetry among farmers (MoA&FW, 2020). The scope of this platform maybe expanded to integrate agricultural financial markets to widen and deepen the scope of agri-financial services. For mainstreaming such innovative mechanisms to weed out information asymmetry, requirement of hard and soft infrastructure, and capacity are necessary pre-conditions. Agricultural extension centres need to be overhauled and enabled to provide services to bridge these gaps.

In the face of climate change, it is imperative to ensure adequate income flow security from agriculture and to introduce a transparent and climate responsive credit policy. While, at present, agricultural credit is a priority sector lending for institutional lenders, approaches for evaluation of credit worthiness must consider climate risks going beyond standard approaches. With risks in production and markets due to climate change, there exists a high volatility of operating cash flow and profit from agricultural activities. As a result, the farmer faces constraint to scale up agricultural activities. Agricultural credit policies are macro level policies. Changes in those macro level policies are impacted by landscape factors and are outside the control of farmers (Pingali et al., 2019).

The formal financial system must accord attention to decreasing reliance of farmers on informal lenders for ease of regulatory management. Further, to ensure better price realisation, infrastructure related to agriculture—both backward and forward linkages in the value chain—are to be developed. The proposed policies of the central government concerning agricultural infrastructure fund are a welcome step in this direction (Express News Service, 2020).

6 Conclusions

Risks to food systems with ripple effects on income security of the agricultural sector and nutritional security of the population can originate from climatic factors, and from the malfunctioning of dynamics and interlinkages between components of the subsystems. Risk triggers are both on the supply side and demand side. It may emerge from supply side factors—degradation of land, change in land use patterns, deteriorating biodiversity, pollution, depletion natural resources, pest attacks, epidemics, emerging health risks, socio-political conflicts and climate change and disasters. Supply side disruptions during flood, drought and extreme weather events leading to market price volatility are a major cause of concern. Demand side factors stem from inadequate infrastructure and hence access to markets, market failures, migration and displacements, income fluctuations among consumers together with rapidly evolving tastes, preferences and patterns of consumption, changing trade policies, etc. (Bricas et al., 2019). Further, there may be both spatial and temporal variations in risks with different resultant outcomes. It is clear from the above description that climate change induced impacts will exacerbate the pre-existing broad categories of risks—production, market, institutional, financial and personal in Indian agriculture. The management strategies are inter-related. Consequently, while considering risk mitigation strategies, a systemic and holistic approach is likely to elicit maximum benefits for the system.

On an aggregate level, we harvested less than 50% of the genetic potential of most crops (Aggarwal et al., 2008) This gives an immense opportunity to raise food production in a resilient and profitable manner. Several technological and institutional options (Table 1) are now available to build resilience in Indian agriculture to current as well as future climate. Replacement foods such as plant-based meats and focus on solar energy and circular economy could help transform management of climate change in agricultural systems in future. Most of these options are no-regret options with mitigation co-benefits linked to Sustainable Development Goals (SDGs). However, more targeted detailed research can help in identifying exact strategies going forward. This, however, requires significant financial and institutional investment in scaling up these on a large scale. Intelligent use of climate information services and big data analytics can facilitate efficient use and targeting of increased public and private investment in natural capital through management of water, energy, soil quality and natural resources and climate change literacy. Bottom-up farmer level consultation is no less important, if not more, to indicate an equitable path going forward.

While there are numerous technologies available, systemic enabling conditions for nutrition service delivery mechanisms, avoiding market price volatility and providing basic income security for decent living, need to be strengthened. This has become clear from recent experiences during the pandemic COVID-19. There is a clear need for scientific studies to design incentives, sustainable business models to shift current developmental actions and social practices along sustainable development pathways. More research is needed to understand risk profile, implications of various agricultural service delivery models for various social groups to strengthen resilience and finally to reduce loss and damage by investing in climate proof agricultural system. Risks to climate variability have always been there and incremental responses have been helping to guard against adverse impacts but now risks are exacerbating with climate change. Big opportunities are available in targeting climatic services, advisories, insurance and precision agronomy but to scale we need sound business models. Need for right partnerships, science-based actions, policies, market/nonmarket incentives, investments, institutional changes are becoming more important. Investments in natural capital, physical capital, knowledge and human capital and social and institutional capital and valuing their impact for creating green jobs in these sectors and impact on various dimensions of human wellbeing are becoming imperative in policy planning.

References

ADB. (2011). *TA 7417—IND: Support for the national action plan on climate change support to the national water mission.* Asian Development Bank, Manila, Philippines.

Aggarwal, P. K., Hebbar, K. B., Venugopalan, M. V., Rani, S., Bala, A., Biswal, A., Wani, S. P. (2008). *Quantification of yield gaps in rain-fed rice, wheat, cotton and mustard in India.* Global Theme on Agro-eco systems. Report no. 43 Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics 36 p.

Aggarwal, P. K., Chand, R., Bhutani, A., Kumar, V., Goel, S. K., Rao, K. N., Poddar, M. K., Sud, U. C., Krishna Murthy, Y. V. N., Ray, S. S., Murthy, C. S., Sikka, A., Shirsath, P. B., Mishra, J. P., Choudhury, M., Chaudhury, O. P., Joshi, A. K., Sen, G., Tarpara, C. N., Kumar, D., Sahoo, R. N., Kumar, N. S., Yadav, A. K., Singh, T. P., Kannan, H., Satish Raju, G., Sudhakar, M., Singh, K. K., Agarwal, N., Reddy, P. K., Shukla, A., Shanbaug, A., Srivastava, A. K., Mehta, S., Gupta, P. K., Gopalakrishnan, A., Chandel, B. S., Duggal, R. K., Deshmukh, V., Kotwaliwale, N., Vora, P., Kumar, S., & Lochan, R. (2016). *Report of the task force on 'Enhancing technology use in agriculture insurance'.* NITI (National Institute for Transforming India) Aayog, Government of India, 39p.

Bahadur, A., Rai, N., Kumar, R., Tiwari, S. K., Singh, A. K., Rai, A. K., Singh, U., Patel, P. K., Tiwari, V., Rai, A. B., Singh, M., & Singh, B. (2015). Grafting tomato on eggplant as a potential tool to improve waterlogging tolerance in hybrid tomato. *Vegetable Science, 42*(2), 82–87.

Balla, A., Bhaskar, M., Bagade, P., & Raw, N. (2019). Yield losses in maize (*Zea mays*) due to fall armyworm infestation and potential IoT-based interventions for its control. *Journal of Entomology and Zoology Studies, 7*(5), 920–927.

Bhatta, G. D., Aggarwal, P. K., Poudel, S., & Belgrave, D. A. (2015). Climate-induced migration in South Asia: Migration decisions and the gender dimensions of adverse climatic events. *The Journal of Rural and Community Development, 10*(4), 1–23.

Birthal, P. S., Khan, M. T., Negi, D. S., & Agarwal, S. (2014). Impact of climate change on yields of major food crops in India: Implications for food security. *Agricultural Economics Research Review, 27*(2), 145–155.

Bricas, N., Bendjebbar, P., Hainzelin, E., Dury, S., & Giordano, T. (2019). General conclusions. In S. Dury, P. Bendjebbar, E. Hainzelin, T. Giordano, & N. Bricas (Eds.), Food Systems at Risk: New Trends and Challenges (pp. 123–125). FAO, CIRAD and European Commission.

Chakravarthy, A. K., Doddabasappa, B., Shashank, P. R. (2013). The Potential Impacts of Climate Change on Insect Pests in Cultivated Ecosystems: An Indian Perspective. In: S. Nautiyal, K. Rao, H. Kaechele, K. Raju, R. Schaldach (Eds.), *Knowledge Systems of Societies for Adaptation and Mitigation of Impacts of Climate Change. Environmental Science and Engineering*. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-36143-2_9.

Challinor, A. J., Watson, J., Lobell, D. B., Howden, S. M., Smith, D. R. & Chhetri, N. (2014). A meta-analysis of crop yield under climate change and adaptation. *Nature Climate Change, 4*, 287–291.

Choudhary, B. B. (2017). *Climate sensitivity of agricultural production system in trans and upper Gangatic plains of India: potential economic impact and vulnerability* [Ph.D. Thesis]. National Dairy Research Institute, Karnal, India.

Choudhary, J. S., Srinivasa Rao, M., Santhosh, S. M., Bikash, D., Kumari, A., Mukherjee, D., Singh, A. K., & Bhatt, B. P. (2017). Potential changes in number of generations of oriental fruit fly, *Bactrocera dorsalis* (Diptera: Tephritidae) on Mango in India in Response to Climate Change Scenarios. *Journal of Agrometeorology, 19*(3), 200–206.

Dhaliwal, G. S., Jindal, V., Mohindru, B. (2015). Crop losses due to insect pests: Global and Indian Scenario. *Indian Journal of Entomology, 77*(2), 165–168, (also available on https://doi.org/10.5958/0974-8172.2015.00033.4).

Express News Service. (2020). *To check post-harvest wastage PM launches INR one lakh crore agricultural infra fund*. Indian Express, New Delhi, August 10.

FAO. (2018). *Sustainable food systems: Concept and framework*. Retrieved July 15, 2020, from Food and Agriculture Organisation of the United Nations: (also available on http://www.fao.org/3/ca2079en/CA2079EN.pdf)

Ghosh, A., Roy, J. (2006). Coping with extreme climatic events: Analysis of household and community responses from selected hotspots in India. *Science and Culture, Special Issue on Flood Disaster. Risk Reduction in Asia, 72*(1–2), 23–31.

Gopalakrishnan, A., Ignatius, B., George, G. (2017). India's largest Fisheries Research Body Turns 70 - CMFRI's Legacy and Few Recent Achievements. *Fishing Chimes, 37*(1), 38–43.

Guntukula, R., & Goyari, P. (2020). The impact of climate change on maize yields and its variability in Telangana, India: A panel approach study. *Journal of Public Affairs, 20*: e2088, https://doi.org/10.1002/pa.2088.

Haris, A. V. A., Biswas, S., Chhabra, V., Elanchezhian, R., & Bhatt, B. P. (2013). Impact of climate change on wheat and winter maize over a sub-humid climatic environment. *Current Science, 104*(2), 206–214.

IPCC. (2014). Summary for Policymakers. In: Field, C. B., V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1–32.

Jahn, M., Jayamaha, J., Mulhern, W., Ross, D., Rose, M., Treverton, G. (2018). *Global food systems stability and risks: At the nexus of defence and development*. Thomson Reuters and University of

Wisconsin-Madison, available at https://www.thomsonreuters.com/content/dam/ewp-m/documents/thomsonreuters/en/pdf/reports/global-food-system-stability-and-risk-0718.pdf.

Jana, S., Roy J., Marambe, B., Weerahewa, J., Pushpakumara, G., Silva, P., Giashuddin M. Md., Punyawardena, R., Premalal, S. (2014). Home gardens in the Paschim Medinipur District of West Bengal in India: A land use system with multiple benefits. *International Journal of Environment and Sustainable Development, 14*(2),191–206 (also available on https://doi.org/10.1504/IJESD.2015.0686066).

Jana, S., Roy, J. (2019) *Biodiversity and Impacts of Climate Change in home gardens: Evidence from a study in West Bengal*, India. pp 113–132 Ch 7 in the edited volume Current State and Future Impacts of Climate Change on Biodiversity (Eds.), Ashok Kumar Rathore and Pawan Bharati Chauhan ISBN13: 9781799812265, IGI Global. https://www.igi-global.com/book/current-state-future-impacts-climate/231901

Jana, S. K., Roy, J. (2020). Climate change and diseases of plants and animals: A study in home gardens of West Bengal, India. In A. Karmaoui, A. Ben Salem, & A. Shah (Eds.), *Climate Change and Anthropogenic Impacts on Health in Tropical and Subtropical Regions* (pp. 37–62). IGI Global (also available on https://doi.org/10.4018/978-1-7998-2197-7.ch003, https://www.igi-global.com/book/climate-change-anthropogenic-impacts-health/235707)

Kanle Satishchandra, N., Vaddi, S., Naik, S. O., Chakravarthy, A. K., Atlihan, R. (2018). Effect of temperature and CO_2 on population growth of south American tomato moth, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) on tomato. *Journal of Economical Entomology, 111*(4), 1614–1624.

Khatri-Chhetri, A., Aggarwal, P., Joshi, P., & Vyas, S. (2017). Farmers' prioritization of climate-smart agriculture (CSA) technologies. *Agricultural Systems, 151*, 184–191.

Koerner, J., & Loboguerrero, A. M. (2019). *10 things to consider for scaling climate smart agricultural index-based insurances*. InfoNote, CCAFS (also available on https://ccafs.cgiar.org).

Krishnan, R., Sanjay, J., Gnanaseelan, C., Mujumdar, M., Kulkarni, A., & Chakraborty, S. (2020). *Assessment of Climate Change over the Indian Region: A Report of the Ministry of Earth Sciences (MoES), Government of India*. Springer, Singapore.

Kumar, A., Mishra, A. K., Saroj, S., Joshi, P. K. (2017). *Institutional versus Non institutional Credit to Agricultural Households in India: Evidence on Impact from a National Farmers' Survey*. IFPRI Discussion Paper 01614, The International Food Policy Research Institute (IFPRI): Washington, D.C.

Lobell, D. B., Sibley, A. & Ortiz-Monasterio, J. I. (2012). Extreme heat effects on wheat senescence in India. *Nature Climate Change, 2*, 186–189. https://doi.org/10.1038/NCLIMATE1356

Marambe, B., Weerahewa, J., Pushpakumara, G., Silva, P., Punyawardena, R., Premalal, S., Giashuddin, M. Md., Roy, J., Jana, S. (2018). Climate variability and adaptation of homegardens in South Asia: Case studies from Sri Lanka, Bangladesh and India. *Sri Lanka Journal of Food and Agriculture, 4*(2), 7–27.

Medhi, K., Paul, T., Borah, A. K., Bhattacharjya, B. K., Debnath, D., Yengkokpam, S., & Kuberan, G. (2018). Fish Stock Depletion in Indian Inland Open Waters: Present status and Approaches for Sustainable use, Conservation and Management. *Aquaculture Times, 4*(5), 26–32.

Mehajan, R. K., Tewary, A., & Gupta, S. (2019). Towards effective climate services: Indian Context. *Current Science, 117*(8), 1274–1280.

Merga, W., & Alemayehu, D. (2019). Effects of climate change on global arabica coffee (*Coffea arabica* L) production. *Greener Journal of Plant Breeding and Crop Science, 7*(1), 23–30.

MoA&FW. (2020). *e-NAM Mandis Trade Details*. Retrieved from Ministry of Agriculture and Farmers' Welfare, Government of India, also available on https://enam.gov.in/web/dashboard/trade-data.

MoEFCC. (2018). *India: Second biennial update report to the United Nations framework convention on climate change*. Ministry of Environment, Forest and Climate Change, Government of India.

Naresh Kumar, S. (2009). Climate change and Indian agriculture: current understanding on impacts, adaptation, vulnerability and mitigation. *Journal of Plant Biology, 37*(2), 1–16.

Naresh Kumar, S., Singh, A. K., Aggarwal, P. K., Rao, V. U. M., Venkateswarlu, B. (2012). *Climate change and Indian Agriculture: Salient achievements from ICAR network project*. IARI Publication, Indian Agricultural Research Institute, New Delhi.

Naresh Kumar, S., Islam, A., Swarooparani, D. N., Panjwani, S., Sharma, K., Lodhi, N. K., Chander, S., Sinha, P., Khanna, M., Singh, D. K., & Bandyopadhyay, S. K. (2019). *Seasonal Climate Change Scenarios for India: Impacts and Adaptation Strategies for Wheat and Rice* (p. 56). ICAR-IARI Pub TB-ICN: 233/2019.

Naresh Kumar, S., Aggarwal, P. K., Swarooparani, D. N., Saxena, R., Chauhan, N., & Jain, S. (2014a). Vulnerability of wheat production to climate change in India. *Climate Research, 59*, 173–187 (also available on https://doi.org/10.3354/cr01212).

Naresh Kumar, S., Aggarwal, P. K., Kumar, U., Jain, S., Swarooparani, D. N., Chauhan, N., & Saxena, R. (2014b). Vulnerability of Indian mustard (*Brassica juncea* (L) Czernj Cosson) to climate variability and future adaptation strategies. *Mitigation and adaptation strategies to global change, 21*(3), 403–420. https://doi.org/10.1007/s11027-014-9606-Z

Naresh Kumar, S. (2019). Climate change and horticultural crops In K.L. Chadha (Ed.) *Handbook of Horticulture, Vols. I and II,* Vol. I, pp. 83–92. ICAR Publication, Indian Council of Agricultural Research, New Delhi.

Naresh Kumar, S., Govindakrishnan, P. M., Swarooparani, D. N., Chauhan, N., Jain, S., Aggarwal, P. K. (2015). Assessment of impact of climate change on potato and potential adaptation gains in the Indo-Gangetic Plains of India. *International Journal of Plant Production, 9*(1), 151–170.

Naresh Kumar, S., Aggarwal, P. K. (2013). Climate change and coconut plantations in India: Impacts and potential adaptation gains. *Agricultural Systems, 117*, 45–54.

Naresh Kumar, S., Aggarwal, P. K., Saxena, R., Swarooparani, D. N., Jain, S., Chauhan, N. (2013). An assessment of regional vulnerability of rice to climate change in India. *Climate Change, 118*(3–4), 683–699 (also available on https://doi.org/10.1007/s10584-013-0698-3).

Nelson, G. C., Mark, W., Koo, R. J., Robertson, R., Sulser, T., Zhu, T., Ringler, C., Msangi, S., Palazzo, A., Batka, M., Magalhaes, M., Valmonte-Santos, R., Ewing, M, Lee, D. (2009). *Impact on agriculture and costs of adaptation*, IFPRI Food Policy Report, International Food Policy Research Institute, Washington, 19p.

Nowogrodzki, A. (2019). How climate change might affect tea: Changes in temperature and rainfall patterns can affect the growing season, flavour and health benefits of tea. *Nature 566*, S10–S11 (also available on https://doi.org/10.1038/d41586-019-00399-0).

Pathak, H., Nayak, A. K., Jena, M., Singh, O. N., Samal, P., & Sharma, S. G. (2018). *Rice Research for Enhancing Productivity, Profitability and Climate Resilience*. ICAR-National Rice Research Institute, Cuttack, Odisha, p. 527+xv.

Pathak, H., Gupta, A., Venkateswarlu, B., Goswami, G., & Chakradhar, T. (2019). *Global technology watch group: Sustainable agriculture*. Department of Science and Technology, Ministry of Science and Technology, Government of India and Technology Information, Forecasting and Assessment Council, New Delhi (p. 112).

Pathak, H., Pramanik, P., Khanna, M., & Kumar, A. (2014). Climate change and water availability in Indian agriculture impacts and adaptation. *Indian Journal of Agricultural Sciences, 84*, 671–679.

Piara Singh, P., Nedumaran, S., Boote, K. J., Gaur, P. M., Srinivas, K., & Bantilan, M. C. S. (2014). Climate change impacts and potential benefits of drought and heat tolerance in chickpea in South Asia and East Africa. *European Journal of Agronomy, 52*, 123–137.

Piara Singh, P., Boote, K. J., Kadiyala, M. D. M., Nedumaran, S., Gupta, S. K., Srinivas, K., Bantilan, M. C. S. (2017). An assessment of yield gains under climate change due to genetic modification of pearl millet. *Science of the Total Environment, 601*, 1226–1237.

Pingali, P., Aiyar, A., Abraham, M., & Rahman, A. (2019). *Transforming Food Systems for a Rising India*, p. 295. Palgrave Studies in Agricultural Economics and Food Policy. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-14409-8.

Porter, J. R., Xie, L., Challinor, A. J., Cochrane, K., Howden, S. M., Iqbal, M. M., Lobell, D. B., & Travasso, M. I. (2014). Food security and food production systems. In Field, et al., (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects.*

Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, USA, 485–533.

Pragna, P., Sejian, V., Bagath, M., Krishnan, G., Archana, P. R., Soren, N. M., Beena, V. & Bhatta, R. (2018). Comparative assessment of growth performance of three different indigenous goat breeds exposed to summer heat stress. *Journal of Animal Physiology and Animal Nutrition, 102*, 825–836.

Prasad, Y. G., Srinivasa Rao, Ch., Prasad, J. V. N. S., Rao, K. V., Ramana, D. B. V., Gopinath, K. A., Srinivas, I., Reddy, B. S., Adake, R., Rao, V. U. M., Maheswari, M., Singh, A. K., & Sikka, A. K. (2014). *Technology demonstrations: Enhancing resilience and adaptive capacity of farmers to climate variability.*. National Innovations in Climate Resilient Agriculture (NICRA) Project, ICAR-Central Research Institute for Dryland Agriculture, Hyderabad 109 p.

Prasanna, V. (2014). Impact of monsoon rainfall on the total foodgrain yield over. *India Journal of Earth System Science, 123*, 1129–1145.

Rao, C. R., Raju, B. M. K., Rao, A. S., Rao, K. V., Rao, V. U. M., Ramachandran, K., & Rao, C. S. (2016). A district level assessment of vulnerability of Indian agriculture to climate change. *Current Science, 110*(10), 1939–1946.

Rao, M. S., Rama Rao, C. A., Vennila, S., Manimanjari, D., Maheswari, M., & Venkateswarlu, B. (2014). Estimation of number of generations of Spodoptera litura Fab. on peanut in India during near and distant future climate change scenarios. *Scientific Research and Essays, 9*(7), 195–203.

Ray, P., & Chowdhury, S. (2015). Challenges in Indian agriculture and its implications for organising extension. *International Journal of Social Science, 4*(2,3), 201–215.

Rodriguez-Llanes, J. M., Ranjan-Dash, S., Degomme, O., Mukhopadhyay, A., Guha-Sapir, D. (2011). Child malnutrition and recurrent flooding in rural eastern India: a community-based survey, *BMJ Open, 1*:e000109, available at: https://bmjopen.bmj.com/content/1/2/e000109.

Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A. C., Müller, C., Arneth, A., Boote, K. J., Folberth, C., Glotter, M., Khabarov, N., Neumann, K., Piontek, F., Pugh, T. A. M., Schmid, E., Stehfest, E., Yang, H., & Jones, J. W. (2014). Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. *Proceedings of the National Academy of Sciences, 111*(9), 3268–3273, https://doi.org/10.1073/pnas.1222463110.

Roy, J., Ghosh, A., Majumdar, A., Roy, P., Mitra, A. P., Sharma, C. (2005). Socio-economic and physical perspectives of water related vulnerability to climate change: Results of field study in India. *Science and Culture, 71*(7–8), 239–259

Singh, N. P., Bhawana, A., Surendra, S., & Arshad, K. (2019). Mainstreaming climate adaptation in Indian rural development agenda-A micro –macro convergence. *Climate Risk Management, 24*, 30–41.

Somasundaram, J., Sinha, N. K., Dalal, R. C., Lal, R., Mohanty, M., Naorem, A. K., Hati, K. M., Chaudhary, R. S., Biswas, A. K., Patra, A. K., & Chaudhari, S. K. (2020). No-till farming and conservation agriculture in South Asia–Issues, challenges, prospects and benefits. *Critical Review Plant Science*, 1–44.

Some, S. K., Roy, J., & Ghose, A. (2019). Non-CO_2 emission from cropland based agricultural activities in India: A decomposition analysis and policy link. *Journal of Cleaner Production 225*, 637–646.

Srivastava, A., Kumar Naresh, S., Kumar, A. P. (2010). Assessment on vulnerability of sorghum to climate change in India. *Agricultural Ecosystem and Environment 138*, 160–169.

The Economic Survey. (2018). (also available on http://mofapp.nic.in:8080/economicsurvey/.)

TIFAC. (2019). *Global technology watch group: Sustainable agriculture*. Department of Science and Technology, Ministry of Science and Technology, Government of India and Technology Information, Forecasting and Assessment Council (p. 112), New Delhi.

Trivedi, R. K., Chand, B. K., Rout, S. K., Dubey, S. K., Beg, M. M., & Das, U. K. (2015). *Technical bulletin development of climate resilient aquaculture strategies for Sagar and Basant blocks of Indian Sunderban*. West Bengal University of Animal and Fisheries Science.

Vedeld, T., Salunke, S. G., Aandahl, G., & Lanjekar, P. (2014). *Governing extreme climate events in Maharashtra, India.* Final report on WP3.2: Extreme Risks, Vulnerabilities and Community-based Adaptation in India (EVA): A Pilot Study, CIENS-TERI, TERI Press, New Delhi, India.

Vennila, S., Jitender, S., Srinivasa Rao, M., Prabhakar, M., & Sridhar, V. (2018). Impact of climate change on pest scenario in India. In C. Chattopadhyay, R. K. Tanwar, M. Sehgal, A. Birah, S. Bhagat, N. Ahmad, N. Mehta (Eds.), *Handbook of integrated pest management* (pp. 219–225). Indian Council of Agricultural Research (ICAR), New Delhi.

Viswanath, K. P., Sinha, S., Kumar, N., Taru, S., Shalini, S., Shweta, P., Pathak, H., & Shalu, M. S. (2017). *Simulation of leaf blast infection in tropical rice agro-ecology under climate change scenario climatic change* (also available on https://doi.org/10.1007/s10584-017-1942-z)

Vivekanandan, E., Jeyabaskaran, R. (2010). *Impact and adaptation options for Indian marine fisheries to climate change. Climate change adaptation strategies in agriculture and allied sectors*, pp.107–117. Scientific Publishers.

von Grebmer, K., Bernstein, J., Alders, R., Dar, O., Kock, R., Rampa, F., Wiemers, M., Acheampong, K., Hanano, A., Higgins, B., Ní Chéilleachair, R., Foley, C., Gitter, S., Ekstrom, K., & Fritschel, H. (2020). *Global hunger index: One decade to zero hunger: Linking health and sustainable food systems*. Bonn: Welthungerhilfe; and Dublin: Concern Worldwide.

Symbiosis of Water and Agricultural Transformation in India

Mihir Shah and P. S. Vijayshankar

1 Green Revolution: Context and Achievements

Recent revisionist scholarship[1] on the Green Revolution has conclusively established that the assumption of a stagnant food sector in the first two decades after independence is a myth (Balakrishnan, 2007). It also shows that neo-Malthusian fears of starvation in the Indian context were, indeed, exaggerated.[2] At the same time, there is also no denying that the Indian political leadership was deeply troubled by excessive dependence on wheat shipments under the PL-480 Food Aid Programme of the United States of America.[3] We cannot overlook the fact that 90% of the food that the government distributed through the public distribution system (PDS) between 1956 and 1960 came from imports and remained as high as 75% even during the period from 1961 to 1965. In 1965–66, the United States of America shipped 10 million tonnes of wheat to India (Tomlinson, 2013). At that point, India had less than half the food needed to provide a basic subsidised ration to the poorest 25% of the population (Krishna, 1972). Hence, there was a nationalist impulse that propelled

[1] See especially Subramanian (2015). Stone (2019) provides a good summary of the emerging work.

[2] Cullather (2010, Chap. 8) brilliantly teases out how the view that "only chemical fertiliser and birth control could keep mankind off a treadmill to starvation" became dominant in the 1960s, pushing for support to the Green Revolution as the only way to save India from self-destructing through famine.

[3] Especially distressing was the introduction of the "short-tether" policy in 1965–66 by the Lyndon Johnson administration, which refused to commit PL-480 wheat shipments to India more than one month in advance (Tomlinson, 2013).

M. Shah (✉)
Shiv Nadar University, Greater Noida, India
e-mail: mihirbhai25@gmail.com

P. S. Vijayshankar
Samaj Pragati Sahayog, Dewas, India

R. Chand et al. (eds.), *Indian Agriculture Towards 2030*,
India Studies in Business and Economics,
https://doi.org/10.1007/978-981-19-0763-0_5

Table 1 Food grain procurement and buffer stock, 1972–2018 (million tonnes)

Year	Procurement	Buffer stock
1972–73	7.51	2.60
1982–83	14.85	11.10
1992–93	17.16	12.67
2002–03	38.03	32.81
2012–13	72.19	59.76
2017–18	68.20	43.31

Source DAC (2020). https://eands.dacnet.nic.in

the Green Revolution and it cannot be seen as merely a conspiracy of imperialist capital, although it is certainly the case that corporations supplying key inputs to Green Revolution agriculture were major beneficiaries of this radical policy shift.[4]

What also needs to be acknowledged is that following the Green Revolution, India achieved self-sufficiency in food like never before. The buffer stock, which was hardly 3 million tonnes in the early 1970s, had already reached 60 million tonnes in 2012–13 (Table 1), and peaked at almost 100 million tonnes in July 2020 (Dreze, 2021). The single most important fact worth noting here is that in the early 1970s itself, the net sown area had almost reached 140 million hectares and this figure has remained more or less unchanged over the past five decades. During the same period, the gross cropped area has risen steadily with the cropping intensity growing from 119 to 140% (Table 2).

It can then be argued, somewhat more debatably, that without the intensification that occurred under the Green Revolution, the degradation of common lands and forests could have advanced at an even more rapid rate than it has done during this period.[5]

[4] How politically invested the United States of America was in the Green Revolution is quite evident from this articulation by the person who coined the term: "These developments in the field of agriculture contain the makings of a new revolution. It is not a violent Red Revolution like that of the Soviets, nor is it a White Revolution like that of the Shah of Iran. I call it the Green Revolution." From *The Green Revolution: Accomplishments and Apprehensions*, address by William S. Gaud, Administrator, US Agency for International Development, 8 March 1968. How a broad-based political consensus cutting across ideological divisions emerged in the United States of America in the 1960s around the view that "economic development represented the primary defence against an evolving communist strategy of subversion and economic penetration" (p. 154), has been well documented in Cullather (2010).

[5] This proposition is debatable because it is based on deeply problematic assumptions: that alternatives to the Green Revolution necessarily require more land to produce the same output and that the implications of Green Revolution farming for ecology, resilience, income stability and health are small enough to be ignored.

Table 2 All-India net sown area and gross cropped area, 1950–2015

Period	Net sown area ('000 ha)	Gross cropped area ('000 ha)	NSA/TGA (%)	GCA/TGA (%)	GCA/NSA (cropping intensity) (%)
1950–51 to 1954–55	123,248	137,874	37	42	112
1955–56 to 1959–60	130,770	149,418	40	45	114
1960–61 to 1964–65	135,908	156,387	41	48	115
1965–66 to 1969–70	137,863	159,632	42	49	116
1970–71 to 1974–75	139,587	165,438	42	50	119
1975–76 to 1979–80	140,993	171,051	43	52	121
1980–81 to 1984–85	141,467	175,604	43	53	124
1985–86 to 1989–90	139,759	178,031	43	54	127
1990–91 to 1994–95	142,505	185,650	43	56	130
1995–96 to 1999–00	142,178	189,401	43	58	133
2000–01 to 2004–05	139,073	185,602	42	56	133
2005–06 to 2009–10	140,614	192,971	43	59	137
2010–11 to 2014–15	140,806	197,405	43	60	140

Source DAC (2020). https://eands.dacnet.nic.in
Note TGA Total geographical area

2 Constituent Elements of the Green Revolution Paradigm

Subramanian (2015) is right in arguing that these achievements were not the result merely of moving to high-yielding dwarf varieties of seeds. Indeed, it is extremely important to recognise that the Green Revolution was a package deal, a combination of radical changes in the political economy of Indian agriculture, with several path-breaking interventions. These included the following:

- **Higher-yielding seeds and concomitant use of chemical fertilisers and pesticides**: The consumption of fertilisers rose dramatically from 2 million tonnes in 1970–71 to more than 27 million tonnes in 2018–19 (Table 3). Similarly, synthetic pesticide consumption has grown sharply over the past decade (Table 4). Just six

Table 3 Fertiliser consumption in India, 1950–2019

Year	Fertiliser use ('000 tonnes)
1950–51	70
1960–61	294
1970–71	2257
1980–81	5516
1990–91	12,546
2000–01	16,702
2010–11	28,122
2018–19	27,228

Source Fertiliser Association of India. www.faidelhi.org/general/con-npk.pdf

Table 4 Synthetic pesticide consumption in India, 2001–2020

Period	Consumption ('000 tonnes)
2001–04	45.46
2004–07	41.28
2007–10	42.44
2010–13	51.38
2013–16	56.84
2016–19	60.46
2019–20	60.56

Source Agricultural Statistics at a Glance, 2019 for 2001–19; Directorate of Plant Protection, Quarantine and Storage, Department of Agriculture and Co-operation for 2019–20

states (Maharashtra, Uttar Pradesh, Punjab, Telangana, Haryana and West Bengal) together accounted for about 70% of total chemical pesticide consumption in the country in 2019–20.

- **Breakthrough in irrigation**: Following the Green Revolution there was a sea-change in the extent of irrigation, as well as in the way India irrigated her fields. Irrigated area more than doubled, both in absolute terms and as a percentage of net sown area (Fig. 1). Over time, groundwater, especially that provided by deep tubewells, has become the single largest source of irrigation (Fig. 2). This form of irrigation allows farmers greater control over water—as and when, and in the volumes that the crops require it. Over the last four decades, around 84% of total addition to the net irrigated area has come from groundwater. At 250 billion cubic metres (BCM), India draws more groundwater every year than any other country in the world. India's annual consumption is more than that of China and the United States of America (the second and third largest groundwater-using countries) put together (Vijayshankar et al., 2011).

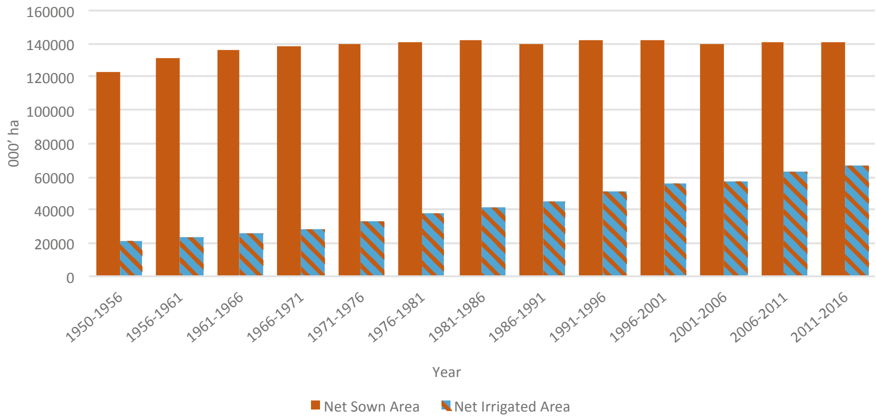


Fig. 1 All-India net sown and net irrigated area, 1950–2016. *Source* DAC (2020). https://eands.dacnet.nic.in

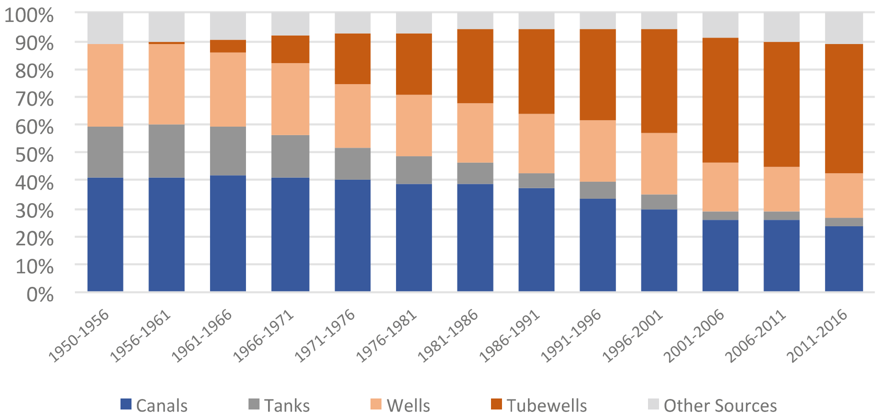


Fig. 2 All-India percentage of irrigation from different sources, 1950–2016. *Note* "Other Sources" largely include groundwater sources, such as dug-cum-borewells. Hence, groundwater could well be said to account for nearly 70% of irrigation today. *Source* DAC (2020). https://eands.dacnet.nic.in

- **Easier availability of credit**: The access to seeds, fertilisers, pesticides and new irrigation technology was made possible by the easier availability of credit. The nationalisation of 14 banks in 1969 was a landmark step in the direction of improving access to reasonably priced credit in rural India. Recent arguments in favour of re-privatisation overlook the fact that the National Credit Council found that before nationalisation not even 1% of India's villages were served by commercial banks. Furthermore, in 1971, the share of banks in rural credit was no more than 2.4%, with most of these loans being made to plantations, not farmers.

It is the easier availability of credit that fuelled the investments that drove India's Green Revolution (Shah et al., 2007).[6]

- **Role of the agricultural extension system**: Since the Green Revolution meant a completely new way of doing farming, a critical role was played by the state-supported agricultural extension system. Today, it may be quite difficult to imagine what a humongous task this was, covering hundreds of thousands of farmers. Of course, the paradigm of agricultural extension during the Green Revolution was what may be described as 'top-down, persuasive and paternalistic technology transfer', which provided specific recommendations to farmers about the practices they should adopt. If an alternative is to be found to the Green Revolution today, great effort will be needed to re-energise and re-orient this extension system, which today finds itself in a state of almost total collapse. It will also be necessary to move towards a much more 'farmer-to-farmer participatory extension system'.
- **A stable market**: The setting up of the Food Corporation of India (FCI) in 1965 and the ensuing—and expanding—procurement operations at minimum support prices (MSPs) ensured a stable market for the farmers.[7] Without this state intervention, left to the vagaries of the free market, the Green Revolution would not have taken off, as the expanded output could have created problems for the farmers, due to a fall in price at times of bumper harvest.[8]

3 Wheels Come Off the Green Revolution

While it is undeniable that the Green Revolution paradigm represents a powerful break from the past that provided India with comfortable food security,[9] it is also true that over the decades that followed, it sowed the seeds of its own destruction, leading to a grave farming crisis in India today. More than 300,000 farmers have committed suicide in the last 30 years, a phenomenon completely unprecedented in Indian history.[10] There is growing evidence of steady decline in water tables and

---

[6] There were, undoubtedly, many problems in the manner in which rural credit was handled, which will be dealt with when we describe the paradigm shift required in the architecture of the Green Revolution.

[7] The Foodgrains Prices Committee (1964) recommended the setting up of the Food Corporation of India "to enable the government to undertake trading operations through which it can influence the market prices". Minimum support prices were to be recommended by the Agricultural Prices Commission, also set up in 1965. With this, another objective was added to the food security system: "to guarantee reasonable prices to the farmers and thereby increase production" (Mooij, 1998).

[8] There were, of course, many limitations in the nature and scope of the procurement operations, which we will describe in the elaboration of the new paradigm.

[9] This is food security defined narrowly as having sufficient buffer stocks to ward off any unexpected price surge following shortfalls in production. This food security is very different from nutritional security, which does not exist even today, which is also why we are advocating a paradigm shift in agriculture.

[10] This data comes from the National Crime Records Bureau, as committing suicide still remains a crime under Indian law.

water quality. At least 60% of India's districts are either facing a problem of over-exploitation or severe contamination of groundwater (Vijayshankar et al., 2011). There is evidence of fluoride, arsenic, mercury and even uranium and manganese in groundwater in some areas. The increasing levels of nitrates and pesticide pollutants in groundwater have serious health implications. The major health issues resulting from the intake of nitrates are methemoglobinemia and cancer (WHO, 2011). The major health hazards of pesticide intake through food and water include cancers, tumours, skin diseases, cellular and DNA damage, suppression of the immune system and other intergenerational effects (Margni et al., 2002).[11] Repetto and Baliga (1996) provide experimental and epidemiological evidence that many pesticides widely used around the world are immune-suppressive. Nicolopoulou-Stamati et al. (2016) provide evidence of pesticide-induced temporary or permanent alterations in the immune systems and Corsini et al. (2008) show how such immune alteration could lead to several diseases. Agricultural workers spraying pesticides are a particularly vulnerable group, especially in India where they are rarely provided protective gear. A study of farm workers in Punjab found significantly higher frequency of chromosomal aberrations in peripheral blood lymphocytes of workers exposed to pesticides, compared to those not exposed (Ahluwalia & Kaur, 2020). A study of 659 pesticides, which examined their acute and chronic risks to human health and environmental risks, concludes that

> evidence demonstrates the negative health and environmental effects of pesticides, and there is widespread understanding that intensive pesticide application can increase the vulnerability of agricultural systems to pest outbreaks and lock in continued reliance on their use. (Jepson et al., 2020)

It is also clear that the yield response to the application of increasingly more expensive chemical inputs is falling. Indoria et al. (2018) show that the average crop response to fertiliser use has fallen from around 25 kg grain/kg of nitrogen, phosphorus and potassium (NPK) fertiliser during the 1960s to a mere 6 kg grain/kg NPK by 2010 (Fig. 3). This has meant higher costs of cultivation, without a corresponding rise in output, even as this intensified application of inputs compels farmers to draw more and more water from below the ground.

Moreover, despite overflowing granaries, the 2021 *Global Hunger Index Report* ranked India 101 out of 116 countries.[12] FAO et al. (2020) estimate that more than 189 million people remained malnourished in India during 2017–19, which is more than a quarter of the total such people in the world.[13] In 2019, India had 28% (40.3

---

[11] Even at low concentration, pesticides exert several adverse effects that may manifest at biochemical, molecular or behavioural levels. The actual transport, presence and impact are, of course, influenced by drainage, rainfall, microbial activity, soil temperature, treatment surface, application rate, as well as the solubility, mobility and half-life of individual pesticides.

[12] https://www.globalhungerindex.org/india.html.

[13] It has also been correctly pointed out that in tackling hunger what matters is not just the size of the buffer stock but its distribution among those who remain in need of it. In July 2020, the buffer stock reached 100 million tonnes but cereal distribution under the PDS and other welfare schemes has been only around 60 million tonnes in 2020–21 (Dreze, 2021).

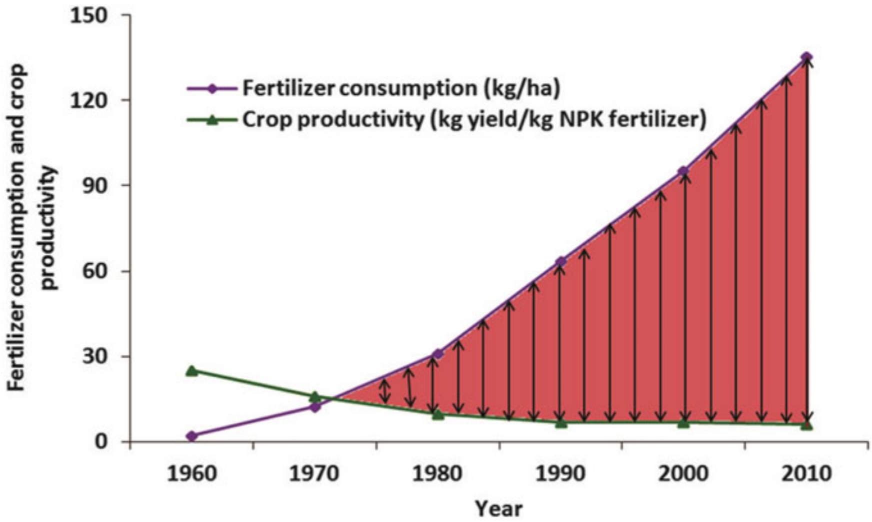


Fig. 3 Relationship between fertiliser consumption and crop productivity. *Source* Indoria et al. (2018, Fig. 2)

million) of the world's stunted children (low height-for-age) and 43% (20.1 million) of the world's wasted children (low weight-for-height) under five years of age.[14]

Paradoxically, at the same time, diabetics have increased in every Indian state between 1990 and 2016, even among the poor, rising from 26 million in 1990 to 65 million in 2016. This number is projected to double by 2030 (Shah, 2019).

4 The Paradigm Shift Required in Agriculture

It is important to understand precisely why this multi-fold unravelling was inherent in the very architecture of the Green Revolution and what can be done to institute a paradigm shift in farming in India.

[14] A new joint study by the Oxford and Lancaster Universities, BITS Pilani and Bocconi University, Italy shows that "there was no evidence that receipt of PDS rice and sugar was associated with improvements in child nutrition" (Bartell et al., 2020).

4.1 Not Quite a Green Revolution: Towards Crop Diversification Reflecting Agroecology of Diverse Regions

It is now widely recognised that the Green Revolution was simply a wheat-rice revolution.[15]

As can be seen from Tables 5 and 6, over the past 50 years, the share of nutri-cereals in cropped area has gone down dramatically in all parts of India. Even in absolute terms the acreage under these cereals has almost halved between 1962–65 and 2012–14. The share of pulses has also drastically come down in the states of Assam, Bihar, Haryana, Himachal Pradesh, erstwhile Jammu and Kashmir, Jharkhand, Odisha, Uttar Pradesh, Uttarakhand and West Bengal. The share of oilseeds appears to have risen, but that is mainly on account of the rise in acreage under soya.[16] Figure 4 shows that the share of soyabean in oilseeds acreage rose from less than 1% in the early 1970s to over 40% in 2016–17, even as the share of the other eight oilseeds has stagnated. Other than soyabean, the only other crops showing a rise in acreage during the period of the Green Revolution are wheat, rice and sugarcane.

The rise in the acreage of wheat and rice is a direct consequence of the procurement and price support offered by the state. In the case of sugarcane and soyabean, the rise in acreage is due to the purchase by sugar mills and soya factories. But the main story of the Green Revolution is the story of rice and wheat, which remain the overwhelming majority of crops procured by the government even today, even after a few states have taken tentative steps towards diversification of their procurement basket to include nutri-cereals and pulses (Table 7). What is worse, public procurement covers a very low proportion of India's regions and farmers (Khera et al., 2020).

This also reflects the fact that the primary target of procurement is the consumer, not so much the farmer. Thus, procurement gets limited to what is needed to meet the requirements of consumers. This showed up in the way imports of pulses were ramped up during 2016–18, even though it had been decided to try and expand procurement of pulses. The latter suffered as a result and pulse growers were the losers. Thus, the pathway for reforms becomes very clear: *we need to greatly expand the basket of public procurement to include more crops, more regions and more farmers*.[17] By doing so we can make a huge dent in solving India's water problem, while at the same time tackling farmer distress and India's nutritional crisis.

A recent study supported by the National Bank for Agriculture and Rural Development (NABARD) and the Indian Council for Research in International Economic

---

[15] Even globally, around 60% of all the plant calories and proteins come from just three grass crops—rice, maize, wheat—even though the FAO claims that at least 30,000 of the 350,000 known plant species on our planet are edible (Miller, 2021).

[16] See Vijayshankar (2016) for an account of how state support played a crucial role in pushing the "soya-wheat revolution" in Madhya Pradesh.

[17] The experience of the *Pradhan Mantri Garib Kalyan Anna Yojana* in 2020 has demonstrated the possibilities and power of expanding pulses in the PDS (Dreze, 2021).

Table 5 All-India and region-wise cropped area (‘000 ha)

Region	Period	Rice	Wheat	Nutri-cereals[a]	Pulses	Oilseeds	Sugarcane	Others	Total
North West	1962–65	5152	6724	7795	7059	4115	1539	1004	33,455
	1980–83	7376	13,160	6250	4193	4154	1825	1941	38,821
	1990–93	7991	13,459	4512	3403	2409	1988	4588	38,236
	2003–06	9096	14,752	3797	2848	1819	2215	5141	39,549
	2012–14	9680	15,291	3319	2410	1659	2252	4741	39,511
East	1962–65	14,623	667	1719	3643	770	231	4105	25,655
	1980–83	15,828	2018	2046	3382	1563	227	3410	28,416
	1990–93	15,948	2121	1307	2847	1830	203	4648	29,050
	2003–06	14,885	2193	1014	1700	1234	603	5757	27,413
	2012–14	16,358	2596	1228	1507	1396	307	4466	27,915
Central	1962–65	5934	5400	21,421	9375	6765	237	10,087	59,338
	1980–83	6494	6494	21,975	10,889	7347	394	11,807	65,596
	1990–93	6822	6409	19,571	11,301	12,128	551	12,404	68,911
	2003–06	7001	7075	16,434	12,086	15,255	590	15,476	73,697
	2012–14	7495	9918	9767	11,887	17,944	1211	17,414	75,711
South	1962–65	7613	319	11,212	2930	3727	255	5733	31,852
	1980–83	7371	314	8908	3388	4140	502	6587	31,366
	1990–93	7169	196	6580	3830	6776	655	7529	32,736
	2003–06	6613	250	5771	4211	5740	655	7798	31,193
	2012–14	7902	210	5595	4755	5455	1294	9790	34,966
All India	1962–65	34,500	13,467	42,368	23,151	14,829	2270	21,184	151,315

(continued)

Table 5 (continued)

Region	Period	Rice	Wheat	Nutri-cereals[a]	Pulses	Oilseeds	Sugarcane	Others	Total
	1980–83	37,779	21,541	39,602	21,872	17,233	2983	24,855	165,698
	1990–93	38,828	21,946	31,400	24,310	22,453	3376	27,011	168,817
	2003–06	38,913	24,147	26,926	20,846	23,973	3648	34,744	173,718
	2012–14	39,616	27,965	23,304	20,973	26,530	5019	35,852	179,260

[a] The Government of India took a historic decision in 2018 of renaming traditional cereals as 'nutri-cereals', dispensing with the long-standing nomenclature, which described them as 'coarse cereals', with an implicit inferior status. In a notification, the agriculture ministry said, "the central government hereby declares millets comprising sorghum (*jowar*), pearl millet (*bajra*), finger millet (*ragi/mandua*), minor millets—foxtail millet (*kangani/kakun*), proso millet (*cheena*), kodo millet (*kodo*), barnyard millet (*sawa/sanwa/ jhangora*), little millet (*kutki*) and two pseudo millets black-wheat (*kuttu*) and ameranthus (*chaulai*) which have high nutritive value as "Nutri Cereals"." (https://www.financialexpress.com/market/commodities/government-renames-millets-as-nutri-cereals/1140338)

Notes 1. Tables 5 and 6 are based on calculations that are an update of the pioneering work of Bhalla and Singh (2009) extended till 2012–14 based on Indian Agricultural Statistics

2. As in Bhalla and Singh (2009), in these calculations, all states of the north-east, except Assam, are excluded and only the 44 major crops are included

3. **North-West**: Haryana, Himachal Pradesh, erstwhile Jammu and Kashmir, Uttar Pradesh and Uttarakhand; **East**: Assam, Bihar, Odisha, Jharkhand, West Bengal; **Central**: Chhattisgarh, Gujarat, Madhya Pradesh, Maharashtra, Rajasthan; **South**: Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Telangana

Table 6 All India and region-wise distribution of cropped area (%)

Region	Period	Rice	Wheat	Nutri-cereals	Pulses	Oilseeds	Sugarcane	Others	Total
North West	1962–65	15	20	23	21	12	5	3	100
	1980–83	19	34	16	11	11	5	5	100
	1990–93	21	35	12	9	6	5	12	100
	2003–06	23	37	10	7	5	6	13	100
	2012–14	25	39	8	6	4	6	12	100
East	1962–65	57	3	7	14	3	1	16	100
	1980–83	56	7	7	12	6	1	12	100
	1990–93	55	7	5	10	6	1	16	100
	2003–06	54	8	4	6	5	2	21	100
	2012–14	59	9	4	5	5	1	16	100
Central	1962–65	10	9	36	16	11	0	17	100
	1980–83	10	10	34	17	11	1	18	100
	1990–93	10	9	28	16	18	1	18	100
	2003–06	10	10	22	16	21	1	21	100
	2012–14	10	13	13	16	24	2	23	100
South	1962–65	24	1	35	9	12	1	18	100
	1980–83	24	1	28	11	13	2	21	100
	1990–93	22	1	20	12	21	2	23	100
	2003–06	21	1	19	14	18	2	25	100
	2012–14	23	1	16	14	16	4	28	100
All India	1962–65	23	9	28	15	10	2	14	100
	1980–83	23	13	24	13	10	2	15	100
	1990–93	23	13	19	14	13	2	16	100
	2003–06	22	14	16	12	14	2	20	100
	2012–14	22	16	13	12	15	3	20	100

Relations (ICRIER) estimated that about 78% of India's water is consumed in agriculture (Sharma et al., 2018). FAO's AQUASTAT database puts this figure closer to 90% (FAO, 2019). The NABARD-ICRIER study identified three "water guzzler" crops—rice, wheat and sugarcane—which occupy about 41% of the gross cropped area and consume more than 80% of irrigation water. Shah (2019) suggests that sugarcane, which occupies just 4% of cropped area, uses up 65% of irrigation water in Maharashtra. In Karnataka, rice and sugarcane, which cover 20% of cropped area, consume as much as 70% of irrigation water (Karnataka Knowledge Commission, 2019). This has meant grave inequity in the distribution of irrigation water across crops and farmers, and also a terrible mismatch between existing water endowments and the water demanded by these water-guzzling crops. The main reason why farmers grow such crops even in areas of patent water shortage is the structure of incentives,

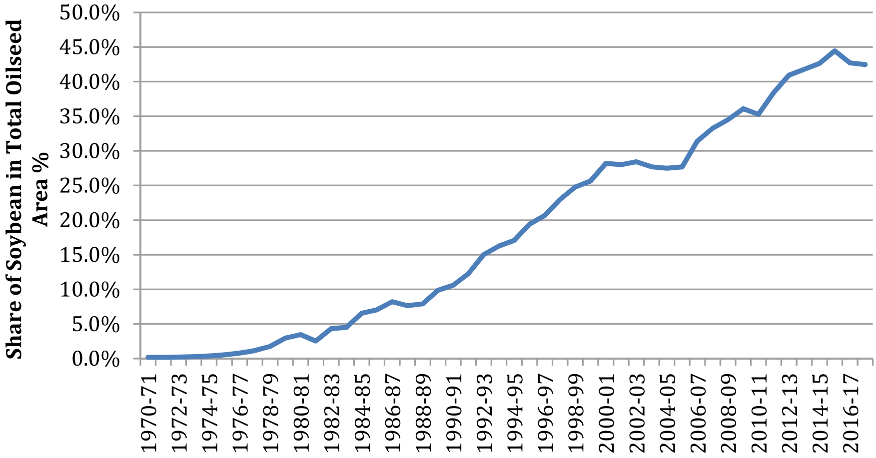


Fig. 4 Share of soyabean in total area under oilseeds. *Source* DAC (2018). *Agricultural Statistics at a Glance*

Table 7 Share of crops in public procurement, 2007–2019 (%)

Year	Rice	Wheat	Nutri-cereals	Pulses	Total
2007–08	70	29	1	0	100
2008–09	58	40	2	0	100
2009–10	52	41	7	0	100
2010–11	53	45	2	0	100
2011–12	55	44	1	0	100
2012–13	47	52	1	0	100
2013–14	55	43	2	0	100
2014–15	53	46	1	1	100
2015–16	55	45	0	0	100
2016–17	61	36	0	3	100
2017–18	54	44	0	2	100
2018–19	37	58	0	5	100

Source DAC (2018)

as they find that these crops have steady markets. Even a small reduction in the area under these crops, in a region-specific manner and in a way that does not endanger food security, would go a long way in addressing India's water problem.

Thus, the first element of the paradigm shift required in Indian agriculture is to change this distorted structure of incentives. The most important step in this direction is for the government to diversify its crop procurement operations in a very carefully calibrated, location-specific manner, to align with local agroecologies. The best way of doing this is to start procurement of crops that match the agroecology of each region.

India's cropping pattern before the Green Revolution included a much higher share of millets, pulses and oilseeds. These agroecologically appropriate crops must urgently find a place in public procurement operations. As this picks up pace, farmers will also gradually diversify their cropping patterns in alignment with this new structure of incentives. The largest outlet for the millets, oilseeds and pulses procured in this manner—in line with the *POSHAN Abhiyaan*[18] launched by the Government of India—would be the supplementary nutrition and meals provided under the Integrated Child Development Services (ICDS) and the *Pradhan Mantri Poshan Shakti Nirman Yojana* (PM POSHAN Scheme),[19] as also the grains provided through the PDS.

A few state governments are also slowly moving forward in this direction. The Odisha Millets Mission (OMM) initiated in 2017–18 works on four verticals—production, processing, marketing and consumption, through a unique institutional architecture of partnerships with academia and civil society. As of 2020–21, the programme, aimed at encouraging 100,000 farmers to cultivate millets, had spread across 76 blocks in 14 districts. The *mandia ladoos* (finger millet sweet) prepared by women self-help groups (SHGs) and introduced by the Government of Odisha under the ICDS have proved extremely popular among the pre-school children (Jena & Mishra, 2021). Reports from the ground in 2020 describe the overwhelming enthusiasm, especially among tribal farmers, who were typically hitherto excluded, and how they undertook arduous journeys to reach government procurement centres (Dinesh Balam, personal communication).

A similar noteworthy example is that of the tribal-dominated Dindori district in Madhya Pradesh, a malnutrition hotspot in recent decades. Here a state government-civil society partnership has led to a revival in the cultivation of *kodo* (Dutch millet) and *kutki* (little millet), which are renowned for their anti-diabetic and nutritional properties. The Government of Madhya Pradesh's Tejaswini Rural Women's Empowerment programme helped women SHG federations develop a business plan for establishing a supply-chain for *kodo* bars and *barfis* (fudge), which were included in the ICDS supplementary nutrition programme. The products were clinically tested for their nutrient content at laboratories certified by the National Accreditation Board for Testing and Calibration Laboratories (NABL), to ensure appropriate standards of taste and quality (Mathur & Ranjan, 2021). These are the kinds of reforms and outreach all states need to pursue, with support from the Centre.

Done at scale, this would enable a steady demand for these nutritious crops and help sustain a shift in cropping patterns, which would provide a corrective to the currently highly skewed distribution of irrigation to only a few crops and farmers. It would also be a significant contribution to improved nutrition, especially for children,

[18] *POSHAN* (PM's Overarching Scheme for Holistic Nourishment) *Abhiyaan* is the Government of India's flagship programme to improve nutritional outcomes among children and women.

[19] *Pradhan Mantri Poshan Shakti Nirman Yojana* (PM's Nutritional Capacity Building Scheme) is the expanded version of the earlier Mid Day Meal Scheme.

and a powerful weapon in the battle against the twinned curse of malnutrition and diabetes.

It is quite evident that a major contributor to this "syndemic" is the displacement of whole foods in the average Indian diet by energy-dense and nutrient-poor, ultra-processed food products.[20] Recent medical research has found that some millets contain significant anti-diabetic properties. According to the Indian Council of Medical Research, foxtail millet has 81% more protein than rice. Millets have higher fibre and iron content, and a low glycemic index. Millets also are climate-resilient crops suited for the drylands of India. If children were to eat these nutri-cereals—which provide a higher content of dietary fibre, vitamins, minerals, protein and antioxidants and a significantly lower glycemic index—India would be better placed to solve the problems of malnutrition and obesity.

To clarify, this is not a proposal for open-ended public procurement. That would be neither feasible nor desirable. The argument is for diversification of the procurement basket to include crops suited to local agroecologies. A useful benchmark could be 25% of the actual production of the commodity for that particular year/season (to be expanded up to 40%, if the commodity is part of the PDS), as proposed under the 2018 PM-AASHA[21] scheme. Without such an initiative, the announcement of MSPs for 23 crops every year is reduced to a token ritual, with little benefit to most farmers.

If such a switch in cropping patterns, to reflect the agroecological diversity of India, were to be effected, what volume of water would India save by the year 2030? We have made an attempt to quantify the water that could be saved each year in 11 major agricultural states: Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Telangana and Tamil Nadu.[22] These states together accounted for about 66% of the total irrigated area of the country in 2015–16. We quantify the baseline water used in the production of crops using the average (mean) yields and areas for each crop in each state in the most recent ten-year period for which data are available. We compare the baseline water use to two exploratory scenarios of crop replacements:

Scenario 1 (small change): Replacement of high water-demanding crops with low water-using ones to the extent of 10–25% of the crop area in the *kharif* season and 25% in the *rabi* season; and

Scenario 2 (higher change): Replacement of high water-demanding crops with low water-using ones to the extent of 25–50% of the crop area in the *kharif* season and 50% in the *rabi* season.

[20] A 2019 report by the Lancet Commission, *The Global Syndemic of Obesity, Undernutrition, and Climate Change,* draws attention to this phenomenon. See also Gulati and Misra (2014).

[21] *Pradhan Mantri Annadata Aay SanraksHan Abhiyan* (PM-AASHA) is aimed at ensuring remunerative prices to farmers for their produce.

[22] The basic data on yield, area under cropping and production is derived from the database of Directorate of Agriculture and Co-operation (DAC), Government of India.

Table 8 Crop replacements scenarios by state and seasons

State	Scenario I (% replacement)		Scenario II (% replacement)	
	Kharif	Rabi	Kharif	Rabi
Andhra Pradesh	10	25	25	50
Bihar	10	25	25	50
Gujarat	25	25	50	50
Haryana	25	25	50	50
Karnataka	25	25	50	50
Madhya Pradesh	10	25	25	50
Maharashtra	25	25	50	50
Punjab	25	25	50	50
Rajasthan	0	25	0	50
Tamil Nadu	10	0	25	0
Telangana	10	25	25	50

Rice is the major irrigated crop in the southern states of Andhra Pradesh, Karnataka, Telangana and Tamil Nadu, while wheat is the major irrigated crop in Bihar, Gujarat, Madhya Pradesh and Rajasthan. Both rice and wheat are heavily irrigated in Punjab and Haryana. We explore possible crop switches in both *kharif* and *rabi* seasons. In each state, we have taken one high water footprint crop in each season and estimated water saving by switching the area under this crop to two lower water footprint crops. Table 8 gives the list of states and seasons analysed.

First, we quantify baseline crop production based on recent yield and area data.[23] Our purpose is to build different scenarios to demonstrate the potential of water savings through crop replacements. For estimating the irrigation water use in these crop replacement scenarios, we have calculated blue water footprints, which represent the volume of water consumed during crop production in m^3 per tonne. Season and state-specific water footprints for cereal crops were drawn from Kayatz et al. (2019) and for other crops from Mekonnen and Hoekstra (2011).[24] In this method, the total evapo-transpiration (ET) requirement of the crops is estimated using FAO's CROPWAT model. National and state specific ET for each of the crops studied is generated, which is modified by the crop factor (k) to get estimated consumptive use of water or total water footprint (TWF) by each crop in each state. The proportion of the green water footprint (GWF) is estimated by modelling effective rainfall during

[23] We use time-series data for the period 2008–17, the latest ten-year period for which data from the DAC is available for each selected crop in each season (DAC, 2020). Area multiplied by yield gives estimates of crop production.

[24] Their data is for the period 1996–2005, which is the most recent available estimate for non-cereal crops at the state level. These figures have not been updated as this would require a substantial analysis, beyond the scope of this paper. Nevertheless, our analysis provides a meaningful order of magnitude of the change in water use that can be achieved through this shift in cropping pattern.

the season. The difference between TWF and GWF is attributed to the irrigation component or the blue water footprint (BWF) of crops.[25] The BWF is multiplied by crop production, to get estimated blue water use by crops in each state in each season.[26]

To estimate the potential for annual water savings, we propose crop switches in both *kharif* and *rabi* crops in different states, through the scenarios in Table 8.[27]

In these 11 states, we take the area under three most water-intensive crops, namely rice, wheat and sugarcane, and re-distribute the area to the replacement crops,[28] which are largely pulses and nutri-cereals. The choice of the replacement crops is governed by an analysis of the cropping pattern of the concerned state in the period before the monoculture of the Green Revolution took firm roots there. Thus, these are crops suited to the agroecology of each region and, therefore, their revival has a solid basis in both agricultural science and farmer experience. The water savings were calculated based on the change in irrigation water required for each state in each season. Irrigation water savings are given as the difference between the water-use at baseline as compared to the crop replacement scenarios. In order to make suitable and realistic proposals for crop replacements, we consider several factors:

- **Seasons**: Crop production is strongly determined by seasons, which need to be taken into account while proposing replacements. For example, since most of the nutri-cereals are grown in the kharif season, we cannot propose a replacement of wheat (a predominantly winter crop) with nutri-cereals like *jowar*. Crop growing seasons for rice in Tamil Nadu are such that the proposals for replacement have to consider if the sowing and harvesting time of the replacement crops match those of rice. Similarly, for replacement of an annual crop like sugarcane in Maharashtra, we have identified a crop sequence covering both the *kharif* and *rabi* seasons, so that the replacement of one crop is with a group of two or more crops.
- **Source of irrigation and extent of control over water**: Crops grown in command areas of large dams are largely irrigated by the field-flooding method. It is, therefore, difficult to replace rice grown in the canal commands and floodplains of rivers like the Godavari and Krishna in Andhra Pradesh with any other crop. However, in the non-command areas of Andhra Pradesh and Telangana, mainly the undulating and upland regions, it is possible to replace rice because the major

[25] It is assumed that crops are irrigated only to meet the ET requirement and there is no over-irrigation. To the extent that the farmer has no direct way of measuring ET or predict rainfall, this would lead to an underestimation of the actual water use by farmers.

[26] Not all water footprints are seasonal—only those from cereals are. ET/yield changes and their effect on crop water requirements have not been modelled. Baseline for water savings assumes no change in the adoption of water saving technology.

[27] The percentage shift in crop area in *kharif* and *rabi* varies between different states. Here, we have considered the difficulty of replacing a major irrigated crop like rice in the southern Indian states where it also happens to be the main staple crop of the area. We have also considered the possibility that in the water-logged areas of North Bihar, nothing else except rice can grow and hence replacing it would be difficult. In such situations, we have reduced the area shift from 25 and 50% in Scenarios I and II to 10% and 25% respectively.

[28] We keep the sum of the water-intensive and replacement crops area constant.

source of irrigation here is groundwater. The situation in Punjab and Haryana is similar, since groundwater accessed through tubewells is the major source of irrigation.

- **Soil conditions and agronomy**: Once certain crops like rice are continuously grown in an area, the soil conditions change considerably so that any crop replacement may become difficult. This particularly applies to the low-lying regions of West Bengal, Odisha and Chhattisgarh. Similarly, when inter-cropping is practised, there are certain crop combinations involved. So, when we propose replacement of one crop (such as soyabean in Madhya Pradesh), we need to also propose replacement of other crops in the crop mix when the inter-crop does not match with the replacement crop.

Based on these considerations and limiting factors, Table 9 brings together the state-specific and season-specific crop replacements proposed.

Table 10 provides a comparison of the total blue water saved (cubic kilometres or billion cubic metres) in 11 states after crop replacements in Scenarios I and II, as compared to the irrigation water required to produce the water-intensive crops in the baseline scenario.

Given that water-intensive crops currently occupy over 30% of the gross irrigated area in these states, the amount of water saved annually is considerable. This water could be diverted to critical and supplementary irrigation for millions of small and marginal farmers, while also reducing the pressure on rural drinking water sources.

Table 9 State-specific and season-specific crop replacements

State	Water intensive crop		Replacement crop	
	Kharif	Rabi	Kharif	Rabi
Andhra Pradesh	Rice	Rice	*Tur*, Groundnut	Gram, Sesame
Telangana	Rice	Rice	*Tur, Jowar*	Gram, Sesame
Bihar	Rice	Wheat	*Tur, Urad*	Gram, Lentils
Gujarat	Cotton	Wheat	*Tur, Bajra*	Gram, Rapeseed
Haryana	Rice	Wheat	*Tur, Bajra*	Gram, Rapeseed
Karnataka	Rice	Wheat	*Tur*, Groundnut	Gram, Moong
Madhya Pradesh	Soybean	Wheat	Maize, *Jowar*	Gram, Rapeseed
Maharashtra[a]	Sugarcane	Wheat	*Jowar, Tur*	Gram, Rapeseed
Punjab	Rice	Wheat	*Tur, Moong*	Gram, Rapeseed
Rajasthan[b]	Miscellaneous crops	Wheat	No change	Gram, Rapeseed
Tamil Nadu[c]	Rice		*Tur, Urad*	

[a] Sugarcane is an annual crop
[b] We make no change in *kharif* in Rajasthan, as the crops are mostly already low water consuming ones
[c] In Tamil Nadu, agricultural seasons do not exactly correspond to the *kharif-rabi* distinction applied in the rest of the country

Table 10 Comparison of annual irrigation water under different crop scenarios

State	Blue water use (BCM/Year)			Blue water saving (%)	
	Baseline	Scenario I	Scenario II	Scenario I	Scenario II
Andhra Pradesh	10.06	8.15	6.08	19	40
Telangana	5.46	4.33	3.12	21	43
Bihar	7.80	6.35	4.74	19	39
Gujarat	13.22	10.35	7.48	22	44
Haryana	8.39	7.42	6.38	12	24
Karnataka	1.17	0.97	0.82	17	30
Madhya Pradesh	14.92	12.16	9.40	19	37
Maharashtra	13.93	10.58	7.24	24	48
Punjab	14.26	11.58	8.26	19	42
Rajasthan	15.71	13.97	13.13	11	16
Tamil Nadu	5.45	4.95	4.20	9	23
	110.35	**90.81**	**70.83**	**18**	**36**

It can be argued that these crop replacements will result in some reduction in total output because of differentials in yields across crops.[29] However, it must be borne in mind that the rapidly deteriorating water situation increasingly poses a very serious constraint to maintaining the productivity levels of water-intensive crops, especially in states like Punjab and Haryana. An extremely important recent study has concluded that

> given current depletion trends, cropping intensity may decrease by 20% nationwide and by 68% in groundwater-depleted regions. Even if surface irrigation delivery is increased as a supply-side adaptation strategy, cropping intensity will decrease, become more vulnerable to inter-annual rainfall variability, and become more spatially uneven. We find that groundwater and canal irrigation are not substitutable and that additional adaptation strategies will be necessary to maintain current levels of production in the face of groundwater depletion. (Jain et al., 2021)

Hence, it would be fallacious to assume that output levels of water-intensive crops can be sustained indefinitely in heavily groundwater dependent states like Punjab and Haryana. At the same time, our proposal is for aligning cropping patterns with regional agroecology and that includes raising the share of Eastern India in the national output of water-intensive crops like rice. Ironically, even though this region has abundant water resources, it depends on groundwater scarce regions for its supply of food grains. It has been correctly pointed out that "Eastern states which are safe in their groundwater reserves and net importers, also have the highest yield gaps and therefore the greatest unmet potential to increase production" (Harris et al., 2020,

[29] What is encouraging, however, is that in recent times, the productivity of nutri-cereals has been going up because of which despite a sharp reduction in the acreage under nutri-cereals, their production has not declined. This is a positive sign leading us to believe that with greater R&D investments in nutri-cereals, their productivity can be further improved.

p. 9). Raising the share of rice procured from Eastern India would greatly help a move in this direction, as would tweaking electricity tariffs there (Sidhu et al., 2020). We must also clearly recognise that food stocks over the last decade have greatly exceeded the 'buffer norm', which is around 31 million tonnes for wheat and rice. Indeed, even after all the additional drawals following the COVID-19 pandemic, the Central pool still had 63 million tonnes in stock in October 2020 (Husain, 2020).[30]

Moreover, the nutritional content of the crop mix we are proposing is definitely superior. Increasing consumption of nutri-cereals over rice and wheat could reduce iron-deficiency anaemia, while the increased consumption of pulses could reduce protein-energy malnutrition (DeFries et al., 2018). The impact on farmers' incomes is also likely to be positive because of lower input requirements and costs of production associated with our crop-mix. What would help significantly is more emphasis on research and development (R&D) in the replacement crops, stronger farmer extension support for them, as also expanded procurement and higher price support in order to create the right macro-economic environment for crop replacement.[31]

4.2 Monoculture Impairs Resilience: Return to Polycultural Biodiversity

Farming faces twin uncertainties, stemming from the market and the weather. For such a risky enterprise to adopt monoculture is patently suicidal.[32] But that is what the Green Revolution has moved Indian farming towards: more and more land under one crop at a time and year-on-year production of the same crop on the same land.

This reduces the resilience of farm systems to weather and market risks, with even more grave consequences in this era of rapid climate change and unpredictable patterns of rainfall. In 2018 and 2019, India had at least one extreme weather event every month. In different regions, these included shortages and excesses of rainfall, higher and lower temperatures etc., many of which exceeded the bounds of normal expectation. A recent report of the Ministry of Earth Sciences (MoES), Government of India (Krishnan et al., 2019) finds that June to September rainfall over India has declined by around 6% from 1951 to 2015, with notable decreases over the Indo-Gangetic plains and the Western Ghats. During the same period, the frequency of daily precipitation extremes, with rainfall intensities exceeding 150 mm per day, increased by about 75% over central India. Dry spells were 27% more frequent during 1981–2011 compared to 1951–1980. Both the frequency and spatial extent of droughts have increased significantly between 1951 and 2016. Climate models

[30] So much so that India has been a major exporter of rice in recent years and may now be also expanding its wheat exports substantially (Damodaran, 2021).

[31] It is encouraging to note that recent increases in MSPs have tended to favour our replacement crops and not rice and wheat.

[32] In complex organic systems, there is always a trade-off between efficiency and robustness (Csete & Doyle, 2002).

project an increase in the frequency, intensity and area under drought conditions in India by the end of the twenty-first century.

The persistence of monoculture makes India even more vulnerable to disruptions from climate change and extreme weather events, for it has by now been conclusively established that

> crops grown under 'modern monoculture systems' are particularly vulnerable to climate change as well as biotic stresses, a condition that constitutes a major threat to food security … what is needed is an agro-ecological transformation of monocultures by favoring field diversity and landscape heterogeneity, to increase the productivity, sustainability, and resilience of agricultural production. … Observations of agricultural performance after extreme climatic events in the last two decades have revealed that resiliency to climate disasters is closely linked to farms with increased levels of biodiversity. (Altieri et al., 2015)
>
> The vast monocultures that dominate 80% of the 1.5 billion hectares of arable land are one of the largest causes of global environmental changes, leading to soil degradation, deforestation, depletion of freshwater resources and chemical contamination. (Altieri & Nicholls, 2020)

It has also been shown that plants grown in genetically homogenous monocultures lack the necessary ecological defence mechanisms to withstand the impact of pest outbreaks. Francis (1986) summarises the vast body of literature documenting lower insect pest incidence and the slowing down of the rate of disease development in diverse cropping systems compared to the corresponding monocultures. In his classic work on inter-cropping, Vandermeer (1989) provides innumerable instances of how inter-cropping enables farmers to minimise risk by raising various crops simultaneously. Natarajan and Willey (1986) show how polycultures (intercrops of sorghum and peanut, millet and peanut and sorghum and millet) had greater yield stability and showed lower declines in productivity during a drought than monocultures.

Most recently, the largest ever attempt in this direction (Tamburini et al., 2020) has included a review of 98 meta-analyses and a second-order meta-analysis based on 5160 original studies comprising 41,946 comparisons between diversified and simplified practices. They conclude:

> Enhancing biodiversity in cropping systems is suggested to promote ecosystem services, thereby reducing dependency on agronomic inputs while maintaining high crop yields. Overall, diversification enhances biodiversity, pollination, pest control, nutrient cycling, soil fertility, and water regulation without compromising crop yields. (Tamburini et al., 2020)

A recent report of the FAO's Commission on Genetic Resources for Food and Agriculture also brings out the key role of biodiversity in sustaining crop production:

> The world is becoming less biodiverse and there is good evidence that biodiversity losses at genetic, species and ecosystem levels reduce ecosystem functions that directly or indirectly affect food production, through effects such as the lower cycling of biologically essential resources, reductions in compensatory dynamics and lower niche occupation. (Dawson et al., 2019)

Moreover, as a recent study of agro-biodiversity in India argues, "when we lose agricultural biodiversity, we also lose the option to make our diets healthier and our food systems more resilient and sustainable" (Thomson Jacob et al., 2020).[33] It is thus clear how a move away from monoculture towards more diverse cropping patterns would increase resilience against climate and market risks, while also reducing water consumption, without compromising productivity.

4.3 Rejecting the Originative Flaw (Soil as an Input–Output Machine)

The fundamental question that needs to be raised about the Green Revolution is its overall strategy, its conception of the agricultural production system in general, and of soils in particular. The overarching strategy was one of "betting on the strong", which meant focusing investment and support on farmers, regions and crops that were seen as most likely to lead to an increase in output (Tomlinson, 2013). It was a "commodity-centric" vision, where the idea was to deploy such seeds as would maximise output per unit area, given the right doses of fertilisers and pesticides. The amount of chemical nutrients applied demanded correspondingly larger inputs of water, which, in turn, made the resultant ecosystem extremely favourable to the profusion of pests, which threatened output unless pesticides were utilised to kill them.

This is a perspective that exclusively focuses on productivity (output/area) of a given crop by specifically targeting soil nutrients or pest outbreaks (Hecht, 1987). Such a view is atomistic, and assumes that "parts can be understood apart from the systems in which they are embedded and that systems are simply the sum of their parts" (Norgaard & Sikor, 1995). It is also mechanistic, in that relationships among parts are seen as fixed, changes as reversible and systems are presumed to move smoothly from one equilibrium to another. Such a view ignores the fact that often parts cannot be understood separately from their wholes and that the whole is different (greater or lesser) than the sum of its parts. It also overlooks the possibility that parts could evolve new characteristics or that completely new parts could arise (what is termed as 'emergence' in soil science literature).[34] As Lent (2017) argues:

> Because of the way a living system continually regenerates itself, the parts that constitute it are in fact perpetually being changed. It is the organism's dynamic patterns that maintain its coherence. … This new understanding of nature as a self-organized, self-regenerating system extends, like a fractal, from a single cell to the global system of life on Earth.

---

[33] This understanding is reflected in the National Biodiversity Mission launched by the Prime Minister's Science, Technology, and Innovation Advisory Council in March 2019, which includes a *Biodiversity and Agriculture Programme* that "will aim to reconcile the traditional tension that exists between increasing food production on one hand and preserving biodiversity on the other. By launching a first-ever quantitative inventory of the contribution of biodiversity in forests, rivers, estuaries and agro-ecosystems to India's food and nutritional security, citizens will be empowered with credible information on the judicious use of bioresources." (Bawa et al., 2020).

[34] Addiscott (2010), Baveye et al. (2018), Falconer et al. (2012).

On the other hand, in the Green Revolution vision, the soil was seen essentially as a stockpile of minerals and salts, and crop production was constrained as per Liebig's Law of the Minimum—by the nutrient least present in the soil. The solution was to enrich the soil with chemical fertilisers, where the soil was just a base with the physical attributes necessary to hold roots: "Crops and soil were brute physical matter, collections of molecules to be optimised by chemical recipes, rather than flowing, energy-charged wholes" (Mann, 2018).

Thus, the essential questions to be posed to a continued blind adherence to the Green Revolution approach, in the face of India's growing farm and water crises, are:

1. Is the soil an input–output machine, a passive reservoir of chemical nutrients, to be endlessly flogged to deliver, even as it shows clear signs of fatigue?
2. Or is it a complex, interacting, living ecosystem to be cherished and maintained so that it can become a vibrant, circulatory network, which nourishes the plants and animals that feed it?
3. Will a toxic, enervated ecosystem with very poor soil quality and structure, as also gravely fallen water tables, be able to continue to support the agricultural production system?

In the words of Rattan Lal, the Indian-American soil scientist, who is also the 2020 World Food Prize winner:

> Soil is a living entity. It is full of life. The weight of living organisms in a healthy soil is about 5 ton per hectare. The activity and species diversity of soil biota are responsible for numerous essential ecosystem services. Soil organic matter content is an indicator of soil health, and should be about 2.5% to 3.0% by weight in the root zone (top 20 cm). But soil in Punjab, Haryana, Rajasthan, Delhi, Central India and Southern parts contains maybe 0.5% or maybe 0.2%.[35]

According to FAO, generating 3 cm of top soil takes 1000 years, and, if current rates of degradation continue, all of the world's top soil could be gone within 60 years.[36] Lal favours compensation for farmers through payments (around INR 1200 per acre per year) for soil protection, which he regards as a vital ecosystem service.

It is important to understand the key relationship between soil quality and water productivity and recognise that every land-use decision is also a water-use decision (Bossio et al., 2008). Lal (2012) explains how soil organic matter (SOM) affects the physical, chemical, biological and ecological qualities of the soil. In physical terms, higher SOM improves the water infiltration rate and the soil's available water-holding capacity. Chemically, it has a bearing on the soil's capacity to buffer against pH, as also its ion-exchange and cation-exchange capacities, nutrient storage and availability and nutrient-use efficiency. Biologically, SOM is a habitat and reservoir for the gene pool, for gaseous exchange between the soil and the atmosphere and for

---

[35] Interviews to Indian Express (22 June 2020) and Mint (12 June 2020).

[36] https://www.scientificamerican.com/article/only-60-years-of-farming-left-if-soil-degradation-continues, 5 December 2014.

carbon sequestration. Ecologically, SOM is important in terms of elemental cycling, ecosystem carbon budget, filtering of pollutants and ecosystem productivity.[37]

A recent overview of global food systems rightly points to the "paradox of productivity":

> as the efficiency of production has increased, the efficiency of the food system as a whole – in terms of delivering nutritious food, sustainably and with little waste – has declined. Yield growth and falling food prices have been accompanied by increasing food waste, a growing malnutrition burden and unsustainable environmental degradation. (Benton & Bailey, 2019)

Benton and Bailey urge policy-makers to move from the traditional preoccupation with Total Factor Productivity (TFP) towards Total System Productivity (TSP):

> A food system with high TSP would be sufficiently productive (to meet human nutritional needs) whilst imposing few costs on the environment and society (so being sustainable), and highly efficient at all stages of the food chain so as to minimize waste. It would optimize total resource inputs (direct inputs and indirect inputs from natural capital and healthcare) relative to the outputs (food utilization). Maximizing TSP would maximize the number of people fed healthily and sustainably per unit input (direct and indirect). In other words, it would increase overall systemic efficiency. (ibid.)

In the light of this understanding, attempts are being made all over the world to foster an ecosystem approach, with higher sustainability and resilience, lower costs of production, as also economy in water use, along with higher moisture retention by the soil. Broadly, these alternatives to the Green Revolution paradigm come under the rubric of agroecology. In the latest quadrennial review of its Strategic Framework and Preparation of the Organization's Medium-Term Plan, 2018–21, the FAO states:

> High-input, resource-intensive farming systems, which have caused massive deforestation, water scarcities, soil depletion and high levels of greenhouse gas emissions, cannot deliver sustainable food and agricultural production. Needed are innovative systems that protect and enhance the natural resource base, while increasing productivity. Needed is a transformative process towards 'holistic' approaches, such as agroecology and conservation agriculture, which also build upon indigenous and traditional knowledge.

Hecht (1987) provides an excellent summary of the philosophy underlying agroecology:

> At the heart of agro-ecology is the idea that a crop field is an ecosystem in which ecological processes found in other vegetation formations such as nutrient cycling, predator/prey interactions, competition, commensalism, and successional changes also occur. Agro-ecology focuses on ecological relations in the field, and its purpose is to illuminate the form, dynamics, and function of these relations (so that) … agro-ecosystems can be manipulated to produce better, with fewer negative environmental or social impacts, more sustainably, and with fewer external inputs.

A recent overview sums up key features of the approach embodied by agroecology:

---

[37] Several studies have documented the depletion of soil organic matter and organic carbon in the soils of north west India after the adoption of the Green Revolution (Chauhan et al., 2012; Ghosh et al., 2017; Pal et al., 2009).

> Over the past five years, the theory and practice of agroecology have crystalized as an alternative paradigm and vision for food systems. Agroecology is an approach to agriculture and food systems that mimics nature, stresses the importance of local knowledge and participatory processes and prioritizes the agency and voice of food producers. As a traditional practice, its history stretches back millennia, whereas a more contemporary agroecology has been developed and articulated in scientific and social movement circles over the last century. Most recently, agroecology—practised by hundreds of millions of farmers around the globe—has become increasingly viewed as viable, necessary and possible as the limitations and destructiveness of 'business as usual' in agriculture have been laid bare. (Anderson et al., 2021)

In India, a large number of such alternatives to the Green Revolution paradigm have emerged over the past two decades. These include natural farming, non-pesticide managed agriculture, organic farming, conservation agriculture, low external input sustainable agriculture, etc. but they all share a common base of agroecological principles, rooted in the local context. Recently some state governments have given a big push to this movement. The biggest example is that of the Community Based Natural Farming programme of the Government of Andhra Pradesh (GoAP), which started in 2016.[38] Crop-cutting experiments by the State Agriculture Department claim higher average yields, reduced costs and higher net incomes for 'natural' farmers compared to 'non-natural' farmers, in all districts and for all crops. Encouraged by the results, the GoAP has now resolved to cover the entire cultivable area of 80 lakh hectares in the state by 2027 (Vijay Kumar, 2020). This would then become the largest challenge to the Green Revolution ever undertaken.

Support has also been forthcoming from the Government of India. At an event organised by the NITI Aayog on 29 May 2020, the Union Minister for Agriculture stated:

> Natural farming is our indigenous system based on cow dung and urine, biomass, mulch and soil aeration […]. In the next five years, we intend to reach 20 lakh hectares in any form of organic farming, including natural farming, of which 12 lakh hectares are under *Bharatiya Prakritik Krishi Paddhati Programme*.[39]

At the same event, the NITI Aayog Vice-Chairman stressed the need to take natural farming to scale:

> In states like Andhra Pradesh, Telangana, Gujarat, Himachal Pradesh and Madhya Pradesh this is being practised already quite widely. It has proven its benefit on the ground. Now is the time that we should scale it and make it reach 16 crore farmers from the existing 30 lakhs. The whole world is trying to move away from chemical farming. Now is the time to make Indian farmers aware of its potential.[40]

---

[38] Initially called Zero Budget Natural Farming, this label, suggestive of a certain kind of fundamentalism and exaggeration, has now been dropped.

[39] 'Agroecology and Natural Farming Could Accelerate Inclusive Economic Growth in India' (https://pib.gov.in/PressReleasePage.aspx?PRID=1628285).

[40] 'COVID-19 has led to more thrust on agroecology, natural farming: NITI Aayog' (thefactnews.in/covid-19-has-led-to-more-thrust-on-agroecology-natural-farming-niti-aayog).

These agroecological alternatives embody a paradigm shift in farming and have a crucial role to play in redressing both farmer distress and India's worsening water crisis.

4.4 Water Saving Seeds and Technologies

Through careful micro-level trials and experimentation by their field centres, the Indian Agricultural Research Institute (IARI) and state agricultural universities have developed several crop varieties, which require less water than conventional Green Revolution seeds. For example, the low-irrigation wheat varieties Amar (HW 2004), Amrita (HI 1500), Harshita (HI 15231), Malav Kirti (HI 8627) and Malav Ratna (HD 4672), developed at the IARI Wheat Centre in Indore, give fairly good yields at a much lower level of water consumption (Gupta et al., 2018). These varieties are also prescribed by the ICAR-NICRA (Indian Council for Agricultural Research-National Innovations on Climate Resilient Agriculture) project, through their district-level drought adaptation plans.[41] Adoption of these varieties by farmers would need training and facilitation by *Krishi Vigyan Kendras*[42] (KVKs) so that they are able to understand the new agronomic practices that these varieties would involve. Their large-scale adoption could go a long way in reducing the water footprint of water-intensive crops.[43]

Adoption of water saving practices can also achieve the same result (as summarised in Table 11). System of Rice Intensification is a combination of practices which, together, reduce heavy input use in rice. Conservation agriculture and tillage refers to methods where the soil profile is not disturbed by tilling. Drip irrigation takes water application closer to the root systems of plants (Narayanamoorthy, 2004). Direct Seeding of Rice enables sowing of rice without nurseries or transplanting. Uneven soil surface affects the germination of crops, reduces the possibility of spreading water homogenously and reduces soil moisture. Therefore, land levelling within farms[44] is a precursor to good agronomic, soil and crop management practices.

---

41 http://www.nicra-icar.in/nicrarevised/index.php/state-wise-plan.

42 Agriculture Science Centres.

43 Three thousand varieties of rice were being cultivated in eastern India before the Green Revolution (Shiva & Prasad, 1993). If revived, this rich agro-biodiversity could play a big role in reducing water demand.

44 Quite unfortunately, however, what has got emphasised in Punjab is land levelling outside farms, resulting in a loss of natural topography and drainage systems through the destruction of the small hillocks or *tibbas.* For an account of the impact of this on Punjab's water crisis, see Kulkarni and Shah (2013).

Table 11 Impact of water saving practices on blue water use in different states

	State	Practices	Crops	Blue water saved compared to conventional practices (%)	References
1	Andhra Pradesh	System of rice intensification	Rice (Kh)	50	Ravindra and Bhagya Laxmi (2011)
2	Bihar	Conservation agriculture[a]	Rice (Kh)	24	Laik et al. (2014)
	Bihar	System of wheat intensification	Wheat (Rb)	17.5	Kumar et al. (2011)
3	Gujarat	System of rice intensification	Rice (Kh)	33	Mevada et al. (2016)
	Gujarat	Drip irrigation	Wheat (Rb)	48	Singh (2013)
4	Haryana	Laser land levelling	Rice (Kh)	30	Ladha (2009)
	Haryana	Conservation tillage and soil residue cover	Wheat (Rb)	18	Ladha et al. (2016)
5	Karnataka	Direct dry seeding of rice	Rice (Kh)	46	Soriano et al. (2018)
6	Maharashtra	Drip irrigation	Sugarcane (Annual)	57	Pawar et al. (2013)
7	MP	Drip irrigation	Wheat (Rb)	28.4	Chouhan et al. (2015)
8	Punjab	Laser land levelling	Rice (Kh)	25.0	Ladha (2009)
	Punjab	Drip irrigation	Wheat (Rb)	21.1	Suryavanshi and Buttar (2016)
9	Rajasthan	Deficit irrigation	Wheat (Rb)	17	Rathore et al. (2017)
10	Tamil Nadu	Young seedlings, wide spacing with alternate wetting and drying irrigation	Rice (Kh)	79.8	Oo et al. (2018)
11	Telangana	System of rice intensification	Rice (Kh)	50	Ravindra and Bhagya Laxmi (2011)

[a] Conservation agriculture can also minimise risk to climate extremes (Aryal et al., 2016)
Note Kh Kharif; *Rb* Rabi

4.5 Reversing the Neglect of Rainfed Areas: Focus on Green Water and Protective Irrigation

One of the most deleterious consequences of the Green Revolution has been the neglect of India's rainfed areas, which currently account for 54% of the sown area.[45] The key to improved productivity of rainfed farming is a focus on soil moisture and protective irrigation. Protective irrigation seeks to meet moisture deficits in the root zone, which are the result of long dry spells. Rainfed crops can be insulated to a great extent from climate variabilities through two or three critical irrigations, complemented in each case by appropriate crop systems and in situ water conservation. In such a scenario, provision needs to be made for just about 100–150 mm of additional water, rather than large quantities, as in conventional irrigation.

Lal (2012) provides a comprehensive list of options for increasing green water in rainfed farming:

> (i) increase water infiltration; (ii) store any runoff for recycling; (iii) decrease losses by evaporation and uptake by weeds; (iv) increase root penetration in the subsoil; (v) create a favorable balance of essential plant nutrients; (vi) grow drought avoidance/adaptable species and varieties; (vii) adopt cropping/farming systems that produce a minimum assured agronomic yield in a bad season rather than those that produce the maximum yield in a good season; (viii) invest in soil/land restoration measures (i.e., terraces and shelter belts); (ix) develop and use weather forecasting technology to facilitate the planning of farm operations; and (x) use precision or soil-specific farming technology using legume-based cropping systems to reduce losses of Carbon and Nitrogen and to improve soil fertility. Similarly, growing crops and varieties with better root systems is a useful strategy to reduce the risks in a harsh environment. The root system is important to drought resistance.

This kind of approach to rainfed areas, with a strengthening of the agricultural extension system on a participatory basis, would make a major contribution to the paradigm shift needed in farming to solve India's water problem.

Clearly, there is robust scientific support for exploring alternatives to Green Revolution farming, which needs to be an essential part of the response to both the crises of water and agriculture in India. However, there is also a need to make a strong argument against any kind of fundamentalism on both sides. Those who insist on business-as-usual are being fundamentalist and irresponsible because they are turning a blind eye to the distress of India's farmers and the grave water crisis in the country. On the other hand, it is also important that those working for alternatives adopt procedures for transparent verification and evaluation of their efforts. What is more, the efforts will need multiple forms of support from the government, similar to the multi-pronged approach adopted at the time of the Green Revolution. We would like to propose a few essential steps here:

---

[45] Rainfed areas provide 89% of national millet production, 88% of pulses, 73% of cotton, 69% of oilseeds and even 40% of rice production. It has been shown that there is a strong overlap between the incidence of poverty and rainfed regions. Thus, requisite emphasis on these regions could make a huge contribution to both poverty reduction and nutritional security in India (Expert Committee, 2019).

- Building on the intuition of the Hon'ble Prime Minister who initiated the Soil Health Card Scheme, the soil testing capacities of the entire country need to be urgently and comprehensively ramped up. This means not only establishing more soil testing laboratories, but also testing on a much wider range of parameters, based on the 'living soils' vision, where testing is extended to the 3Ms (moisture, organic matter and microbes). This will make it possible to assess over time whether the claims of different farming approaches can be validated as being truly 'regenerative' and for an assessment to be made about the kinds of interventions that may or may not be required in each specific context.
- Widespread and affordable facilities must be made available for testing the maximum residue level of chemicals in farm produce, in line with regulations of the Food Safety and Standards Authority of India (FSSAI), without which there will be no guarantee that the produce meets required health safety standards.
- This also requires large-scale and separate processing, storage and transport facilities for the produce of 'natural farmers' so that it does not get contaminated by the produce of conventional chemical farmers. Storage of pulses needs careful attention to moisture and temperature. Dry and cool pulses can be stored for longer periods. This demands major investments in new technologies that are now easily available. For crops like millets, processing remains an unaddressed challenge. Therefore, millet-processing infrastructure needs to become a priority, to incentivise farmers to move to water-saving crops and also to move them up the value chain.
- The present farm input subsidy regime that incentivises production with a high intensity of chemical inputs must shift to one that supports the production of organic inputs and provides payment for farm ecosystem services, like sustainable agriculture practices, improving soil health etc. This can, in fact, become a way to generate rural livelihoods, especially if the production of organic inputs could be taken up at a large scale by federations of women SHGs and farmer producer organisations (FPOs).
- The SHG-bank linkage would also be crucial in order to ensure that credit actually reaches those who need it the most and whose dependence on usurious rural moneylenders grew after strict profitability norms were applied to public sector banks in 1991 (Shah, 2007). Shah et al. (2007) explain how SHGs led by women enable these banks to undertake sound lending, rather than the botched-up, target-driven lending of the Integrated Rural Development Programme (IRDP) in the years following bank nationalisation. The SHG-Bank Linkages Programme has not only benefitted borrowers, but has also improved the profitability of many bank branches in rural and remote areas, thus mitigating the inclusion-profitability dilemma that afflicted public sector banks in the first two decades after nationalisation. As a result, formal rural credit has once again made a comeback during the last decade, after a period of decline in the 1990s and early 2000s. Such credit support will be crucial if the paradigm shift in farming proposed in this chapter is to be scaled up on the ground.
- Finally, the entire agricultural extension system needs to be rejuvenated and revamped, to make it align with this new paradigm. Special focus must be placed

on building a whole army of Community Resource Persons (CRPs), farmers trained in all aspects of agroecology, who would be the best ambassadors of this fresh perspective and understanding, working in a truly 'rhizomatic' manner, allowing for multiple, non-hierarchical points of knowledge representation, interpretation and sharing.[46]

Thus, to carry forward the agroecological revolution in India, there is a need for an overarching architecture very similar to the one that propelled the Green Revolution in its heyday, even though each of its constitutive elements would be radically different. It is only if the pattern of subsidies is changed and these reforms are put in place by the government that the paradigm shift in farming proposed in this paper will be able to take off in real earnest. Otherwise doubts about its authenticity and power could remain.

5 The Paradigm Shift Required in Water[47]

Just as the Green Revolution paradigm fundamentally misrecognises the essential nature of soils as living ecosystems, the dominant policy discourse on water fails to acknowledge the principal characteristics of water as an intricately interconnected, common pool resource. The multiple crises of water in India today could be said to stem from this essential misapprehension. Atomistic and competitive overexploitation of aquifers and the inability to manage catchment and command areas of large dams are the biggest examples of how the water crisis has got aggravated.

What makes things worse—but also creates an opening for a new beginning—is the fact that definite limits are being reached for any further construction of large dams or groundwater extraction. Thus, the strategy of constructing large dams across rivers is increasingly up against growing basin closure. In addition, the possibilities of further extraction of groundwater are reducing, especially in the hard rock regions, which comprise around two-thirds of India's land mass. This is why the Twelfth Five Year Plan clearly spoke of the need for a fundamental shift from more and more construction of dams and extraction of groundwater, towards sustainable and equitable governance and management of water.

[46] A "rhizome has no beginning or end; it is always in the middle, between things, interbeing, *intermezzo*." (Deleuze & Guattari, 1987).

[47] This section relies heavily on both Shah (2013) and Shah et al. (2016), where these arguments are fleshed out in fuller detail.

5.1 *Participatory Irrigation Management in the Irrigation Commands*

India has spent more than INR 4 trillion on the construction of dams, but trillions of litres of water stored in these reservoirs is yet to reach the farmers for whom it is meant. There is a growing divergence between the irrigation potential created [113 million hectares (mha)] and the irrigation potential actually utilised (89 mha). While this gap of 24 mha reflects the failure of the irrigation sector, it is also low-hanging fruit: by focusing on this, India can quickly bring millions of hectares under irrigation. Moreover, this can be achieved at less than half the cost of building new dams, which are becoming increasingly unaffordable. There are massive delays in the completion of projects and colossal cost over-runs of, on an average, 1382% in major projects and 325% in medium dams (Planning Commission, 2013), in addition to which there are humongous human and environmental costs.[48]

Major river basins like Kaveri, Krishna, Godavari, Narmada and Tapti have reached full or partial basin closure, with few possibilities of any further dam construction. In the Ganga plains, the topography is completely flat and storages cannot be located there, as they would cause unacceptable submergence. Further north in the Himalayas—comparatively young mountains with high rates of erosion—the upper catchments have little vegetation to bind the soil. Rivers descending from the Himalayas, therefore, tend to have high sediment loads. There are many cases of power turbines becoming dysfunctional because of the consequent siltation. Climate change is making the predictability of river flows extremely uncertain. Diverting rivers will also create large dry regions, with adverse impact on local livelihoods. The neo-tectonism of the Brahmaputra valley, and its surrounding highlands in the eastern Himalayas, means that modifying topography by excavation or creating water and sediment loads in river impoundments can be dangerous. Recent flooding events in Uttarakhand and Nepal bear tragic testimony to these scientific predictions.

There is, therefore, an urgent need for reforms focused on demand-side management, jettisoning the over-emphasis on ceaselessly increasing supply. These reforms have already been tried and tested in many countries across the globe. There are also significant successful examples of reform pioneered within India in command areas like Dharoi and Hathuka in Gujarat, Waghad in Maharashtra, Satak, Man and Jobat

[48] The old engineering maxim of not letting river water flow "wastefully" into the sea stands badly discredited today. Indeed, recent scientific research advises caution in tampering with run-off from major rivers. The 2014–2020 multi-institution Ocean Mixing and Monsoon (OMM) Programme of the Ministry of Earth Sciences has confirmed that flows of river water into the Bay of Bengal lead to fundamental changes in the response of the Bay of Bengal sea surface temperature to tropical cyclones and the monsoons. Reduction of flows from major rivers would affect the salinity and depth of the upper mixed layer, and modify the temperature of the Northern Bay of Bengal. This could impact variations of rainfall, including rainfall carried inland by monsoon low-pressure systems and depressions born in the Bay of Bengal. It is, therefore, almost certain that tampering with run-off from major rivers will impact monsoon rainfall, in unknown and unanticipated ways (https://incois.gov.in/omm/index.jsp).

in Madhya Pradesh, Paliganj in Bihar and Shri Ram Sagar in Andhra Pradesh. These successes have now to be taken to scale.

Reforms in this context imply a focus on better water management and last-mile connectivity. This requires the de-bureaucratisation or democratisation of water. Once farmers themselves feel a sense of ownership, the process of operating and managing irrigation systems undergoes a profound transformation. Farmers willingly pay irrigation service fees to their Water Users Associations (WUAs), whose structure is determined in a transparent and participatory manner. Collection of these fees enables WUAs to undertake proper repair and maintenance of distribution systems and ensure that water reaches each farm.

This kind of participatory irrigation management (PIM) implies that the State Irrigation Departments only concentrate on technically and financially complex structures, such as main systems, up to secondary canals. The tertiary-level canals, minor structures and field-channels are handed over to the WUAs, which enables better last-mile connectivity and innovative water management. This includes appropriate cropping patterns, equity in water distribution, conflict resolution, adoption of water-saving technologies and crop cultivation methods, leading to a rise in India's overall water-use efficiency, which is among the lowest in the world.

PIM, it must be acknowledged, is not a magic bullet; studies across the world reveal specific conditions under which it works. These need to be carefully adhered to. While these are issues for state governments to tackle, the Centre also has a critical role to play in incentivising and facilitating the former to undertake these reforms. Release of funds to states for large dam projects must be linked to their progress on devolutionary reforms and empowering WUAs. States committed to the national goal of *har khet ko paani* (water for every farm) will not view this as an unreasonable imposition. In order to allay any apprehensions, the Centre should also play an enabling role, helping officers and farmers from different states to visit pioneering PIM proofs-of-concept on the ground sites, so that they can learn and suitably adapt them to their own command areas.

5.2 Participatory Groundwater Management

In a classic instance of vicious infinite regress,[49] tubewells—which were once seen as the solution to India's water problem—have tragically ended up becoming the main cause of the crisis. This is because borewells have been indiscriminately drilled, without paying attention to the nature of aquifers or the rock formations within which the groundwater is stored. Much of India is underlain by hard rock formations, with limited capacity to store groundwater and very low rates of natural recharge. Once water is extracted from them, it takes very long for them to regain their original levels.

[49] Where the presumed solution to a problem not only fails to provide a solution but instead continues to only aggravate the problem (Stanford Encyclopaedia of Philosophy, 2018).

For decades, aquifers have been drilled everywhere at progressively greater depths, lowering water tables and degrading water quality. It is also not often understood that over-extraction of groundwater is perhaps the single most important cause of the peninsular rivers drying up. For these rivers to keep flowing after the rains stop, they need base-flows of groundwater. But when groundwater is over-extracted, the direction of these flows is reversed and 'gaining' rivers get converted into 'losing' rivers. Springs, which have historically been the main source of water of the population in mountainous regions, are also drying up in a similar way.

Reversing this dire situation requires a careful reflection on the nature of groundwater and a recognition that it is a common-pool resource. Groundwater, by its very nature, is a shared heritage. While the land under which this water is located can be divided, it is not possible to divide the water, a fugitive resource that moves in a fluid manner below the surface. Competitive and individual extraction leads to a mutually destructive cycle, where each user tries to outdo the others in drilling deeper and deeper, till the point where virtually no groundwater left. Indeed, this point is being reached in many aquifers in India today. How, then, can India protect and continue to use its single most important natural resource without driving it to extinction?

One commonly proposed solution is to metre and licence the use of groundwater. While this might make sense for the few very large consumers, such as industrial units, it would be impossible to implement on a large-scale, bearing in mind that India has more than 45 million wells and tubewells. Fortunately, there are a few examples that show the way forward. A million farmers in the hard rock districts of Andhra Pradesh have come together to demonstrate how groundwater can be used in an equitable and sustainable manner (World Bank, 2010). With the co-operation of hydro-geologists and civil society organisations, facilitated by the government, these farmers clearly understood the nature of their aquifers and the kinds of crops that could be grown with the groundwater they had. Careful crop-water budgeting enabled them to switch to less water-intensive crops, more suited to their specific agroecology. It needs to be noted that this initiative required a strong mooring in both science and social mobilisation. Such examples have mushroomed all over India, especially in Maharashtra, Madhya Pradesh, Kutch and Sikkim. All of them are based on collective action by farmers, who have come together to jointly manage their precious shared resource. They have developed protocols for pumping of water, sequencing of water use as well as distance norms between wells and tubewells, and strictly adhere to them, once they understand that this is the only way they can manage to meet both their farm and domestic requirements.

Taking these innovations to scale requires massive support from the government. Paradoxically, as groundwater has become more and more important, groundwater departments, at the Centre and in all the states, have only become weaker over time. This trend needs to be reversed urgently and state capacities strengthened in a multi-disciplinary manner. The Twelfth Plan saw the initiation of the National Aquifer Management Programme and the government recently launched the *Atal*

Bhujal Yojana (Atal Groundwater Scheme).[50] While both of these are pioneering initiatives, the likes of which the world has never seen before, they are yet to take off. The primary reason is that the requisite multi-disciplinary capacities are missing within government. Besides, they cannot be implemented by the government alone. They demand a large network of partnerships with stakeholders across the board: universities, research centres, panchayati raj institutions and urban local bodies, civil society organisations, industry and the people themselves.

5.3 Breaking the Groundwater-Energy Nexus and Legal Reform

It is also necessary to break the groundwater-energy nexus that has only encouraged the mining of groundwater by making both power and water virtually free for the farmers. The solution cannot be marginal cost pricing, which would have an extremely adverse impact on the access to groundwater for millions of small and marginal farmers and endanger their livelihoods. We cannot afford to kill the goose that lays the golden egg (WLE, 2015). A possible way forward could be to emulate the *Jyotigram Yojana* (Village Lighting Scheme) of the Government of Gujarat, through the separation of power feeders. The key here is the rationing of high-quality power to farmers for eight hours. Many states have now followed Gujarat's example, with different hours of rationing: Punjab (five hours), Rajasthan and Karnataka (six hours), Andhra Pradesh (seven hours), Haryana, Madhya Pradesh, Maharashtra and Tamil Nadu (nine hours). While the jury is still out on the effectiveness of this measure in containing groundwater use, a recent study by Ryan and Sudarshan (2020) seems to suggest that it might be working well.

Concomitantly, urgent legal reform is required because groundwater continues to be governed by British common law of the nineteenth century, whose provisions seriously limit access to groundwater for small and marginal farmers. The common-law doctrine of absolute dominion gives landowners the right to take all water below their own land. The legal status of groundwater is effectively that of a chattel to the land. When water is extracted from below the land, the principle of *damnum absque injuria* (damage without injury) legally sanctifies unlimited volumes of abstraction, which can adversely impact water levels in neighbouring wells or tubewells.

The science of hydrogeology explains that water flowing underneath any parcel of land may or may not be generated as recharge on that specific parcel. Recharge areas for most aquifers are only a part of the land that overlies the entire aquifer. Hence, in many cases, water flowing underneath any parcel of land will have infiltrated the land and recharged the aquifer from another parcel, often lying at a distance. When many users simultaneously pump groundwater, complex interference results between different foci of pumping, which is a common feature in many parts of India, where

[50] Named after former Prime Minister Atal Bihari Vajpayee, the *Atal Bhujal Yojana* is a scheme for management of ground water.

wells are located quite close to one another. This is typically how water tables have plunged and there is no legal protection available against such consequences, thereby endangering the lives and livelihoods of millions of farmers.

The Government of India has drafted a Model Groundwater (Sustainable Management) Bill, 2017 (Cullet, 2019). It should be formally approved, so that state governments can use this model to adopt groundwater legislation giving priority to protection measures at the aquifer level and an access framework centred on ensuring the realisation of equitable and sustainable groundwater management and governance.

5.4 Protecting and Rejuvenating India's Catchment Areas

There is a pressing need to understand that the health of the country's rivers, ponds and dams is only as good as the health of their catchment areas. In order to protect the country's water sources, the areas from where they 'catch' their water need to be protected and rehabilitated.

A 2018 study of 55 catchment areas (Sinha et al., 2018) shows that there has been a decline in the annual run-off generated by major river basins, including Baitarni, Brahmani, Godavari, Krishna, Mahi, Narmada, Sabarmati and Tapi, and this is not due to a decline in rainfall but because of economic activities destructive of their catchment areas. The fear is that if this trend continues, most of these rivers will almost completely dry up.

All over the world, including in China, Brazil, Mexico, Costa Rica and Ethiopia, attempts are being made to pay for the ecosystem services provided for protecting catchment areas, keeping the river basin healthy and green. If the channels through which water flows into rivers are encroached upon, damaged, blocked or polluted, the quantity and quality of river flows are adversely affected. The natural morphology of rivers has taken hundreds of thousands of years to develop. Large structural changes to river channels can lead to unforeseen and dangerous hydrological, social and ecological consequences.

How, then, is the imperative of economic development and its negative impacts on water availability and river flows to be reconciled? This is possible only by adopting a completely different approach to development—one where interventions are woven into the contours of nature, rather than trying to dominate it. Most of India gets its annual rain within intense spells in a short period of 40–50 days. The speed of rainwater as it rushes over the ground needs to be reduced by carefully regenerating the health of catchment areas, treating each part in a location-specific manner, as per variations in slope, soil, rock and vegetation. Such watershed management helps recharge groundwater and increase flows into ponds, dams and rivers downstream. This can generate multiple win-wins: soil erosion is reduced, forests regenerated, water tables rise, rivers are rejuvenated, employment generated, farmer incomes improve, thereby reducing indebtedness, and bonded labour and distress migration gradually eliminated. The most important success factor is building capacities among the local people so that they can take charge of the watershed programme from planning, design and implementation right up to social audit. The Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) scheme must be recast on a watershed basis and its enormous resources used for watershed and river rejuvenation, as also for the restoration of traditional water harvesting systems that still exist in so many parts of India, even if in a state of decay and disrepair.

This regenerative work must be integrated with groundwater-related demand management initiatives, for it is groundwater base-flows that keep rivers flowing after the monsoon. River catchments and aquifers must be always managed together within a river basin protection programme. Fundamentally, what all of this demands is bottom-up participatory management in every river basin in India.

5.5 *Building Trans-Disciplinarity in Water*

Both at the Centre and in the states, government departments dealing with water resources include professionals predominantly from the disciplines of civil engineering, hydrology and hydrogeology. There is an urgent need for them to be equipped with multi-disciplinary expertise covering all the disciplines relevant to the paradigm shift in water management that this chapter proposes. This multi-disciplinary expertise must also cover water management, social mobilisation, agronomy, soil science, river ecology and ecological economics. Agronomy and soil science would be needed for effective crop water budgeting, without which it will not be possible to align cropping patterns with the diversity of agroecological conditions. To develop practices to maximise the availability and use of green water, soil physical and plant biophysical knowledge will need to be harnessed. What will also be needed is a better understanding of river ecosystem dynamics, including the biotic inter-connectedness of plants, animals and micro-organisms, as well as the abiotic physical and chemical exchanges across different parts of the ecosystem. Ecological economics would enable the deep understanding and necessary valuation of the role of ecosystem services in maintaining healthy river systems. Without an adequate representation of social science and management expertise, sustainable and equitable management of water resources to attain democratisation of water will not be possible. Social science expertise is also required to build a respectful dialogue and understanding of the underlying historical cultural framework of traditions, beliefs and practices on water in a region-specific manner, so that greater learning and understanding about water could be fostered.

Since systems such as water are greater than the sum of their constituent parts, understanding whole systems and solving water problems necessarily requires multi-disciplinary teams, engaged in inter-disciplinary projects, based on a trans-disciplinary approach, as is the case in the best water resource government departments across the globe.

5.6 Overcoming Hydro-schizophrenia

Water governance and management in India has generally been characterised by three kinds of hydro-schizophrenia: that between (a) surface and groundwater, (b) irrigation and drinking water and (c) water and wastewater.

Government departments, both at the Centre and in the states, dealing with one side of these binaries have tended to work in isolation from, and without co-ordination with, the other side. Ironically, groundwater departments have tended to become weaker over time, even as groundwater has grown in significance in India. A direct consequence of surface water and groundwater being divided into watertight silos has been that the inter-connectedness between the two has neither been understood nor taken into account while understanding emerging water problems. For example, it has not been understood that the post-monsoon flows of India's peninsular rivers derive from base-flows of groundwater. Over-extraction of groundwater in the catchment areas of rivers has meant that the many of the larger rivers are shrinking and many of the smaller ones have completely dried up. A reduction in flows also adversely affects river water quality. Treating drinking water and irrigation in silos has meant that aquifers providing assured sources of drinking water tend to get depleted and dry up over time, because they are also used for irrigation, which consumes much higher volumes of water. This has had a negative impact on the availability of safe drinking water in many parts of India. When the planning process segregates water and wastewater, the result generally is a fall in water quality, as wastewater ends up polluting supplies of water. Moreover, adequate use of wastewater as a resource to meet the multiple needs of water is not sufficiently explored.

Without bridging these silos into which we have divided water, it will be impossible to address the grave water challenges facing the country.

5.7 Building Multi-stakeholder Partnerships

The paradigm shift in water can only be built on an understanding that wisdom relating to it is not the exclusive preserve of any one sector or section of society. It is imperative, therefore, that the Central and state governments take the lead in building a novel architecture of enduring partnerships with the primary stakeholders of water.[51]

This is also critical because the challenges of groundwater management, catchment area treatment and river rejuvenation, as also ensuring that the last farm gets water in command areas, requires people's participation and true democratisation of water. This involves building respectful and lasting dialogue based on a process of mutual learning. Water governance and management at all levels must be informed by, and involve the understanding of, perspectives and experience on water that all

[51] Nesshover et al. (2017) clearly show that for nature-based solutions (of the kind suggested in this chapter) to succeed, multi-stakeholder partnerships are an essential pre-condition.

primary stakeholders bring to the table. The indigenous knowledge of Indians with a long history of water management is an invaluable intellectual resource that must be fully leveraged.

It is also necessary to ensure that the participation of primary stakeholders must not be nominal, passive or merely consultative, as has tended to happen in the past. Their participation must be both empowering and empowered, so that stakeholders are able to take into account all available information and expertise while making decisions, and their voice has a definite bearing and influence on processes and outcomes.[52]

6 Conclusion

The unprecedented COVID-19 pandemic provides an urgent context to the discussion in this paper. It has reminded everyone, like never before, of how circumscribed the economy necessarily is by the nature of the larger ecosystem governing it. It is not merely a matter of realising the constraints within which everyone operates but of re-envisioning the response: moving from a paradigm of linear mechanics to thinking in terms of complex dynamics. As the imprint of humans on the planet grows ever larger in the epoch of the Anthropocene, this shift becomes imperative. Change now is no longer going to be uni-vocal or uni-directional. The harder we impact the Earth, the more impossible becomes our dream of command-and-control over it. We need, more and more, to learn to deal with the unforeseen and the inherently unpredictable. The pandemic forces everyone to acknowledge that this is now imperative, not just for greater prosperity but also for the very survival of human life on Earth.

According to Kate Brown, MIT Professor of Science, Technology and Society:

> Within the uniform predictability of modern agriculture, the unpredictable emerges … Two-thirds of cancers have their origins in environmental toxins, accounting for millions of annual fatalities … we inhabit not the Earth but the atmosphere, a sea of life; as swimmers in this sea, we cannot be biologically isolated … Biologists have begun questioning the idea that each tree is an "individual"—it might be more accurately understood as a node in a network of underworld exchanges between fungi, roots, bacteria, lichen, insects, and other plants. The network is so intricate that it's difficult to say where one organism ends and the other begins.[53]

More specifically, it is clear that

> There is a large list of deadly pathogens that emerged due to the ways in which we practice agriculture, among which are: H5N1-Asian Avian Influenza, H5N2, multiple Swine Flu variants (H1N1, H1N2), Ebola, Campylobacter, Nipah virus, Q fever, hepatitis E, Salmonella enteritidis, foot-and-mouth disease, and a variety of influenzas. (Altieri & Nicholls, 2020)

---

[52] Agarwal (1994) offers a very useful typology of the ways in which participation occurs in development programmes and enunciates the conditions under which it is truly meaningful.

[53] https://councilontheuncertainhumanfuture.org/the-pandemic-is-not-a-natural-disaster/.

This necessitates a paradigm shift in our structures of thought, to be able to grasp complex adaptive systems[54] (where the complexity of the behaviour of the whole system cannot be completely grasped by an understanding of its individual parts), of which farming and the water cycle both are important examples. Thus, an appreciation of inter-connectedness becomes essential to understanding the nature of the problem and to suggesting meaningful solutions.

It is this understanding that underlies the paradigm shifts in water and agriculture advocated in this chapter. Ironically, those resisting this change claim to be speaking the language of science, while completely ignoring how both best practice and theory are evolving globally. All of the policy prescriptions advocated in this chapter rely on nationally and globally tried and tested best practices in both water and farming—practices that range from technological advances to management systems and governance reform.

If farming continues to be as water-intensive as it is in India today, there will be no way for the country to meet the drinking water and livelihood requirements of its people. If farming methods pay no attention to the soil that sustains them, then food security will be in ever-greater danger. If the exclusive focus on rice and wheat in the support provided to farmers continues, India will be completely unable to tackle the twinned syndemic of malnutrition and diabetes.

We cannot continue to mindlessly extract groundwater without realising how that is destroying the resource itself, as also the rivers that both feed and are being fed by it. We cannot go on building dams without being mindful of what that could mean for the very integrity of India's monsoon cycle. We cannot continue to destroy our catchment areas and still hope for our rivers to survive and sustain us. If India's river basins survive, we also will. Otherwise like many great river valley civilisations of the past, we too will perish!

Acknowledgements We would like to thank Francesca Harris of the Centre on Climate Change and Planetary Health at the London School of Hygiene and Tropical Medicine for conducting the scenario analysis and help in drafting Sect. 4 of this chapter. Francesca Harris is funded by the Sustainable and Healthy Food Systems (SHEFS) programme supported by the Wellcome Trust's Our Planet, Our Health programme [grant number: 205200/Z/16/Z].

We would also like to thank the anonymous reviewers of this paper who helped us tighten many of our arguments. We are grateful to the discussants and other participants at the National Dialogue *Indian Agriculture Towards 2030* where an earlier draft of this paper was presented in January 2021. Finally, we are extremely thankful to Jean Dreze for taking out time to give us detailed comments on the paper.

References

Addiscott, T. M. (2010). Soil mineralization: An emergent process? *Geoderma, 160*(1).

Agarwal, B. (1994). *A field of one's own: Gender and land rights in South Asia.* Cambridge University Press.

[54] Holland (1998), Gal (2012).

Ahluwalia, M., & Kaur, A. (2020). Assessment of chromosomal aberrations among agricultural workers exposed to pesticides in Punjab, India. *Journal of Biochemical and Molecular Toxicology*, http://doi.org/10.1002/jbt.22646.

Altieri, M. A., & Nicholls, C. I. (2020). Agroecology and the reconstruction of a post-COVID-19 agriculture. *The Journal of Peasant Studies, 47*(5).

Altieri, M. A., et al. (2015). Agroecology and the design of climate change-resilient farming systems. *Agronomy for Sustainable Development, 35*, 869–890.

Anderson, C. R., et al. (2021). *Agroecology now!: Transformations Towards More Just and Sustainable Food Systems*. Palgrave Macmillan, Cham.

Aryal, J. P., et al. (2016). Conservation agriculture-based wheat production better copes with extreme climate events than conventional tillage-based systems: A case of untimely excess rainfall in Haryana, India. *Agriculture, Ecosystems & Environment, 233*, 325–335.

Balakrishnan, P. (2007). The recovery of India: Economic growth in the Nehru era. *Economic and Political Weekly, 42*(45–46).

Bartell, J., et al. (2020). Subsidising rice and sugar? The public distribution system and nutritional outcomes in Andhra Pradesh, India. *Journal of Social Policy*, *50*(4), 681–705, https://doi.org/10.1017/S0047279420000380

Baveye, P. C., et al. (2018). Emergent properties of microbial activity in heterogeneous soil microenvironments. *Frontiers in Microbiology, 9*, 1929.

Bawa, K. S., et al. (2020). Envisioning a biodiversity science for sustaining human well-being. *Proceedings of the National Academy of Sciences*, *117*(42), http://doi.org/10.1073/pnas.2018436117

Benton, T. G., & Bailey, R. (2019). The paradox of productivity: Agricultural productivity promotes food system inefficiency. *Global Sustainability, 2*.

Bhalla, G. S., & Singh, G. (2009). Economic liberalisation and Indian agriculture: A state-wise analysis. *Economic and Political Weekly, 44*(52).

Bossio, D., et al. (2008). Land degradation and water productivity in agricultural landscapes. In D. Bossio & K. Geheb (Eds.), *Conserving land, protecting water. Comprehensive assessment of water management* (Series 6). Centre for Agriculture and Bioscience International (CABI).

Chauhan, B. S., et al. (2012). Productivity and sustainability of the rice-wheat cropping system in the Indo-Gangetic plains of the Indian subcontinent: Problems, opportunities, and strategies. *Advances in Agronomy, 117*, 315–369.

Chouhan, S. S., Awasthi, M. K., & Nema, R. K. (2015). Studies on water productivity and yields responses of wheat based on drip irrigation systems in clay loam soil. *Indian Journal of Science and Technology, 8*(7), 650.

Corsini, E., Liesivuori, J., Vergieva, T., Van Loveren, H., & Colosio, C. (2008). Effects of pesticide exposure on the human immune system. *Human & Experimental Toxicology, 27*(9).

Csete, M. E., & Doyle, J. C. (2002). Reverse engineering of biological complexity. *Science, 295*(5560), 1664–1669.

Cullather, N. (2010). *The hungry world: America's cold war battle against poverty in Asia*. Harvard University Press.

Cullet, P. (2019). Model groundwater (Sustainable Management) bill, 2017: A new paradigm for groundwater regulation. http://doi.org/10.1080/24730580.2019.1565567

DAC (Directorate of Economics and Statistics, Department of Agriculture, Co-operation and Farmer Welfare). (2018 and 2020). *Agricultural statistics at a glance*. Ministry of Agriculture and Farmers Welfare, Government of India. https://eands.dacnet.nic.in/

Damodaran, H. (2021, January 14). First rice, now wheat: India rides on global grain trade bandwagon. *Indian Express*.

Dawson, I. K., et al. (2019). *Contributions of biodiversity to the sustainable intensification of food production—Thematic study for the state of the world's biodiversity for food and agriculture*. Food and Agriculture Organization of the United Nations, Rome.

DeFries, R., Chhatre, A., Davis, K. F., Dutta, A., Fanzo, J., Ghosh-Jerath, S., Myers, S., Rao, N. D., & Smith, M. R. (2018). Impact of historical changes in coarse cereals consumption in India on micronutrient intake and anaemia prevalence. *Food and Nutrition Bulletin, 39*(3), 377–392.

Deleuze, G., & Guattari, F. (1987). *A thousand plateaus: Capitalism and schizophrenia.* University of Minnesota Press.

Dreze, J. (2021, January 23). Imbalances in India's cereal economy need more than a short-term fix. *Indian Express.*

Expert Committee. (2019). *Report on policies and action plan for a secure and sustainable agriculture.* Report submitted to the Principal Scientific Advisor, Government of India.

Falconer, R. E., et al. (2012). Emergent behavior of soil fungal dynamics: Influence of soil architecture and water distribution. *Soil Science, 177*(2), 111–119.

FAO, IFAD, UNICEF, WFP, & WHO. (2020). *The state of food security and nutrition in the world 2020. Transforming food systems for affordable healthy diets.* FAO. http://doi.org/10.4060/ca9692en

FAO-AQUASTAT. (2019). Food and Agriculture Organization. http://www.fao.org/aquastat/en/. Accessed July 21, 2020.

Francis, C. A. (Ed.). (1986). *Multiple cropping systems.* London.

Gal, O. (2012). Understanding global ruptures: A complexity perspective on the emerging middle crisis. In T. Dolphin & D. Nash (Eds.), *Complex new world*. The Institute for Public Policy Research (IPPR).

Ghosh, P. K., Hazra, K. K., Venkatesh, M. S., & Nath, C. P. (2017). Increasing soil organic carbon through crop diversification in cereal—Cereal rotations of Indo-Gangetic plain. *Proceedings of the National Academy of Sciences*, India.

Gulati, S., & Misra, A. (2014). Sugar intake, obesity, and diabetes in India. *Nutrients, 6*(12), 5955–5974.

Gupta, A., et al. (2018). *Wheat varieties notified in India since 1965*. ICAR-Indian Institute of Wheat & Barley Research.

Harris, F., et al. (2020). Trading water: Virtual water flows through interstate cereal trade in India. *Environmental Research Letters, 15*(12):125005, https://doi.org/10.1088/1748-9326/abc37a.

Hecht, S. B. (1987). The Evolution of Agroecological Thought. In M. A. Altieri, John G. Farrell, Susanna B. Hecht, Matt Liebman, Fred Magdoff, Bill Murphy, Richard B. Norgaard, Thomas O. Sikor (Eds.), *Agroecology: The Science of Sustainable Agriculture*, CRC Press, London.

Holland, J. H. (1998). *Emergence: From chaos to order*. Helix Books.

Husain, S. (2020). *Why governments need to advise farmers on alternative cropping patterns.* The Wire, New Delhi, October 21, available at. https://thewire.in/agriculture/wheat-rice-msp-procurement-cropping-patterns-data

Indoria, A. K., et al. (2018). Alternative sources of soil organic amendments for sustaining soil health and crop productivity in India—Impacts, potential availability, constraints and future strategies. *Current Science, 115*(11).

Jain, M., Fishman, R., Mondal, P., Galford, G.L., Bhattarai, N., Naeem, S., Lall, U., Singh, B., & DeFries, R.S. (2021). Groundwater depletion will reduce cropping intensity in India. *Science Advances*, *7*(9):eabd2849, https://doi.org/10.1126/sciadv.abd2849.

Jena, D., & Mishra, S. (2021). *Procurement and public distribution of millets in Odisha—Lessons and challenges.* Policy Brief PB1RRAN0121, RRA Network, India.

Jepson, P. C., Murray, K., Bach, O., Bonilla, M., & Neumeister, L. (2020). Selection of pesticides to reduce human and environmental health risks: A global guideline and minimum pesticides list. *The Lancet Planetary Health, 4*(2), e56–e63.

Karnataka Knowledge Commission. (2019). *Karnataka state water policy.* Government of Karnataka.

Kayatz, B., et al. (2019). More crop per drop: Exploring India's cereal water use since 2005. *Science of the Total Environment, 673*, 207–217.

Khera, R., et al. (2020). *MSP—The factoids versus the facts.* The Hindu, New Delhi, December 19, available at https://www.thehindu.com/opinion/lead/msp-the-factoids-versus-the-facts/article33367929.ece.

Krishna, R. (1972). Government operations in foodgrains. In: P. Chaudhuri (Ed.), *Readings in Indian Agricultural Development*, George Allen and Unwin, London.

Krishnan, R., et al. (Eds.). (2019). *Assessment of climate change over the Indian region.* Report of the Ministry of Earth Sciences. Government of India.

Kulkarni, H., & Shah, M. (2013). Punjab water syndrome: Diagnostics and prescriptions. *Economic and Political Weekly, 48*(52).

Kumar, A., et al. (2011). Performance of system of wheat intensification (SWI) and conventional wheat sowing under north eastern plain zone of India. *Annals of Agricultural Research, 36*(3).

Ladha, J. K. (2009). *Integrated crop and resource management in the rice-wheat system of South Asia: Los Baños.* International Rice Research Institute, Los Baños, Philippines.

Ladha, J. K., et al. (2016). Agronomic improvements can make future cereal systems in South Asia far more productive and result in a lower environmental footprint. *Global Change Biology, 22*(3), 1054–1074.

Laik, R., et al. (2014). Integration of conservation agriculture with best management practices for improving system performance of the rice–wheat rotation in the eastern Indo-Gangetic plains of India. *Agriculture, Ecosystems & Environment, 195*, 68–82.

Lal, R. (2012). Soil water and agronomic production. In R. Lal & B. A. Stewart (Eds.), *Soil water and agronomic productivity*. CRC Press.

Lent, J. (2017). *The patterning instinct: A cultural history of humanity's search for meaning*. Prometheus.

Mann, C. C. (2018). *The wizard and the prophet: Two ground breaking scientists and their conflicting visions of the future of our planet*. Penguin.

Margni, M., et al. (2002). Life cycle impact assessment of pesticides on human health and ecosystems. *Agriculture, Ecosystems & Environment, 93*, 379–392.

Mathur, M., & Ranjan, S. (2021). *Can magicmillets provide a solution for malnutrition?*, Outlook Poshan 2.0, The Outlook Group, New Delhi, February 21, available at: https://poshan.outlookindia.com/story/poshan-news-can-magic-millets-provide-a-solution-for-malnutrition/374898.

Mekonnen, M. M., & Hoekstra, A. Y. (2011). The green, blue and grey water footprint of crops and derived crop products. *Hydrology & Earth System Sciences Discussions, 8*(1).

Mevada, K., Patel, M., & Chauhan, N. (2016). Performance of System of Rice Intensification (SRI) technique in rice (Oryza sativa L.) on farmer's field. *Gujarat Journal of Extension Education, 2016*, 13.

Miller, N. (2021). *The forgotten foods that could excite our tastebuds.* BBC Future, BBC, London, available at: https://www.bbc.com/future/bespoke/follow-the-food/the-forgotten-plants-that-could-excite-our-tastebuds. Accessed February 23, 2021.

Mooij, J. (1998). Food policy and politics: The political economy of the public distribution system in India. *Journal of Peasant Studies, 25*(2), 77–101.

Narayanamoorthy, A. (2004). Drip irrigation in India: Can it solve water scarcity? *Water Policy, 6*, 117–130.

Natarajan, M., & Willey, R. W. (1986). The effects of water stress on yields advantages of intercropping systems. *Field Crop Research, 13*, 117–131.

Nesshover, C., et al. (2017). The science, policy and practice of nature-based solutions: An interdisciplinary perspective. *Science of the Total Environment, 579*, 1215–1227.

Nicolopoulou-Stamati, P., Maipas, S., Kotampasi, C., Stamatis, P., & Hens, L. (2016). Chemical pesticides and human health: The urgent need for a new concept in agriculture. *Frontiers in Public Health, 4*, 148. http://doi.org/10.3389/fpubh.2016.00148

Norgaard, R. B., & Sikor, T. O. (1995). In M. A. Altieri (Ed.), *The methodology and practice of agroecology.*

Oo, A. Z., et al. (2018). Methane and nitrous oxide emissions from conventional and modified rice cultivation systems in South India. *Agriculture, Ecosystems & Environment, 252*, 148–158.

Pal, D. K., Bhattacharyya, T., Srivastava, P., Chandran, P., & Ray, S. K. (2009). Soils of the Indo-Gangetic plains: Their historical perspective and management. *Current Science, 96*(9).

Pawar, D., Dingre, S., & Surve, U. (2013). Growth, yield and water use in sugarcane (Saccharum officinarum) under drip fertigation. *Indian Journal of Agronomy, 58*(3), 396–401.

Planning Commission. (2013). *Twelfth five year plan.* Government of India.

Rathore, V. S., Nathawat, N. S., Bhardwaj, S., Sasidharan, R. P., Yadav, B. M., Kumar, M., et al. (2017). Yield, water and nitrogen use efficiencies of sprinkler irrigated wheat grown under different irrigation and nitrogen levels in an arid region. *Agricultural Water Management, 87*, 232–245.

Ravindra, A., & Bhagya Laxmi, S. (2011). Potential of the system of rice intensification for systemic improvement in rice production and water use: the case of Andhra Pradesh, India. *Paddy and Water Environment, 9*(1), 89–97.

Repetto, R., & Baliga, S. S. (1996). Pesticides and immunosuppression: The risks to public health. *Health Policy and Planning, 12*(2), 97–106.

Ryan, N., & Sudarshan, A. (2020). Do India's farmers use too much water? *VoxDev*, 24 July 2020. https://voxdev.org/topic/energy-environment/do-india-s-farmers-use-too-much-water

Shah, M. (2007). *The crowning of the moneylender*. The Hindu, New Delhi, September 1, available at: https://www.thehindu.com/todays-paper/tp-opinion/the-crowning-of-the-moneylender/article2015255.ece

Shah. M. (2013). Water: Towards a paradigm shift in the 12th plan. *Economic and Political Weekly, 48*(3).

Shah, M. (2019). *Water reform must begin at the farm.* Business Standard, New Delhi, June 7, available at: https://www.business-standard.com/article/opinion/water-reform-must-begin-at-the-farm-119060700054_1.html

Shah, M., Rao, R., & Vijayshankar, P. S. (2007). Rural credit in 20th century India: Overview of history and perspectives. *Economic and Political Weekly, 42*(15).

Shah, M., et al. (2016). *Report of the committee on restructuring CWC and CGWB.* Ministry of Water Resources, Government of India.

Sharma, B., et al. (2018). *Water productivity mapping of major Indian crops.* NABARD-ICRIER.

Shiva, V., & Prasad, R. (1993). *Cultivating diversity: Biodiversity conservation and seed politics.* Natraj Publishers.

Sidhu, B. S., et al. (2020). Power tariffs for groundwater irrigation in India: A comparative analysis of the environmental, equity, and economic tradeoffs. *World Development, 128.*

Singh, O. (2013). Hydrological and farming system impacts of agricultural water management interventions in North Gujarat. *Indian Journal of Agricultural Economics, 68*(902-2016-66839).

Sinha, J., et al. (2018). Assessment of the impacts of climatic variability and anthropogenic stress on hydrologic resilience to warming shifts in Peninsular India. *Scientific Reports*. https://doi.org/10.1038/s41598-018-32091-0

Soriano, J. B., Wani, S. P., Rao, A. N., Sawargaonkar, G. L., & Gowda, J. A. (2018). Comparative evaluation of direct dry-seeded and transplanted rice in the dry zone of Karnataka, India. *Philippine Journal of Science, 147*(1), 165–174.

Stanford Encyclopedia of Philosophy. (2018, July 20). *Infinite regress arguments.* https://plato.stanford.edu/entries/infinite-regress/

Stone, G. D. (2019). New histories of the Indian green revolution. *The Geographical Journal, 185*(2), 129–252.

Subramanian, K. (2015). *Revisiting the green revolution: Irrigation and food production in 20th century India* (Ph.D. thesis), Kings College, London.

Suryavanshi, P., & Buttar, G. (2016). Economic feasibility of micro-irrigation methods for wheat under irrigated ecosystem of central Punjab. *Indian Journal of Economics and Development, 12* (1a).

Tamburini, G., et al. (2020). Agricultural diversification promotes multiple ecosystem services without compromising yield. *Science Advances, 6*, eaba1715.

Thomson Jacob, C., Parida, A., & Krishna Kumar, N. K. (2020). Conservation of India's agro-biodiversity towards increasing food, nutritional and livelihood security. *Current Science, 119*(4).

Tomlinson, B. R. (2013). *The economy of modern India from 1860 to the twenty-first century*. Cambridge University Press.

Vandermeer, J. (1989). *The ecology of intercropping*. Cambridge University Press.

Vijay Kumar, T. (2020). *Note on AP community-managed natural farming programme.* Internal Memo.

Vijayshankar, P. S. (2016). Regional inequality: A long view. *Seminar*, 682.

Vijayshankar, P. S., Kulkarni, H., & Krishnan, S. (2011). India's groundwater challenge and the way forward. *Economic and Political Weekly, 46*(2).

WHO. (2011). *Nitrate and nitrite in drinking water*. World Health Organisation, Geneva.

WLE. (2015). *Groundwater and ecosystem services: A framework for managing smallholder groundwater-dependent agrarian socio-ecologies—Applying an ecosystem services and resilience approach.* International Water Management Institute—Consultative Group for International Agricultural Research Program on Water, Land and Ecosystems (WLE). http://doi.org/10.5337/2015.208

World Bank. (2010). *Deep wells and prudence: Towards pragmatic action for addressing groundwater overexploitation in India.* World Bank, Washington D.C., available at: https://openknowledge.worldbank.org/handle/10986/2835

Pests, Pandemics, Preparedness and Biosecurity

N. K. Krishna Kumar and S. Vennila

1 Introduction

India is a growing global power with consistent high economic and technological growth. However, the share of agriculture in the gross domestic product is declining. Reduced input-use efficiency of the factors of production, soil organic carbon and fertility, water table, nutrition and livelihood security, food safety coupled with vagaries of climate change and increased pests and pandemics and human-animal conflict due to overlapping food niche characterise Indian agriculture at present (ICAR, 2020). Agriculture offers livelihood to about 58% of India's 1.38 billion population. The production of food grain and horticultural crops are 296 and 320 million metric tonnes (MMT), respectively, from 142 million hectares leading to apparent self-sufficiency. Furthermore, ~US$ 29 billion was the share of exports during 2020. India has the largest livestock population of 536 million with milk production of 198 MT (IBEF, 2020). Poultry at 852 million (DAHD, 2020) together with livestock and fisheries contributes to protein nutrition. Fisheries and allied sectors provide livelihood to more than 14.5 million and the marine resources of India comprise an exclusive economic zone of two million sq. km, a continental shelf area of 30,000 km^2 and a coastline of 8,118 km with annual marine fish landings of 3.50 MMT (CMFRI, 2020). Agriculture and allied sectors remain the fulcrum in determining the country's social and economic status in terms of food, nutritional and environmental security. Demand projections for food grains is 345 MMT by 2030 and high-value commodities of horticulture, dairy, livestock and fish are increasing faster than food

N. K. Krishna Kumar (✉)
Entomological Society of India, New Delhi, India
e-mail: kumariihr@yahoo.com

S. Vennila
National Research Centre for Integrated Pest Management, Indian Council of Agricultural Research, LBS Building, Pusa Campus, New Delhi 110012, India

R. Chand et al. (eds.), *Indian Agriculture Towards 2030*,
India Studies in Business and Economics,
https://doi.org/10.1007/978-981-19-0763-0_6

grains by more than 100%. One of the serious impediments in enhancing productivity with sustainability to achieve the millennium goals is the pandemics, which cut at the edifice of production and productivity across sectors of agriculture, horticulture, livestock and fisheries in addition to threatening biodiversity, food safety and ecosystem services.

Pests are both native and transboundary in nature affecting human health, agriculture-cum-allied sectors. World witnessed many transboundary pest outbreaks, some regional and others pandemic in nature. Their outbreak or epidemics or pandemics lead to famine as in locust plague and mass migration as in late blight of potato leading to economic, environmental and social chaos. This is true when zoonotic impact human health on a global scale. In India, being a predominantly tropical/subtropical country and with little elasticity between demand and production, even a small upheaval can lead to strong social and political turmoil as seen with diseases impacting onions, tomato and potato crops. Often, the impact of pests and pandemics on the natural biodiversity and ecosystem services is direct. The indirect costs associated with ecological imbalance, food safety, migration and health go unnoticed and unaccounted. Increased travel and international trading of agricultural commodities amidst fluctuating environmental factors and changing sociocultural milieu has continuously contributed to new and emerging pests in India in the last 50 years including the recent pandemics of corona virus disease 2019 (COVID-19). Global trade, travel and climate change impact all systems of the one earth but the intentional and unnoticeable effects of various factors of pest dynamics require a wholesome biosecurity that allows careful capture of significant temporal and spatial trends of biodiversity and ecosystem services with the objective of mitigating potential threats before they assume pandemic proportion. Thus, in an era of aspirations for achieving food and nutritional security with food and environmental safety amidst climate change, it is imperative to address the status of pests, pandemics and the preparedness to tackle them from a scientific biosecurity framework. The current chapter examines the key problems of pests and possible pandemics among various components (human/plants/animals/birds/fish) in the Indian context while examining the possible steps to be undertaken in the coming decade towards mitigation keeping the Sustainable Development Goals in focus.

2 Pests and Pandemics: Crops

Potential productivity of agricultural and horticultural crops is challenged by insect pests, diseases, weeds, nematodes and some vertebrates. Their impacts on farmers, consumers and all organisms down the food web are significant and often devastating. During each cultivation cycle of agricultural and horticultural crops, production and productivity losses of ~15.7% occur in India owing to pests (Dhaliwal et al., 2015) accounting to ~US$ 36 billion. Of the 173 invasive alien species documented, 54, 25 and 22 represent terrestrial plant species, pathogens and insects, respectively, till 2018 (Sandilyan, 2016).

2.1 Transboundary Plant Pests

Transboundary pests are a serious threat to food security and environment, a condition exacerbated in recent decades by the globalised movement of people and commodities. India witnessed an upsurge of desert locust in 2020 with their swarms attaining epidemic proportions during COVID-19 pandemic. Rajasthan was on high alert with swarms entering Madhya Pradesh, Uttar Pradesh, Punjab, Haryana Gujarat and Telangana between May and June. As in the first week of July 2020, FAO had sounded a high alert with the possibility of more swarms of locusts likely to migrate from Somalia to along India-Pakistan border (FAO, 2020a, b). Cassava mealybug (CMB) is the latest invasive insect in 2020 first observed in Thrissur, Kerala (Joshi et al., 2020) and has spread to Tamil Nadu causing 9–46% infestation. Prevention of spread to unaffected areas and action for eradication (ICAR-NBAIR, 2020) and importation of CMB-specific parasitoid, *Anagyrus lopezi* is currently underway. The fall armyworm (FAW) invaded maize in India during May 2018, and spread across all maize growing states. Recently it was also reported from Bangladesh. India recommended eight insecticides however, with conservation and augmentative biocontrol-cum cultural control interventions given prime importance (AFFRC, 2019). Rugose spiralling whitefly (RSW), first noticed on coconut from Tamil Nadu and Kerala in 2016, later spread to Andhra Pradesh, Karnataka, Goa and Assam, through infested seedlings and transportation of plant materials (CPCRI, 2019). Banana, mango, sapota, guava, cashew, maize, ramphal (local fruit in India), oil palm, Indian almond, water apple, jack fruit and many ornamental plants are host crops of RSW (NBAIR, 2020). Natural buildup of the parasitoid, *Encarsia* in RSW endemic areas and enhancing its niche survival are given focus at present. South American Tomato Moth (SATM), an invasive insect on tomato both under greenhouse and field conditions, was reported in 2014 (Sridhar et al., 2014) with its spread to several states, has established as a regular pest. While natural incidence of *Metarhizium anisopliae* on larval SATM was up to 35%, resistance breeding through screening of wild and cultivated tomato genotypes is underway as a long-term management strategy. Papaya mealybug (PMB) caused significant damage to agricultural and horticultural crops since its documentation in 2007 at Coimbatore, Tamil Nadu. Mulberry crop over 1500 ha in Tamil Nadu too got destroyed (Shekhar et al., 2011). However, classical biological control using *Acerophagus papayae* from Puerto Rico is a success story that reduced incidence of PMB from 49 to 3%. Cotton mealybug (CMB) first recorded in Gujarat in 2005 caused yield loss of 30–40% in Punjab amounting to INR 1590 million during 2007 (Dhawan et al., 2007) and 40–50% in Gujarat. Infestation of CMB was reported from 71, 141, 124 and 194 species of plants belonging to 27, 45, 43 and 50 families, respectively, across cotton growing zones in India (Vennila et al., 2011) and the parasitoid, *Aenasius bambawalei* offered fortuitous biological control (Gautam et al., 2009). Invasive eucalyptus gall wasp (EGW) of 2001 (Anonymous, 2007), spread across south (Jacob et al., 2007), central (Kumar et al., 2007) and northern states threatening the productivity of paper and pulp industry in 2007, however, is being kept under check presently by the native parasitoids (Ramanagouda et al., 2011). Other established invasive plant pests in India include silver leaf whitefly (Ananthakrishnan, 2009), coconut eriophyid mite (Sathiamma et al., 1998), spiralling whitefly (Mani, 2010) and coffee berry borer (Singh & Ballal, 1991) that are managed on need basis. Occurrence of *Fusarium* wilt (race 1) infecting Cavendish in 2010 (Thangavelu et al., 2011) and tropical race 4 (TR4) reported from Uttar Pradesh in 2017 was also recorded from Bihar, Madhya Pradesh, Gujarat and Maharashtra. Productivity of banana, especially Cavendish varieties is highly reduced by TR4 in several parts of the country (FAO, 2019) and the poor man's source of nutrition was at stake. Infected areas in Bihar and Uttar Pradesh saw a remarkable control of TR4 on account of microbial consortium developed by the Indian Council of Agricultural Research (ICAR). Citrus greening disease is destructive in major citrus belts of Maharashtra, Punjab, Southern and North-East India with its transmission through grafts and psyllid vector (Das, 2008) necessitating supply of disease-free citrus seedlings to reduce its incidence and damage.

3 Emerging Pest Problems: Insects and Diseases

Pest problems from the categories of insects, diseases, nematodes and weeds of economically important crops of agriculture and horticulture including protected cultivation emerge or change due to alteration in climate and crop production practices. Outbreaks of plant hoppers (Anonymous, 2018; Chander & Patel, 2010, Prakash et al., 2014) and swarming caterpillar (Anonymous, 2009; Tanwar et al., 2010) on rice are noticed every now and then owing to congenial weather exacerbated by excessive nitrogenous fertilisers, closer spacing and indiscriminate insecticide use. Neck blast in Karnataka during periods of unseasonal rainfall (Chethana et al., 2016) and bakanae (Bashyal et al., 2014; Gupta et al., 2015) occurrence across basmati growing tracts are the diseases of rice creating havoc. Increasing incidence of aphids in wheat, barley and oats (Sharma & Saharan, 2011) and yellow/stripe rust of wheat in severe form at certain pockets of north Indian states (Sharma, 2014) make the emerging scenario. At a time when per capita consumption of protein is declining with increasing number of mouths to feed, the production of pulse crops is threatened by biotic risks such as gram pod borer, spotted pod borer, pod sucking bugs and pod fly in addition to the major fungal and wilt diseases. A recent phenomenon is the delayed withdrawal of Southwest monsoon and excess precipitation leading to many fungal diseases across crops including pulses in Karnataka and Maharashtra. Outbreaks of defoliators on soybean in Maharashtra in 2008 (Lokare et al., 2014), stem rot on groundnut in the north of West Bengal (Baskey et al., 2020) and sunflower necrosis (Sardaru et al., 2013) add to perennial shortage of edible oils in India, wherein, the imports exceed domestic production. Increased incidence of bollworms/borers, resistance to *Bt* in pink bollworm and sap feeding insects such as whitefly in Punjab in 2015 take a toll on production and productivity of cotton. Changing scenarios of insects during and post *Bt* era are a continuum with current plant protection revolving around pink bollworm and sap feeders (ICAR-NCIPM, 2019). White grubs (Anonymous, 2017) and disease *pokkah boeng* (Viswanathan, 2020) gained importance in recent years.

Sucking insects (hoppers, mites, thrips and whitefly) pose significant problems to horticultural production. Many species besides being direct pests, are effective vectors of plant pathogens such as viruses and phytoplasma. While fruit fly complex is a major problem in many horticultural crops, leaf weevil devastating mango and litchi in Punjab (Sharma et al., 2015), mango shoot gall psylla at Uttarakhand (Kadam et al., 2017), sapota seed borer in Maharashtra (Patel, 2001) and litchi stink bug outbreak in Jharkhand (Jaipal et al., 2013) are hindrances to fruit cultivation. Bacterial blight of pomegranate epidemic in Karnataka, Andhra Pradesh and Maharashtra (Mondal & Sharma, 2009) and mango sudden decline (MSD) in Andhra Pradesh and anthracnose on fruits cause widespread damage. Incidence of chilli gall midge (Nagaraju, 2000) and *Solenopsis* mealy bug attacking vegetables of Malvaceae, Solanaceae, Leguminosae and Cucurbitaceae are the emerging problems. Whitefly as a sucking pest and vector cause extensive economic damage in chilli, tomato and okra (Halder et al., 2013). Hadda beetle on cowpea and bitter gourd (Singh et al., 2014), plume moth in bottle gourd (Rai et al., 2014) and diamondback moth in crucifers (Ahmed et al., 2009) also cause serious menace.

Potato late blight, an annual threat of North India (Chowdappa et al., 2011), has been causing epidemics in southern states of India on tomato and potato since 2008 (Chowdappa et al., 2013) possibly due to A2 clonal lineage introduced from Europe (Chowdappa et al., 2015). Giant African snail is detrimental to colocasia, elephant foot yam, cucumber, cowpea, field bean, pea, ladies' finger and tomato with its sporadic outbreaks among crops of bitter gourd, beans, bottle gourd, chilli, tomato and cauliflower (Puri & Mote, 2004). Diseases caused by tospoviruses (Prabhakar et al., 2017) vectored by thrips have emerged as a limiting factor for the sustainable production of tomato and watermelon. Aphid transmitted papaya ring spot virus is of major significance that can impact availability of vitamin A to the common man. *Stemphylium* blight and iris yellow spot virus associated with onions and anthracnose on many horticultural crops, are emerging as serious threats. Occurrence of insects and diseases inside polyhouses exceed open field cultivation because of favourable moisture and humidity (Singh et al., 2017) and absence of environmental resistance. The uninterrupted cultivation under greenhouses contributed towards high incidences of soil-borne diseases (Sharma, 2012) and especially root knot nematodes. Severity of powdery mildew, bacterial wilt and root rots was found more alarming with dominance of *tospo* and leaf curl viral diseases in protected cultivation (Somasekhar et al., 2012).

3.1 Emerging Pest Problems: Nematodes and Weeds

Nematode problem is gaining momentum across all cropping systems of Indian agriculture. Plant-parasitic nematodes cause 21.3% crop losses across 19 horticultural and 11 field crops (Kumar et al., 2020). Root knot, reniform, lesion, foliar, burrowing and bulb-cum-stem nematodes are the most destructive and difficult to control pests that certifications have become essential nowadays for protected cultivation in glass and polyhouses. Both ecto- and endo-parasitic nematodes inflicting serious damage are a cause of concern in forests. A potential risk of introduction of pine wilt nematode in the Himalayan region of Indian territory exists through the import of coniferous wood and their products especially from China through Nepal, Bhutan and Myanmar (Khan, 2020). Declining organic matter and pH directed micro-irrigation and fertigation have accentuated the problem both in the open and protected conditions. Weeds also cause reduction in yields of various crops and are more harmful than insects and diseases with potential crop yield losses ranging between 15 and 76% (Gharde et al., 2018). Herbicide resistance in weeds, changing climate, direct-seeded rice and zero cultivation led weed species, plant parasitic *Orobanche* in mustard and alien weeds viz*., Parthenium, Lantana, Ageratum, Chromolaena* and *Mikania* (Rao, 2018) have become aggressive despite wider use of chemical and bio herbicides for weed control (Kaur et al., 2014).

3.2 Pests and Pandemics: Livestock

Vast agro climatic, geographical regions and cultural differences have led to differential husbandry practices as well as diseases occurrence in livestock. In recent years, emerging and re-emerging diseases of livestock, poultry and piggery have tremendously increased along with growing demand for and supply of meat, milk, eggs and fish. Fresh and processed products are witnessing increased trade and likelihood of carriers of contaminants. Breach of biosecurity in intensified livestock production and management systems is often the reason for spread of zoonotic and other animal diseases with considerable impact on public health. The societal conundrum that exists in the country prohibits the drastic measure of slaughtering and disposal of the infested and in-contact animals and hence the rate and speed of disease spread are faster even if identified on time; besides wet markets, across the country, are very conducive for zoonotic diseases. Foot and mouth disease (FMD) is a continuing epidemic decreasing the productivity of cattle, meat, wool, etc., due to unrestricted movement of animals across Indian states and incomplete vaccination. In FMD control areas, there is built-up of herd immunity and substantial fall (Subramaniam et al., 2013). Outbreak of *Peste-des-petits* ruminants (PPR) affecting goats and sheep in Tripura is a transboundary disease (Begum et al., 2016) and about 99% nucleotide identities existed with Bangladeshi viral strains (Muthuchelvan et al., 2014). Several PPR outbreaks were encountered in India with high morbidity (50–90%) and mortality (50–85%; Muthuchelvan et al., 2015). Bluetongue transmitted by *Culicoides* spp. was severe in Karnataka, Andhra Pradesh and Tamil Nadu (Hemadri & Hiremath, 2011) and impacted the farmers in the recent past.

Lumpy skin disease (Anonymous, 2020a), a capripox infectious viral disease, transmitted by mosquitoes and flies is fast spreading among cattle and bovines in districts of Maharashtra and Assam. Sheep poxvirus and goat poxvirus cause economic losses to small ruminant husbandry with mortality of young animals exceeding 50% in almost all states (Bhanuprakash et al., 2011). Bovine herpesvirus-1, higher in crossbred and exotic breeds, causes economic losses through reduction in milk yield and impact on national and international trade of germplasm and livestock. Bovine viral diarrhoea in cattle (Sood et al., 2007), sheep and goats (Mishra et al., 2009) and buffaloes (Mishra et al., 2008) are also important. Picobirnaviruses are emerging threat to mammalian and avian species associated with enteric and respiratory infections. Bacterial diseases viz*.,* haemorrhagic septicemia, black quarter, anthrax, brucellosis, leptospirosis, listeriosis, tuberculosis, bovine tuberculosis and para tuberculosis are infectious on livestock with some of them having zoonotic significance. Anthrax is one of the top five zoonotic diseases in India. Listeriosis is also fatal to ruminants (sheep, goat, cattle, buffalo and camel), non-ruminants (horse, pig, canine, rodent, wild animals and birds) and humans (Dhama et al., 2013, 2015).

Bovine tuberculosis is a chronic bacterial zoonotic disease, which easily spreads to humans through inhalation of aerosols or ingestion of unpasteurised infected milk (Prasad et al., 2005). Parasitic diseases viz*.,* fascioliasis in sheep, trypanosomiasis in wild animals, dogs, horses, camels, donkeys, cattle and buffaloes, bovine tropical theileriosis in indigenous cattle and crossbreeds and babesiosis in bovines are regular pests of ruminants (Saminathan et al., 2016). Recent incidence of tick-borne disease causing Congo-haemorrhagic fever associated with sheep has made inroads into Rajasthan and is an emerging zoonotic disease (Tripathi et al., 2020). The slaughterhouse wastes thrown outside become agents for further spread of vector-borne diseases of animals closely associated with wet market. Although rinderpest of cattle in the past has been eradicated, the same cannot be said of FMD and anthrax diseases.

In pigs, incidence of brucellosis, swine erysipelas, greasy pig disease, *Streptococcus suis* infection and methicillin resistant *Staphylococcus aureus* infections are common and widespread. Injudicious use of antimicrobials in pig rearing has resulted in emergence of multiple drug-resistant bacteria with significant public health implications. Antimicrobial resistant bacteria are transmitted to humans through direct contact and through the environment, pork and pork products (Rajkhowa et al., 2018). Viral diseases among pigs are classical swine fever, rotavirus infection, FMD and porcine reproductive and respiratory syndrome. India reported first case of African swine fever and its outbreaks in Assam and Arunachal Pradesh both in domestic pigs and wild boar during 2020. Porcine circovirus-2 infection is an emerging disease and its tracking of the epidemiological pattern in northeast hilly regions of India (28% of pig population) gives an alarm for alertness (Rajesh et al., 2020). Diseases of poultry that have produced historical panzootic along with zoonosis are avian influenza and Newcastle (Ranikhet) disease. Furthermore, viral diseases viz*.,* fowl pox and avian leukosis, the bacterial diseases like tuberculosis, fowl cholera and *Escherichia coli* infections cause outbreaks in poultry farms. Other fatal infections are due to tick fever, infectious coryza, protozoans causing coccidiosis, internal (round and tape worms) and external (lice, ticks, mites and fleas) parasites are debilitating pestilence to birds and workers (Singh, 2020). Avian malaria can be threatening to the poultry and needs to be kept under vigil. Farm families are often exposed to the bovine encephalitis, swine flu and many other diseases of piggery in addition to virus influenza of poultry. Avian influenza had hit 12 Indian states alongside of COVID-19 pandemic during 2021 and the chicken consumption got reduced by 20%.

3.3 Pests and Pandemics: Fisheries

Primary constraint to sustainable aquaculture is the occurrence of diseases affecting product trade and socioeconomic status of fishers. Growth of shrimp aquaculture in India during last two decades has significantly increased the diseases (Pantoja et al., 2008). The loss due to disease outbreaks in shrimp farms located in nine coastal districts was estimated to be INR 10,000 million (Binesh & Jithendran, 2013). Disease occurrence is variable in ponds, open-water and cage culture. Mostly, the protozoan ciliates, monogenetic trematodes and crustacean ecto parasites are reported. The *Ichthyophthirius,* causes white spot or ich in freshwater fishes. Bacterial diseases of septicemia, edwardsiellosis, flexibacteriosis, bacterial gill disease, mycobacteriosis and columnaris are often reported in semi-intensive or intensive pond culture systems (Das, 1999; Fegan et al., 1991). Saprolegniasis and epizootic ulcerative syndrome are important fungal diseases in fish culture (Durai et al., 2015). Many viral infections viz*.,* white tail/white muscle, monodon baculovirus, yellow head disease, white spot disease, Taura syndrome virus, infectious hypodermal and hematopoietic necrosis virus, hepatopancreatic parvovirus, infectious myonecrosis virus, acute hepatopancreatic necrosis/early mortality syndrome and hepatopancreatic microsporidiosis are of concern to Indian aquaculture (Mishra et al., 2017). Cyprinid herpesvirus-2, koi ranavirus, carp oedema virus, megalocytivirus and goldfish hematopoietic necrosis herpes virus are the diseases of ornamental fish culture (Glazebrook et al., 1990). Outbreaks of Tilapia lake virus was reported in West Bengal and Kerala (Behera et al., 2018). Intensive shrimp farming with imported *Penaeus vannamei* (Rajendran et al., 2016) brought in microsporidians, which is causing huge loss to Indian shrimp industry.

3.4 Pests and Pandemics—Effects on Food, Nutrition, Employment and Environment

In India, with its higher population density and poverty, the requirement of food and nutrition is of paramount importance for development of children and adults including women. Number of persons in the age group of 50 and above would increase significantly in coming years with each one requiring different but calibrated amounts regarding energy and protein. Indian farming is becoming more complex due to competing factors of growing population, land competition, climate change, food, feed and nutritional expectations, labour availability, mechanisation, producer and consumer dilemmas, price policies, scarce capital, environmental consciousness in addition to societal pressure on basic health and safety expectations. All these factors would offset the balance of country's economy vis-à-vis nutritional or energy requirements to be achieved in a sustainable way. Any reduction in supply of pulses and edible oils would adversely impact the nutritional food intake of population, especially economically weaker section of the society. Horticultural crops serve as the best alternatives to food crops economically and ecologically in providing nutritional security. Both fruits and vegetables are primary sources of minerals and proteins in addition to other compounds such as antioxidants. The requirement of vitamin A, C, B1, B12 and many others are absolutely met by the Indian mass to a larger extent through horticultural crops, which are highly susceptible to pests. Although, horticultural production seems to have increased whether it would keep pace with the increasing demands of rising population and the middle-class segment is a matter of concern. Social changes associated with rural youth shifting to urban areas for education and work vis-à-vis changing pattern of food preference have transformed the balance between demand and supply of type and quantity of food items not to mention of the variety of processed and semi-processed products in use.

Demand-driven growth in livestock production in rural and semi urban areas will enable millions of poor to escape the poverty trap besides contributing towards women empowerment. Share of poultry and other meat that serve as source of protein, vitamins and minerals is expected to grow from 12 to 24% by 2030 on account of rapidly changing consumer behaviour. The poultry industry in India is constantly advancing due to the use of modern technology and switching from live bird to fresh chilled and frozen poultry product market. Poultry sector is to produce designer eggs. These are organic eggs rich in omega 3 fatty acids and with lower levels of saturated fats and cholesterol. Poultry industry with its growth rate of 12–15% is providing a low cost source of dietary protein to the consumers as well as employment opportunities. Weak hygiene and inadequate biosecurity in rural settings of poultry are often compensated arbitrarily by intensive use of antibiotics. Unsafe disposal of poultry litter leads to multi-drug resistance properties in bacteria. Antimicrobial resistance is thus the greatest threat in our fight against infectious diseases. Antibiotics such as tetracycline, doxycycline and ciprofloxacin, critical to human health, are used for growth promotion in poultry. A more concerning issue is the use of colistin for growth promotion, prophylaxis and therapeutic purposes in poultry that move in food chain. Rampant use of benzathine penicillin for animal use is obvious through six manufacturers as against just one for human use. Misuse of antibiotics and presence of *Salmonella* and cholesterol in poultry meat are the cases of unsafe food of human consumption. With increasing consumption of seafood globally, aquaculture has grown dramatically over the years and as per an estimated report the infectious microbial diseases of fish cause loss of around US$ 6 billion each year. Changing forest expose the domestic livestock to a new range of pathogens and vectors that previously existed only in wildlife niches. While pandemics are once a while, everyday living circumstances of humans happen in an environment which is highly infectious prone. Closer or overlapping contact between wildlife, animals and humans and organised livestock and poultry farming in close association with people cause spread of infectious diseases with potential to threaten health, economies and food security while compromising biosecurity. Increased trade of raw commodities and processed foods carry the pathogens that act as food poisons affecting health of humans in addition to introducing new organism into countries and continents (Yadav et al., 2020). Whether it is food or nutritional security or human health they are all fundamentally interconnected and lack of nutritional food and its safety make the population susceptible to several diseases. Many of the pests and pandemics not only impact farmers directly at farm level but also through disruption of supply chain and position of agriculture at national level impacting food and nutrition of a wider population. Workers engaged in cattle, pig or poultry farming when impacted by zoonotic diseases migrate to their home districts or states that result in reduction of labour availability to farmers as it happened with the pandemic of COVID-19. Mass movement or displacement of labour has not only left the employment in agricultural and non-agricultural sectors vacant but the movement itself served as a cause for secondary spread of pandemic.

3.5 Pests and Pandemics—Effects on Biodiversity

Most of the problems in agriculture from soil health, pestilence, zoonotic, pandemics and food safety can be traced to adverse impact of intensive, mono-cropping, seriously threatening natural as well as agro biodiversity in soil, forests and aquatic systems. Pest infestation at a pandemic level reflects an invasive or loss of biodiversity. Population growth to 1.6 billion by 2050 seeks higher provisioning for energy and commodities aggravated by changing dietary habits and climate change. Demographic pressure would compel modification of natural landscapes and intensification of agriculture and allied sectors leading to biodiversity loss per se. Biodiversity loss leads to increased pests and pandemics and vice versa. Epicentres shall sprout as humans, livestock and wildlife share large pools of microorganisms in proximity. Further, manifestations of new species or adaptation of existing species to new hosts would result in changing structure and rate of emerging infectious diseases. Loss of species can increase encounter rates between pathogens and hosts when the lost species are not hosts for the pathogen. Expansion of agricultural areas through deforestation can lead to increased wildlife-human and livestock-wildlife contact with livestock-human transmission leading to a range of infectious disease outbreaks and emergency events and modification of transmission mechanism. Besides agricultural encroachment, road construction, logging, dam building, irrigation, wetland modification, mining, the concentration or expansion of urban environments, coastal zone degradation and modification of natural landscapes cause a cascade of factors that exacerbate infectious disease emergence. Use of drugs such as antibiotics, vaccines and agrochemicals destroy the biodiversity and openly impact the ecosystem services with the expected management practices of pests during pandemics. Indiscriminate policies and practices over the last 60–70 years with scant respect for environment and biodiversity have caused India maximum harm. The nation must resolve to leave the current forests and natural landscapes to safeguard biodiversity and to avoid frequent and virulent pest outbreaks. One of the factors leading to emergence of epicentres of zoonotic is the wet meat market especially when wild animals are slaughtered as in the case of COVID-19. Serious thinking on this is needed to prevent future zoonotic and epidemics so as not to repeat the events of Spanish flu of 1920 and COVID-19.

3.6 Pests, Pandemics and Biosecurity

Most of the zoonotic viruses have significant possibilities in bioterrorism and have potential to wipe out humans and animals although neither any evidence exists as on date nor any sane person on earth would attempt to exploit microbes that are less evolved than mankind. Advances in molecular biology such as gene editing can make profound changes in genetic manipulations of organisms, and implications of such technologies in occurrence of pandemic and its mitigation need serious thinking. Institution of appropriate and timely biosecurity measures is an important instrument for protection and improvement of animal health. Breach in biosecurity due to ignorance and lapses in adoption of timely biosecurity measures in management of livestock, poultry and fish are salient reasons for the high incidence of emerging and transboundary infectious diseases. India's stance, like most of the nations across the globe, to the ongoing COVID-19 biosecurity crisis is largely responsive and reactive than being proactive from a biosecurity perspective, exposing low level preparedness towards pandemics (Athavale, 2020). In India, biosecurity has remained next to biosafety even after four decades of legislation. The proposed Agricultural Biosecurity Bill and the National Biotechnology Regulatory Authority aim to establish an integrated national biosecurity system covering plant, animal and marine issues. Under the Integrated disease surveillance programme, a network of public laboratories with biosafety practices and infrastructure was established although upgradations are needed to be continuous considering technological advancements. In India, about 30 bio-safety level (BSL) laboratories of the level of BSL-III or BSL-II+ are currently under operation with only two BSL-IV facilities. Prevention of transmission of pathogens across intra- and inter-country borders warrants devising biosecurity measures at par with international standards. International guidelines are developed by WHO, FAO and OIE (OIE, 2020) in respect of human, plant and animal pests and pandemics. For handling the most dangerous transboundary pests more of BSL-III and BSL-IV laboratories in the country are required to ensure biosafety, biosecurity and biocontainment. Biosecurity needs to be observed from farm to national to regional and international levels in a bottom-up approach. Farm level biosecurity practices are available for crops, cattle, sheep, pig, poultry and fish production systems with best designs in terms of phyto/zoo sanitary measures such as quarantine, rodent and vector control, disinfection of animal sheds and premises, proper disposal of dung, urine, feed and fodder wastes and proper carcass disposal for effective management of infectious diseases although ground level adherence is still wanting. India needs to take a look into its biosecurity preparedness and plug all the big gaps to prevent being blindsided to dangerous biological agents either man-made or natural. A number of biosecurity preparedness measures applicable for zoonotic and human diseases, have implications for plant quarantine, which is lagging behind leading to a cascade of invasive pests affecting field and horticultural crops.

4 Impact of Climate Change on Pests and Pandemics

Climate change through global warming, depletion of ozone layer, rise in sea level or increase in vector-borne and communicable diseases, has the potential to affect agricultural production and hence pressure on livestock industry. Effects of climate change on animal production include climatic influences on quantity and quality of feed and fodder resources such as pastures, forages, grain and crop residues and the severity and distribution of livestock diseases and parasites. Global warming could increase water, shelter and energy requirements of livestock for meeting projected milk demands. Increasing sea and river water temperature is likely to affect fish breeding, migration and harvests. Population dynamics of insect/vectors and epidemiology of diseases are highly influenced by temperature and relative humidity. It is predicted that climate change-induced aberrations favour invasive pests and diseases at the cost of natural regulation. Heavy damages due to the pod borer in pigeon pea and chickpea from early warming (3–5 °C) in North India and outbreaks of gram and spotted pod borers in South India due to unseasonal (extended) rains during October–November were observed (NCIPM, 2017). Trend of sucking insects (leafhoppers and thrips) and peanut bud necrosis incidence on groundnut was greater at hot semi-arid over arid zones with associated climatic variability quantified (Vennila et al., 2018, 2019). It has come to the fore that despite insect transmitted, or vector-borne viral diseases cannot be controlled through pesticides, they will increase under the climate change scenarios. One of the pests that explodes with higher temperature is the red spider mite that infests a wide range of crops both in the open and under protected conditions. It is not an understatement that most of the new insecticides are acaricides. The increased incidence of pathogens be it bacteria, spirochetes, viruses, phytoplasma etc., can drastically impact productivity, nutritional quality besides the availability of seeds and quality planting materials. Although demographic pressures will continue to increase on crop production in the coming decade, the solution lies in understanding ecological dimensions of pandemics both at micro level as in case of soil health, nematode infestation and soil-borne pathogens influenced by reduced soil organic matter and pH etc., and macro level climate change induced by global warming, excess and intensive precipitation. Weather based early warning system serves as climate resilient tool for desert locust (aided by FAO) and diseases of potato and grape in India. Simple protocols for field level implementation on assessment of pests and pandemics using technology driven proxy indicators are being piloted under *Pradhan Mantri Fasal Bima Yojana* initiative of Government of India integrating multiple stakeholders on a single platform (PMFBY, 2020).

A probable 10–40% loss in crop production, likely aggravation of heat stress in dairy animals reducing milk production to the tune of 1.6 million tonnes and increasing sea and river water temperature impacting fish breeding, migration and harvest are projected (Prabhakar, 2018). Shift in distribution of vector-borne disease of livestock such as blue tongue that has 27 serotypes across the globe is anticipated (Shyam et al., 2014). The poultry segment faces a number of interrelated stress from climate change such as higher temperatures affecting growth rates, egg production and health and disease management. Poultry farming in Karnataka by 2030 with an increasing temperature (0.8–3.3 °C) is likely to result in increasing incidences of heat stress-related morbidity and antibiotic use, the latter causing immune system compromise leaving broiler chickens more susceptible to bacterial infections (Jennifer & Jayant, 2019). Perception of coastal fishermen of Kerala indicated that the prime impact of climate change would be a sea level rise and consequent changes in habitat, frequency of extreme events, variability in the catch and revenue of fishery followed by economic and environmental aspects with social parameter scoring the least (Vass et al., 2009). On the positive side, limited social and industrial economic activities during COVID-19 pandemic resulted in improved air quality by 30–60% (Mahato et al., 2020) although it could only be temporary. India has a strong and unique programme of National Innovations in Climate Resilient Agriculture (NICRA) across all sectors of agriculture viz., crops, horticulture, livestock, fisheries, natural resource management and extension for research and development on one platform for addressing the impact of climate change. Development and implementation of multi-location, multi sector mitigative and adaptive cum resilient strategies to combat challenges posed by climate change to Indian agriculture is the mission (Prabhakar, 2018).

5 Pests and Pandemics: Preparedness and Policy Needs

Pandemics change the very edifice our living, business, commerce, health, travel, education, research and politics exposing the vulnerability of humankind and environment despite advancements of information technology, molecular biology, data management and communication involving multilateral global organisations such as World Health Organization (WHO, 2020), Food and Agriculture Organization of the United Nations (FAO, 2020c) and *Office International des Epizooties* (World Organization for Animal Health) (OIE, 2020). At times, the exotic pests get unreported either due to non-detection or fear of losing trade. Despite new technologies of animal and plant health management, the % loss to their productivity remains the same and hence the solutions have to be highly tangible. Twenty-first century is determined by the sustainability and environmental protection targets. Since, the direct and indirect losses due to pests and pandemics are economically and socially immeasurable and all countries are equally vulnerable, there is an urgent need for trans-national collaboration and co-operation through a global initiative to monitor, sensitise, train and manage.

Plant-quarantine legislation in India aims to secure protection from the ingress of exotic pests during import and export under the aegis of Department of plant protection and quarantine and storage (DPPQ&S), the National plant protection organisation for the International Plant Protection Convention (IPPC) of United Nations. As the sole international standards setting body for plant health, the IPPC works closely with FAO, national and regional plant health authorities, academia and private sector representatives to lower the risks of fall armyworm under the framework of 'FAO global action on FAW control' (FAO, 2020d) in which India is also partnering. While strengthening of sea and air ports are needed to strictly examine the planting materials brought into the country by passengers from abroad and extensive networking with neighbouring countries is a must for monitoring invasive pests. A better preparative approach towards managing invasive pests would be through such established networks operating across countries that could facilitate quick and ease of import of natural enemy or other resources upon pest invasion, if possible obviating the need for formalities of request for import that cause inordinate delays. The investment of time and resources by DPPQ&S in implementation of IPM dilutes the mandate of quarantine and ignores the reinforcement of diagnostic laboratories and pest risk analysis. Department of Biotechnology under the Ministry of Science and Technology takes care of biosafety issues in dealing with genetically modified organisms, and issues on biological warfare are dealt by the Ministry of Home Affairs. The Centre for Animal Disease Research and Diagnosis of Indian Veterinary Research Institute, Izatnagar, with its five regional disease diagnostic laboratories and state diagnostic laboratories, is involved in quarantine, eradication and vaccination/management of and animal, fish, respectively, following standards of the OIE that are further promoted by WHO and FAO. Chaudhary Charan Singh National Institute of Animal Health, Baghpat, is the nodal institute to do quality control and licensing of veterinary biologicals in India. Several animal health schemes have been initiated in the states and at the Centre, such as the national project on rinderpest eradication, contagious bovine pleuropneumonia eradication, FMD control and additional schemes and programmes are implemented by the Department of Animal Husbandry and Dairying under the Ministry of Fisheries, Animal Husbandry and Dairying of Government of India (Anonymous, 2020b). National Accreditation Board for Certification Bodies for the testing and calibration of laboratories is the sole accreditation body in India that provides third party assessment of the technical competence of testing including medical and calibration laboratories, proficiency testing providers and reference material producers (NABL, 2020).

Under Indian set up, lack of timely convergence of agencies has often resulted in delayed declaration of pest invasiveness making detection surveys poor with slow or no eradication measures. Similarly, critical areas such as upgradation of diagnostic laboratories, quarantine facilities, strengthening of risk analysis mechanism, research prioritisation, development of database and adherence to standard operation procedures of WHO/FAO/OIE need effective implementation. There is need for a stronger national biosecurity policy with coordination, collaboration and convergence among organisations, institutions, department and ministries for work on invasive and emerging pests with focus on developing pest risk-analysis models and early-warning system. Addressing issues from an environment, biosecurity and ecosystem services perspective and in a bottom-up approach starting from village to the region to nation to globe would contribute to automatic reduction of the numerous problems associated with human, plant and veterinary health. Human resources with expertise and well defined roles need to be deployed with networking to a national platform having centralised reporting on transboundary and emerging pests. Regional microbial repository with bioinformatics on infectious diseases with their geographic and temporal distributions, barcoded/molecular characterised diagnostic protocols, strains/serotypes/lineages/variant groups, vaccine escape/drug resistant mutants and epidemiology along with services of pest risk mapping require greater attention. Pest diagnostics happen through visual, microscopic, fluoroscopic and radiographic methods, electronic nose (e- nose) systems (Cui et al., 2018), DNA barcoding and high-throughput molecular methods. Environmental DNA (eDNA) technology coupled with isothermal nucleic acid amplification tests (iNAATs) including loop-mediated isothermal amplification (LAMP) (Ministry of Agriculture, Forestry & Fisheries of Japan, 2019), biosensors, hyperspectral techniques and artificial intelligence are gaining importance in recent times.

Approach to effective management of pests and pandemics depends on the type of pest and a single solution does not fit for all, although there are common elements. While the quarantine or invasive pests require an effective and successful timely reporting for their containment or eradication, for pests with rapid spread (e.g. locusts, avian flu etc.,) a centralised approach is needed in terms of database, resource use and training. In this information age, effective pest monitoring is the key, and the collected data should have an open access for further scientific research using innovative tools such as artificial intelligence in combination with human intelligence to derive response information for pest management and target user. Forging alliance with a well-founded global supportive surveillance with good database policies embedded with human resource development would be an investment for the present and immediate future of India.

Management of pests and pandemics at farm level although has gone through many transitional and scientific approaches, holistic health management through tactical integrations and adoption of good agricultural practices must be supported by sound legal framework. Genetic improvement through molecular assisted selection and introgressive breeding for increased yields, tolerance/resistance against pests in crop-animal-avian and fish (Anonymous, 2020c) systems and desired fortification of nutrients (proteins/vitamins/minerals etc.) are continuing pillars of food and livelihood security. Genetic improvement of crop plants, livestock, poultry and fisheries through exploitation of wild, exotic and national germplasm stocks to evolve using science led breeding to result in pest resistant, climate resilient, nutrient fortified and high yielding progenies suitable for diverse agro ecologies, offer high scope to fundamentally tackle pestilence. Utilisation of biotechnological approaches to evolve genetically modified crops/animals resistant to pests and herbicides complemented by robust biosafety trials ably supported by policies and investments for infrastructure development are the need of the hour. Indian Council of Agricultural Research dedicated 17 bio fortified cultivars of eight crops to the nation containing one or more of nutritive elements (e.g. Zn, Fe, Ca), amino acids (lysine, tryptophan) and protein during 2020. Power of science and politics should be synergised to harness the socio-economic-cultural values of or for and by the nation for empowering people with prosperity of health, wealth and dignity vis-à-vis a cleaner and valuable environment.

Implementation of electronic (e)-pest surveillance and digital dissemination of advisories (Vennila et al., 2016) across different states for crop/animal and fish sectors have led to adoption of scientific pest management by the farming community. The ongoing programmes viz., crop pest surveillance and advisory project (CROPSAP, Maharashtra), horticulture pest surveillance and advisory project (HortSAP, Maharashtra) and e-pest surveillance in vegetables (Haryana) are a few successful examples for digital surveillance and delivery of the pest management advisories to farmers with absence of pest outbreaks. Many mobile apps as information and expert systems along crops and theme areas of plant protection are currently available (Vennila, 2016). Information network system for animal productivity and health, a desktop/android-based field application facilitates capturing of real-time data on breeding, nutrition and health at farmer's doorstep. Features of easy replicability, extensive area coverage, efficient use of resources and extreme robustness of e-based pest surveillance fulfil the policy adoption of integrated pest management and 'Digital India' together. Surveys and surveillance at all levels of production systems would aid in immediate reporting of an invasive pest or outbreak and simultaneously offer alertness to everyone concerned. Surveys and surveillance require dedicated deployment of tools including the standard methodologies and personnel, and it has always been an endeavour of public sector. However, manufacturers/dealers of agri-inputs (seeds/fertilisers/farm machinery/agrochemicals/veterinary biologicals) should contribute to centralised platform of national surveillance with traceability associated with input distribution. Increased investment in infrastructure development with participation of the private sector having backward and forward integration would be a better policy perspective.

In plant health management, India has a total of 292 pesticides registered and per hectare consumption of pesticides in India is on rise (600 g/ha) after 2009–10 (DPPQ, 2020). Injudicious use of pesticides has led to problems of resistance (Dhaliwal & Koul, 2010; Fand et al., 2019; Sethi & Dilawari, 2008; Thind et al., 2009), resurgence and residues. Not all crops have registered plant protection chemicals and farmers often use off label products that have implications on food safety and export. Hence grouping of crops and commodities (554 numbers) in line with the codex classification and guidelines for label expansion and recognition with respect to maximum residue limits was a step forward by the government. Pesticide market, which is projected to reach INR 292.9 billion by 2023 is fraught with non-genuine products in markets (Croplife, 2015). Recent draft notification on ban of 27 pesticides comprising eight fungicides, 12 insecticides and seven herbicides across 134 formulations for 74 crops is subject to scrutiny. Therefore, the Pesticide Management Bill, 2020 must emphasise on adopting systematic standard operating procedures with transparency with optimisation of benefits between the industries and growers mediated by the government. Mass production technologies ready for agribusiness in biocontrol (ICAR-NBAIR, 2019) are in place for predators and parasitoids against insect pests and microbial pathogens of crops including those for the recently invaded FAW in maize. Upscaling the production of parasitoids, predators and bio pesticides in an entrepreneurial approach or at cottage level for large scale field use is necessary. Enabling policies for quicker registration and quality control are necessary for enhancing of the preparedness for the deliberate use of biological products in agroecosystems.

Sustainability is the most important factor that is not taken too seriously, and desired changes need to be implemented in livestock farming. India became free of the cattle plague, caused by rinderpest virus infection of livestock that existed since early 1950, following efforts over half a century through launching and relaunching of 'National Project on Rinderpest Eradication'. Mass vaccinations and revaccinations of goat tissue virus vaccines (GTV-Edwards and Plowrite and Ferris strains) helped the country to be rinderpest free since November 2004 as endorsed by OIE in 2005. However, collaboration with many other countries continues as one of the preparedness with emphasis on surveillance and to develop as many vaccines as possible and storage (Yadav et al., 2020). Although science-led development of finding vaccines for viral diseases happens, their affordability and availability to cover the entire population are lacking. It is largely the organised livestock and poultry farms that get the vaccines administered while nomadic/stray cattle as left outs continue to harbour diseases. High use of antibiotics in livestock and poultry production is most often attributed to low compliance with regulation and poor antimicrobial stewardship (Laxminarayan & Chaudhury, 2016), as the costs associated with antimicrobial resistance in human health are an externality to the farming industry. The global cost of inaction on containing antimicrobial resistance by 2050 has been estimated to be the lives of 10 million humans every year, reduction of livestock production by 7.5% and of the declined gross domestic product by 3.5%. Hence the requirements are: (i) well established system of systematic surveillance, (ii) coordination among vaccine producers, (iii) maintenance of minimum quality standards capacity building in terms of infrastructure, diagnostics and technologies, (iv) quality control of veterinary biologicals, (v) centralisation of veterinary drug regulation authority, cold chain maintenance during vaccine transportation, (vi) judicious vaccination especially in poultry and canines and (ix) awareness creation on farm level good livestock production practices.

Since growth of culture fisheries has increased the vulnerability to aquatic diseases to transboundary nature is high. Hence, in the globalised environment, issues of sharing water basins, transboundary movement of migratory fish species and aquatic animals, trade and India's alignment to international standards need attention. Regionally, coordinated and cooperative management of shared fishery resources between the centre and states is required for long-term sustainability. Aquaculture sustainability depends on improvement of germplasm and their screening, promotion of usage of specific pathogen-free seed stocks, disease management, farming through international collaboration/cooperation traceability, standards, testing and certification of aquaculture produce along with requisite regulatory framework and infrastructure. Aquaculture zonation and spatial planning consisting of identification of appropriate location, zones and common practice options help in management of diseases, environmental issues, post-harvest and marketing, mitigation of risks, etc. At present, crop-livestock integrated systems are recommended for areas having irrigation facilities or receiving about 1000 mm rainfall where production of surplus crop residues and allocation of some land for fodder cultivation and use of feed supplements are possible. Farming Murrah buffaloes, crossbred cows and mixed farming consisting of crop with an inclusion of 10–20 synthetic backyard poultry breeds boosted income of farmers. Crop-livestock-poultry-fishery integrated farming systems are mostly suitable for high rainfall areas, where paddy is cultivated both in monsoon and after. Cows and buffaloes are maintained in the backyard with crop residues and supplements. Fish is reared in farm ponds and poultry is maintained in cages over the pond with grain and bran supplementation. The droppings of poultry serve as feed for the fish in the pond. Policy for sustainable farming and animal rearing through incentivising farmers to adopt safe and healthy rearing practices of healthy feed/diets for livestock/poultry/fish, medication free rearing, safe disposal and safe processing is essential. Industry at large should be sensitised how higher use of antibiotics hampers health in turn negatively affects sales of both poultry and fishery products and sustainability. It is a sad story if these antibiotics enter honey in the food web. Enhancing the fodder supply, integrated production systems, value addition, information and knowledge sharing through farm advisories, crop-cum-livestock insurance, conservation and promotion of selective, trait-specific native breeds exploiting improved animal breeding, contingent fodder-animal planning, mitigation of greenhouse gas emissions, scaling-up of proven resilient production systems to spread the adaptation options and innovations to a wider community with capacity building of smallholders would certainly build resilience of rainfed production systems in India.

6 Prospects of 'One Health' Approach

Indian agriculture is best personified by the small and marginal farming of crops, cattle (cows, buffaloes, sheep and goat), poultry, fisheries and a complex of many other activities simultaneously taking place. Pest and pandemics would continue to occur and could be with more frequency and intensity and hence proactive approaches are needed. COVID-19 experience demonstrated in addition to loss of millions of human lives the destructive power and ripple effect of a pandemic invisible virus across the spectrum of health, education, travel, politics, livelihood and economics. In a globalised interconnected world with large-scale movement of men and material across the length and breadth of one world, no country or region is excluded from transboundary pests or pandemic diseases. Hence, a revised strong regional and international cooperation, taking hard lessons from COVID-19 pandemic is an urgent need. Changing climate, rapid transport, travel, zoonotic influenced by overlap of man-animal and organised animal husbandry including poultry act as precursor for onset of diseases. As per estimates 8,50,000 viruses are circulating in wild life out of which 20,000 are corona viruses.

The changing land use and deforestation lead to spill over of infections from wildlife into livestock which in turn causes epidemic in humans with the potential of pandemic lurking mankind. Preparedness to tackle zoonotic infections of the future under conditions of climate change and environmental degradation require a concrete approach in unison exploiting the concept of 'One Health' as it recognises interconnectedness of human-animal-plant- environment. One Health is a globally accepted model for research on diagnosis, epidemiology and control of existing and emerging zoonotic threats through collaborative efforts of multiple disciplines working at local, national, regional and global levels to achieve optimal health for all as defined by its task force. Coordination, collaboration, co-operation, communication and commitment are advocated within as well as between sectors. While each sector should enhance its own capacity in terms of infrastructure, diagnostics and technological up-gradations, real time collaboration with other sectors is needed so that experiences and collective wisdom can be pooled and used to improve the health of all components. During 2017, India released the 'National Action Plan on Antimicrobial Resistance' and it needs to be vigorously adopted (Ranjalkar & Chandy, 2019). India through Kerala Veterinary and Animal Sciences University (Anonymous, 2020d) launched 'One Health' research centre for developing a sustainable disease control system using health analytics and data management tools to address the emerging zoonotic threats and prevent emergence of new communicable diseases. Approach of 'One Health' towards preparedness is a forward-looking continuum and requires a long-term commitment for research to thwart the emergence of new communicable diseases. Medical, veterinary, paramedical sectors and bioscience (agriculture and life science) researchers need to scale up the approach across the country for building public health capacity with meaningful international collaborations.

7 Way Forward

The experience of COVID-19 taught humanity at large its vulnerability to life and living, direct and indirect impacts on nation's biosecurity and socio economy. Despite all the interlinked challenges of security and safety of food, environment, health and biodiversity, India's focus is towards sustainably increasing agricultural productivity, farm incomes, food security and sectoral development by building resilience at multiple levels. The diversified Indian agroecosystems and sectors are replete with history of pests and pandemics. Research-cum-developmental organisational set up and industries dealing with health system of human, livestock, poultry and fish have all the paraphernalia needed for an effective preparedness and management of pests and pandemics. But their operational success is fraught with shortcomings of lack of coordination and collaborations. Individual excellence should translate to collective management. Slighter adjustments and reorientation in functioning of stakeholders interlinked through a common hub under the 'One Health' concept would uplift the standards of diagnostics, preparedness and pest management.

Pre-import and post-entry quarantine require need based international cooperation and collaboration and India needs strengthening of plant quarantine with focused efforts on biosecurity along the lines of livestock disease surveys and diagnostic system. In India, DPPQ&S should focus on quarantine and leave implementation of integrated pest management to state bodies to successfully manage invasive and transboundary pests. The 'Biosecurity Bill' introduced in 2013 needs to be operative for better protection of crops/livestock/poultry/fisheries of the country and the region from pests. Reprisal for new and emerging pests need inter departmental coordination, and it is important to have descriptions of pests whether new or emerging or re-emerging with understanding of pest-pest, host-pest and host-pest-environment. National diagnostic laboratories equipped with tools and trained human resources, exclusive electronic pest surveillance systems using standard protocols, and field workers functioning together by convergence of public and private organisations/institutions/departments/industries should be mandatory. Surveillance must be aided compulsorily by geo reference based mobile apps developed using protocols adhering to international phytosanitary standards for invasive pests and national sampling procedures for management emerging pests. An e-reporting system involving artificial intelligence for diagnosis and data analytics integrated at server level with edaphic and weather factors represented in a geo platform would help in geo spatial early warning and subsequent pest management preparedness. Updated scientific information system linked to real time pest scenario derived from e-surveillance would facilitate digital pest management advisories automated for dissemination to end users. Forging a self-reliant integrated 'One Health' management system require partnership of public and private stakeholders for needful production and supply of demand driven human/veterinary vaccines and quality pest protection products for plant/animal/poultry/fish.

Vertical integration of agricultural education is the key to improve the quality of human resources in the country and many more post graduate students must be encouraged to address zoonosis, with focus on epidemiology, ecology, biodiversity, molecular characterisation with expertise in big data analytics. Set of educational curriculum with skills of surveillance in all sectors with adequate training needs special focus to ambush pests and pandemics. Empowering agri-graduates and diploma holders to take up contractual system of plant-animal-poultry-fish protection in identified areas such as field pest/epidemic monitoring, bio agent mass production, manufacture of sensor-based gadgets, coordination of input supply and delivery system of agrichemicals/vaccines at farm level would be prudent to generate employment and to serve as pathway for securing a better health for all. Developing an entrepreneurial capacity for mass production of macrobial (parasitoids and predators), microbial (growth promoters, antagonists, entomopathogens) and plant-based products in addition to mechanical traps at cottage level would aid in sustaining natural farming systems.

Registration of biological control agents that is quick, scientific and with quality assurance will provide impetus to commercialise the technologies. Policy framework facilitating execution of proactive strategies of plant protection by governmental departments with hand holding of growers and input industries is essential. No other time is better than the present for use of digital tools and mass media to execute a unified 'One Health' system. Enhancing production and income of farmers through reduction of yield losses caused by pests should be the motto of plant pest management towards fostering national food and environmental security. Human public health services are given priority over veterinary and plant health in India including the poor insurance schemes for agriculture and allied sectors. However, human and environmental health could be simultaneously improved by the same policy or management actions provided agriculture and animal husbandry expansion and intensification, and other modifications of natural landscapes are implemented in a way that minimises biodiversity losses. Media should play an important role in educating the do's and don'ts during pandemics and hence, media management must go hand in hand with strong scientific research outputs and information reaching the public in a simplified way.

Political environment of India with its neighbours and the rest of the world shall contribute towards sustainable development through mitigation of pests and pandemics. 'We are healthy if our neighbour is healthy' should be the slogan. India has a framework of 'environment' governed under Ministry of Environment and Forest with the Ministry of Agriculture and Farmers' Welfare that functions for agriculture, animal husbandry and related sectors. Since the environment is beyond forest and wildlife, there needs to be a separate Ministry of Environment that could address issues such as climate change, depletion of corals, loss of biodiversity, water, air and ecosystem services holistically and the wider scale of land agriculture, forests, seas, oceans and mountains put together. Environment is global and cannot be confined to forests. Indian agriculture and forestry are two sides of the same coin, and both must be accounted together to tackle problems of shrinking forests, agriculture and allied sectors. Consistency in infrastructure development with political and financial commitment provided on a crop and region neutral basis would transform the ways and means of managing pandemics in the country.

India should align closely with the global community on aspects of carbon emission or footprints and global warming pertaining to climate change both at regional and global level. The melting of ice especially in Himalayan regions and associated soil erosion down the plains need a preparedness. Accurate monitoring of natural disasters of cyclones, drought hailstorms and floods and their forecasts strengthen the preparedness at local and macro level. Health management approach at local level for different sectors must be based on each of agroecological region of different agroclimatic zones of the country with revisits made once in five years for suitable calibrated changes. Sustainable production system begins with natural resource management. Soil health and its enrichment come with enhancement of soil carbon and biodiversity through vegetation and other means. Rivers and water reservoirs are lifeline of entire population and the water consumed and utilised for various purposes need safety guards for which stringent policy decision for each river basin must be promulgated. Considering that agriculture and allied sectors are State subjects in India, investment into improvement of organisational set up such as setting up of plant/animal/fish health clinics equipped with infrastructure for training and advisory and linking the supply chain of agrochemical/antimicrobial/vaccine marketing through such clinics are needed. Nevertheless, a governmental or contractual system of field pest management using standard operating procedures is a plausible strategy. Innovative institutional models, pro-agricultural policies and regulatory mechanisms would accelerate innovations, ensure food security, enhance livelihood opportunities of smallholders and conserve natural resources.

8 Conclusion

In a globalised world, the safety and sustainability of the developed world depends on solutions provided to the less developed countries and global bodies have an immense responsibility. Monitoring of wet markets dealing with wild animals in places such as Congo, Wuhan and other places is the key to mitigate a potential threat. Every new pest reported elsewhere should be in the radar of international scientists who should in turn forewarn potential pest threats based on simulation and prediction models. Therefore, science-led global cooperation and collaboration is a must to mitigate the impact pests and pandemics. Precise and quick diagnostics using molecular taxonomy, in general, and immunisations with quality vaccines against viral pandemics in particular deserve more research and development (R&D). Exploitation of biotechnological tools for whole genome sequencing and for development of resistant genetic stocks of crops/animals and fish, understanding the epidemiology and environmental interactions of pests and pandemics through advanced analytics, and innovations in food processing techniques of therapeutics with inbuilt biosecurity-cum-biosafety associated with trade are the priority areas of R&D to bring about positive transformations in food and health systems. Since R&D is best served with human resource development, India needs investment into development of human resources by international experts in the advanced fields of molecular taxonomy, epidemiological modelling, big data analytics and impact assessment of success and failure in our preparedness to fight pests and pandemics. Like delayed justice, delayed mitigation of pandemic is a denied mitigation and there cannot be any policy paralysis in management of pandemic irrespective of region, religion, country, race or political system. Formulation of legislation should account for multi-sectoral stakeholders in a bottom-up approach, keeping the goal of profitability and sustainability of farming and welfare of the common man as targets. Global collaboration and cooperation, science-led policy decisions, meta-analysis and data management supported by effective and transparent communication across nations in sharing information with human resource development shall contribute to better preparedness leading to better mitigation and management of future pests and pandemics. Working together with optimisation of production and productivity of crops, animals, poultry and fisheries would result in sustainability with profitability.

The time has come to appreciate biodiversity and ecosystem services better and to respond many of our problems including pests and pandemics.

References

AFFRC. (2019). Fall armyworm (*Spodoptera frugiperda* (J.E. Smith); Lepidoptera: Noctuidae). Available on https://www.affrc.maff.go.jp/kokusaikenkyu/attach/pdf/transboundary%20plant%20pests%202019-22.pdf

Ahmed, T., Ansari, M., & Ali, H. (2009). Outbreak of diamondback moth, *Plutella xylostella* in Aligarh, India. *Trends in Bioscience, 2*, 10–12.

Ananthakrishnan, T. (2009). Invasive insects in Indian agriculture, forestry and medicine. *Current Science, 97*, 300–301.

Anonymous. (2007). *The current status on the newly identified eucalyptus tree insect pest*. Forest Department, Tree Biotechnology Project & KEFRI, Kenya Forestry Research Institute Nairobi. Available on http://www.easternarc.org/biotechnology/Eucalyptuschalcid.pdf

Anonymous. (2009). *Studies on pest out-breaks and resurgence in rice ecosystems* (p. 110). Annual report. Central Rice Research Institute.

Anonymous. (2017). *Maharashtra cane crop reels under white grub pest attack*. Available on https://www.thehindubusinessline.com/economy/agri-business/maharashtra-cane-crop-reels-under-white-grub-pest-attack/article9860027.ece

Anonymous. (2018). After an erratic monsoon, farmers in nine states struggle with pest outbreaks. *Down to Earth*, 1–14.

Anonymous. (2020a). *Lumpy skin disease becomes worst nightmare for farmers in a dozen States*. Available on https://www.thehindubusinessline.com/economy/agri-business/lumpy-skin-disease-becomes-worst-nightmare-for-farmers-in-a-dozen%20states/article32841121.ece

Anonymous. (2020b). *Department of Animal Husbandry and Dairying, schemes and programmes*. Available on https://dahd.nic.in/schemesprogrammes

Anonymous. (2020c). *National fisheries policy, 2020*. Available on http://nfdb.gov.in/PDF/NationalFisheriesPolicy2020.pdf

Anonymous. (2020d). *'One Health' concept gains importance*. Available on https://www.thehindu.com/news/national/kerala/one-health-concept-gains-importance/article30832842.ece

Athavale, C. R. (2020). *Biosecurity in India: The way forward*. Available on https://bharatshakti.in/biosecurity-in-india-the-way-forward/

Bashyal, B. M., Aggarwal, R., Banerjee, S., Gupta, S., & Sharma, S. (2014). Pathogenicity, ecology and genetic diversity of the *Fusarium* spp. associated with an emerging bakanae disease of rice (*Oryza sativa* L.) in India. In R. N. Kharwar (Ed.), *Microbial diversity and biotechnology in food security* (pp. 307–314). Springer.

Baskey, S., Khalko, S., Hembram, S., Sharma, B. R., & Ali, S. (2020). Survey for the incidence of stem rot of groundnut in North Bengal districts of West Bengal, India. *International Journal of Current Microbiology and Applied Sciences, 9*, 328–333.

Begum, S. S., Mahato, G., Sharma, P., Sharma, K., Hussain, M., Das, B. C., Hussain, J., De, A., Choudhary, D., Ramakrishn, M. A., & Muthuchelvan, D. (2016). Seroprevalence of *Peste des petits* ruminants in goats in Assam, India. *Asian Journal of Animal and Veterinary Advances, 11*, 210–212.

Behera, B. K., Pradhan, P. K., Swaminathan, T. R., Sood, N., Paria, P., Das, A., & Parida, P. K. (2018). Emergence of tilapia lake virus associated with mortalities of farmed *Nile tilapia Oreochromis niloticus* (Linnaeus 1758) in India. *Aquaculture, 484*, 168–174.

Bhanuprakash, V., Hosamani, M., & Singh, R. K. (2011). Prospects of control and eradication of capripox from the Indian subcontinent: A perspective. *Antiviral Research, 91*, 225–232.

Binesh, C.P., & Jithendran, K. P. (2013). Genetic characterization of betanodavirus isolates from Asian seabass *Lates calcarifer* (Bloch) in India. *Archives of Virology, 158*, 1543–1547.

Chander, S., & Patel, D. N. (2010). Changes in pest profiles in rice wheat cropping system in Indo-Gangetic plains. *Annals of Plant Protection Sciences, 11*, 14–18.

Chethana, B. S., Deepak, C. A., Rajanna, M. P., Ramachandra, C., & Shivakumar, N. (2016). Current scenario of rice diseases in Karnataka. *International Journal of Natural Sciences, 7*, 405–412.

Chowdappa, P., Mohan Kumar, S. P., Sanjeev, S., & Singh, B. P. (2011). *Integrated management of early and late blight of potato and tomato. ORP on Leaf Spot Diseases Series 17*. Indian Institute of Horticultural Research.

Chowdappa, P., Nirmal Kumar, B. J., Madhura, S., Kumar, M. S., Myers, K. L., Fry, W. E., & Cooke, D. E. (2013). Emergence of 13_A2 blue lineage of *Phytophthora infestans* was responsible for severe outbreaks of late blight on tomato in south-west India. *Journal of Phytopathology, 161*, 49–58.

Chowdappa, P., Nirmal Kumar, B. J., Madhura, S., Mohan Kumar, S. P., Myers, K. L., Fry, W. E., & Cooke, D. E. L. (2015). Severe outbreaks of late blight on potato and tomato in South India caused by recent changes in the *Phytophthora infestans* population. *Plant Pathology, 64*, 191–199.

CMFRI. (2020). *Annual report 2019*. Indian Council of Agricultural Research Central Marine Fisheries Research Institute, Kochi. Available on http://www.cmfri.org.in/publication/cmfri-annual-reports

CPCRI. (2019). *Invasion of rugose spiralling whitefly (Aleurodicus rugioperculatus Martin) in South India*. Available on http://cpcri.gov.in/index.php/rti/9-uncategorised/591

Croplife. (2015). *Study on sub-standard spurious/counterfeit pesticides in India 2015*. Report 2015. Available on https://croplife.org/wp-content/uploads/2015/10/Study-on-sub-standard-spurious-counterfeit-pesticides-in-India.pdf

Cui, S., Ling, P., Zhu, H., & Keener, H. M. (2018). Plant pest detection using an artificial nose system: A review. *Sensors, 18*, 378. Available on https://www.mdpi.com/1424-8220/18/2/378/pdf

DAHD. (2020). *20th livestock census-2019* (p. 119). All India Report. Department of Animal Husbandry and Dairying, Ministry of Fisheries Animal Husbandry and Dairying, GoI.

Das, A. K. (2008). Citrus greening (*Huanglongbing*) disease in India: Present status and diagnostic efforts. In *IRCHLB Proceedings*. Available on www.plantmanagementnetwork.org

Das, M. K. (1999). Impact of habitat quality and disease on the fish production in inland water bodies. *Journal of the Inland Fisheries Society of India, 31*, 28–30.

Dhaliwal, G. S., Jindal, V., & Mohindru, B. (2015). Crop losses due to insect pests: Global and Indian scenario. *Indian Journal of Entomology, 77*(2), 165–168.

Dhaliwal, G. S., & Koul, O. (2010). *Quest for pest management: From green revolution to gene revolution*. Kalyani Publishers.

Dhama, K., Karthik, K., Tiwari, R., Shabbir, M. Z., Barbuddhe, S., Malik, S. V., & Singh, R. K. (2015). Listeriosis in animals, its public health significance (food-borne zoonosis) and advances in diagnosis and control: A comprehensive review. *The Veterinary Quarterly, 35*, 211–235.

Dhama, K., Verma, A. K., Rajagunalan, S., Kumar, A., Tiwari, R., Chakraborty, S., & Kumar, R. (2013). *Listeria monocytogenes* infection in poultry and its public health importance with special reference to food borne zoonoses. *Pakistan Journal of Biological Sciences, 16*, 301–308.

Dhawan, A. K., Singh, K., Saini, S., Mohindru, B., Kaur, A., Singh, G., & Singh, S. (2007). Incidence and damage potential of mealybug, *Phenacoccus solenopsis* Tinsley on cotton in Punjab. *Indian Journal of Ecology, 34*, 110–116.

DPPQ. (2020). *Directorate of plant protection, quarantine & storage: Statistical database*. Available on http://ppqs.gov.in/statistical-database

Durai, V., Gulan, B., Johnson, M., Maheswari, M. L., & Pravinkumar, M. (2015). Effect on white gut and white feces disease in semi intensive *Litopenaeus vannamei* shrimp culture system in South Indian state of Tamil Nadu. *International Journal of Marine Science, 5*, 1–5.

Fand, B. B., Nagrare, V. S., & Gawande, S. P. (2019). Widespread infestation of pink bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechidae) on *Bt* cotton in Central India: A new threat and concerns for cotton production. *Phytoparasitica, 47*, 313–325.
FAO. (2019). *Banana Fusarium wilt tropical race 4: A mounting threat to global banana markets*? Available on https://www.fao.org/world-banana-forum/fusariumtr4
FAO. (2020a). *Locust watch (Desert locust) 2020*. Available on http://www.fao.org/ag/locusts/en/archives/archive/index.html
FAO. (2020b). *Desert locust bulletin*. Available on http://www.fao.org/ag/locusts/common/ecg/2555/en/DL500e.pdf
FAO. (2020c). Food and Agriculture Organisation of the United Nations. Available on http://www.fao.org/in-action/en/
FAO. (2020d). *Prevention under the framework of FAO global action on FAW control*. Available on https://www.ippc.int/en/the-global-action-for-fall-armyworm-control/fall-armyworm-faw-prevention-under-the-framework-of-fao-global-action-on-faw-control/
Fegan, D. F., Flegel, T. W., Sriurairatana, S., & Waiyakratthna, M. (1991). The occurrence, development and histopathology of Monodon baculovirus in *Penaeus monodon* in South Thailand. *Aquaculture, 96*, 205–217.
Gautam, R. D., Suroshe, S. S., Gautam, S., Saxena, U., Fand, B. B., & Gupta, T. (2009). Fortuitous biological control of exotic mealybug, *Phenacoccus solenopsis*—A boon for Indian growers. *Annals of Plant Protection Sciences, 17*, 473–474.
Gharde, Y., Singh, P. K., Dubey, R. P., & Gupta, P. K. (2018). Assessment of yield and economic losses in agriculture due to weeds in India. *Crop Protection, 107*, 12–18.
Glazebrook, J. S., Heasman, M. P., & de Beer, S. W. (1990). Picorna-like viral particles associated with mass mortalities in larval barramundi, *Lates calcarifer* Bloch. *Journal of Fish Diseases, 13*, 245–249.
Gupta, A. K., Solanki, I. S., Bashyal, B. M., Singh, Y., & Srivastav, K. (2015). Bakanae of rice—An emerging disease in Asia. *Journal of Animal and Plant Sciences, 25*, 1499–1514.
Halder, J., Rai, A. B., & Kodandaram, M. H. (2013). Compatibility of neem oil and different entomopathogens for the management of major vegetable sucking pests. *National Academy Science Letters, 36*, 19–25.
Hemadri, D., & Hiremath, J. (2011). *Vision 2030* (pp. 1–30). Project Directorate on Animal Disease Monitoring and Surveillance.
IBEF. (2020). *Agriculture in India: Information about Indian agriculture and its importance*. Available on https://www.ibef.org/industry/agriculture-india.aspx
ICAR. (2020). *ICAR vision 2030*. Available on https://icar.org.in/files/ICAR-Vision-2030.pdf
ICAR-NBAIR. (2019). *Technologies ready for agribusiness*. ICAR-National Bureau of Agricultural Insect Resources, Bengaluru. Available on https://nbair.res.in/sites/default/files/left%20menu/icbc-2018/ICAR%20NBAIR%20technologies%20for%20Agribusiness.pdf
ICAR-NBAIR. (2020). *Occurrence of cassava mealybug Phenacoccus manihoti Matile-Ferrero in India*. Available on https://www.nbair.res.in/index.php/node/1260
ICAR-NCIPM. (2019). *Annual report 2018–19*. Available on https://www.ncipm.res.in/NCIPMPDFs/AnnualReport/AnnualReport_2019.pdf
Jacob, J. P., Devaraj, R., & Natarajan, R. (2007). Outbreak of the invasive gall-inducing wasp *Leptocybe invasa* on eucalypts in India. *Newsletter of the Asia Pacific Forest Invasive Species Network, 8*, 4.
Jaipal, S., Choudhary Chandra, S., Moanaro, P., Das, B., & Kumar, S. (2013). Litchi stink bug (*Tessaratoma javanica)* outbreak in Jharkhand, India, on litchi. *Phytoparasitica, 41*, 73–77.
Jennifer, C., & Jayant, D. (2019). *Poultry farming, climate change, and drivers of antimicrobial resistance in India*. Available on www.thelancet.com/planetary-health.e495
Joshi, S., Pai, S. G., Deepthy, K. B., Ballal, C. R., & Watson, G. W. (2020). The cassava mealybug *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Coccomorpha: Pseudococcidae) arrives in India. *Biotaxa, 4772*, 191–194.

Kadam, D. M., Rathore, A. C., Prakash, J. J., Yadav, S. K., & Mehta, H. (2017). Shoot gall psylla: An emerging threat to mango orchards of Uttarakhand. *Popular Kheti, 5*, 112–114.

Kaur, M., Neeraj, K. A., Vikas, K., & Dhiman, R. (2014). *Effects and management of Parthenium hysterophorus: A weed of global significance*. Hindawi Publishing Corporation. Available on https://www.hindawi.com/journals/isrn/2014/368647/

Khan, M. R. (2020). Nematode infestation, a potential threat to Indian forests. *Indian Phytopathology*. http://doi.org/10.1007/s42360-020-00228-9

Kumar, S. S., Kant, S. K., & Emmanuel, T. (2007). Emergence of gall inducing insect *Leptocybe invasa* (Hymenoptera: Eulophidae) in eucalyptus plantations in Gujarat, India. *Indian Forestry, 133*, 1566–1568.

Kumar, V., Khan, M. R., & Walia, R. K. (2020). Crop loss estimations due to plant-parasitic nematodes in major crops in India. *National Academy Science Letters*. https://doi.org/10.1007/s40009-020-00895-2

Laxminarayan, R., & Chaudhury, R. R. (2016). Antibiotic resistance in India: Drivers and opportunities for action. *PLoS Medicine, 13*, e1001974.

Lokare, R., Dangat, U., Adsul, S., & Gholap, M. S. (2014). ICT based plant protection solutions in soybean-based cropping system in Maharashtra. *Soybean Research, 12*, 72–81.

Mahato, S., Pal, S., & Ghosh, K. G. (2020). Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. *Science of the Total Environment*. http://doi.org/10.1016/j.scitotenv.2020.139086

Mani, M. (2010). Origin, introduction, distribution and management of the invasive spiraling whitefly, *Aleurodicus dispersus* Russel in India. *Karnataka Journal of Agricultural Sciences, 23*, 59–75.

Ministry of Agriculture, Forestry and Fisheries of Japan. (2019). *Final report on the "International workshop on facilitating international research collaboration on transboundary plant pests"*, Tsukuba City, Japan. Available on https://www.macs-g20.org/fileadmin/macs/AnnualMeetings/2019Japan/MACSG202019CommuniqueFinal.pdf

Mishra, N., Rajukumar, K., Tiwari, A., Nema, R. K., Behera, S. P., Satav, J. S., & Dubey, S. C. (2009). Prevalence of Bovine Viral Diarrhoea Virus (BVDV) antibodies among sheep and goats in India. *Tropical Animal Health and Production, 4*, 1231–1239.

Mishra, N., Rajukumar, K., Vilcek, S., Tiwari, A., Satav, J. S., & Dubey, S. C. (2008). Molecular characterization of bovine viral diarrhea virus type 2 isolate originating from a native Indian sheep (*Ovis aries*). *Veterinary Microbiology, 130*, 88–98.

Mishra, S. S., Das, R., Choudhary, P., Debbarma, J., Sahoo, S. N., Giri, B. S., & Swain, P. (2017). Present status of fisheries and impact of emerging diseases of fish and shellfish in Indian aquaculture. *Journal of Aquatic Research and Marine Sciences, 5*, 26.

Mondal, K. K., & Sharma, J. (2009). Bacterial blight: An emerging threat to pomegranate export. *Indian Farming, 59*, 22–23.

Muthuchelvan, D., De, A., Debnath, B., Choudhary, D., Venkatesan, G., Rajak, K. K., Sudhakar, S. B., Himadri, D., Pandey, A. B., & Parida, S. (2014). Molecular characterization of *peste-des-petits* ruminants virus (PPRV) isolated from an outbreak in the Indo Bangladesh border of Tripura state of North-East India. *Veterinary Microbiology, 174*, 591–595. http://doi.org/10.1016/j.vetmic.2014.10.027

Muthuchelvan, D., Rajak, K. K., Ramakrishnan, M. A., Choudhary, D., Bhadouriya, S., Saravanan, P., Pandey, A. B., & Singh, R. K. (2015). *Peste-des-petits*-ruminants: An Indian perspective. *Advances in Animal and Veterinary Sciences, 3*, 422–429.

NABL. (2020). *Accredited laboratories search.* Available on https://nabl-india.org/

Nagaraju, D. K. (2000). *Biology, ecology and management of the capsicum gall midge, Asphondylia capparis Rubsaaman (Diptera: Cecidomyiidae) and other insects associated with gall on bell pepper* (Ph.D. thesis), University of Agricultural Sciences, Bengaluru.

NBAIR. (2020). *Rugose spiraling whitefly-Aleurodicus rugioperculatus (Hemiptera: Aleyrodidae).* Available on https://www.nbair.res.in/node/833

NCIPM. (2017). *Annual report (2016–17).* National Research Centre for Integrated Pest Management. Available on https://www.ncipm.res.in/NCIPMPDFs/Annual%20Report/AR2016-17.pdf

OIE. (2020). Office International des Epizooties (World Organization for Animal Health). Available on https://www.oie.int/about-us/

Pantoja, C. R., Lightner, D. V., Poulos, B. T., Nunan, L., Tang, K. F. J., et al. (2008). Paper presented on 'Overview of Diseases and Health Management Issues Related to Farmed Shrimp', OIE Reference Laboratory for Shrimp Diseases Department of Veterinary Science & Microbiology, University of Arizona, Tucson, USA.

Patel, Z. P. (2001). Record of seed borer in sapota, *Manilkara zapota* (Mill.) Forsberg. *Insect Environment, 6*, 149.

PMFBY. (2020). *Revamped operational guidelines.* Available on https://pmfby.gov.in/pdf/RevampedOperationalGuidelines2020.pdf

Prabhakar, I., Vijayaragavan, K., Singh, P., Singh, B., Janakiram Manjunatha, B. L., & Jaggi, S. S. (2017). Constraints in adoption and strategies to promote polyhouse technology among farmers: A multi-stakeholder and multi-dimensional study. *Indian Journal of Agricultural Sciences, 87*, 485–490.

Prabhakar, M. (2018). *Assessment of vulnerability and adaptation to climate change in agriculture*. ICAR-CRIDA. Available on https://icar.org.in/content/short-course-assessment-vulnerability-and-adaptation-climate-change-agriculture-concludes

Prakash, A., Rao, J., Berliner, J., Mukherjee, A., Adak, T., Lenka, S., Singh, N. K., & Nayak, U. K. (2014). Emerging pest scenario in rice in India. *Journal of Applied Zoological Research, 25*, 179–181.

Prasad, H. K., Singhal, A., Mishra, A., Shah, N. P., Katoch, V. M., Thakral, S. S., Singh, D. V., Chumber, S., Bal, S., Aggarwal, S., Padma, M. V., Kumar, S., Singh, M. K., & Acharya, S. K. (2005). Bovine tuberculosis in India: Potential basis for zoonosis. *Tuberculosis, 85*, 421–428.

Puri, S. N., & Mote, U. N. (2004). Emerging pest problems in India and critical issues in their management: An overview. In: B. Subrahamaniyam, V. V. Ramamurthy, & V. S. Singh (Eds.), *Frontier areas of entomological research* (pp. 13–24). IARI.

Rai, A. B., Loganathan, M., Halder, J., Venkataravanappa, V., & Naik, S. P. (2014). Eco-friendly approaches for sustainable management of vegetable pests. In *IIVR Technical Bulletin, 53* (p. 104). IIVR.

Rajendran, K. V., Shivam, S., Praveena, P. E., Rajan, J. J. S., Kumar, T. S., Avunje, S., & Alavandi, S. V. (2016). Emergence of *Enterocytozoon hepatopenaei* (EHP) in farmed *Penaeus* (Litopenaeus) *vannamei* in India. *Aquaculture, 454*, 272–280.

Rajesh, J. B., Rajkhowa, S., Dimri, U., Prasad, H., & Sarma, K. (2020). Need of alertness on Porcine Circovirus 2 in North East India. *International Journal of Veterinary Science and Research, 6*, 038–040. http://doi.org/10.17352/ijvsr.000051

Rajkhowa, S., Neher, S., Pegu, S. R., & Sarma, D. K. (2018). Bacterial diseases of pigs in India: A review. *Indian Journal of Comparative Microbiology Immunology and Infectious Diseases, 39*, 29–37.

Ramanagouda, S. H., Vastrad, A. S., Narendran, T. C., Basavanagoud, K., & Viraktamath, S. (2011). Current status of eucalyptus gall wasp and its native parasitoids in Karnataka. *Journal of Biological Control, 25*, 193–197.

Ranjalkar, J., & Chandy, S. J. (2019). India's national action plan for antimicrobial resistance—An overview of the context, status, and way ahead. *Journal of Family Medicine and Primary Care, 8*, 1828–1834.

Rao, A. N. (2018). The historical and future perspective of weed science research in India. In: Sushilkumar & J. S. Mishra (Eds.), *Fifty years of weed science research in India* (pp. 1–24). Indian Society of Weeds Science.

Saminathan, M., Rana, R., Ramakrishnan, M. A., Karthik, K., Malik, Y. S., & Dhama, K. (2016). Prevalence, diagnosis, management and control of important diseases of ruminants with special reference to Indian scenario. *Journal of Experimental Biology and Agricultural Sciences, 4*, 3338–3367.

Sandilyan, S. (2016). *Invasive alien species of India*. Available on http://nbaindia.org/uploaded/pdf/Iaslist.pdf

Sardaru, P., Anthony Johnson, A. M., Viswanath, B., & Narasimha, G. (2013). Sunflower necrosis disease—A threat to sunflower cultivation in India: A review. *Annals of Plant Sciences, 12*, 543– 555.

Sathiamma, B., Nair, C. P. R., & Koshy, P. K. (1998). Outbreak of a nut infesting eriophyid mite, *Eriophyes guerreronis* (K.) in coconut plantations in India. *Indian Coconut Journal, 29*, 1–3.

Sethi, A., & Dilawari, V. K. (2008). Spectrum of insecticide resistance in whitefly from upland cotton in Indian subcontinent. *Journal of Entomology, 5*, 138–147.

Sharma, D. R., Randhawa, H. S., & Pathania, P. C. (2015). Report on *Rhynchaenus mangiferae* infesting mango and litchi from Punjab in India. In: D. R. Sharma, S. Kumar, & B. Singh (Eds.), *Entomology for sustainable agriculture* (p. 8). PAU.

Sharma, H. C. (2014). Effect of climate change on incidence of insect pests in pigeonpea. *Journal of Crop Improvement, 28*, 229–259.

Sharma, I., & Saharan, M. S. (2011). Status of wheat disease in India with a special reference to stripe rust. *Plant Disease Research, 26*, 156.

Sharma, R. C. (2012). Few pathological threats to vegetable crops and their management under changing climatic conditions. In *Vegetable production under changing climate scenario* (pp. 121–123). DR YS Parmar University of Horticulture and Forestry.

Shekhar, M. A., Narendrakumar, J. B., Sreenivas, B. T., & Divya, S. H. (2011). Papaya mealybug, *Paracoccus marginatus* infesting mulberry in Karnataka. *Insect Environment, 16*, 170–172.

Shyam, S. S., Kripa, V., Zachariah, P. U., Anjana, M., Ambrose, T. V., & Manju, R. (2014). Vulnerability assessment of coastal fisher households in Kerala: A climate change perspective. *Indian Journal of Fisheries, 61*, 98–103.

Singh, H. S., Mandal, S., Misra, R. S., Korada, R. R., Srivastava, S. K., Das, B. K., Pukhram, B., Sahoo, A. K., Anwer, M. A., Saha, T., Prasad, D., Kumar, A., Reyaz, A., Sah, S. B., Kumar, A., Singh, R. G., Nayak, U. S., & Das, A. (2014). Emerging pests of vegetables, ginger and tuber crops in eastern India. *Journal of Applied Zoological Research, 25*, 171–176.

Singh, M. C., Singh, J. P., Pandey, S. K., Dharinder, M., & Varun, S. (2017). Factors affecting the performance of greenhouse cucumber cultivation—A review. *International Journal of Current Microbiology and Applied Sciences, 6*, 2304–2323.

Singh, R. (2020). *Current scenario & challenges of poultry sector of India*. Available on https://www.pashudhanpraharee.com/current-scenario-challenges-of-poultry-sector-of-india/

Singh, S. P., & Ballal, C. R. (1991). Status of coffee berry borer, *Hypothenemus hampei* (Ferr.) (Coleoptera: Scolytidae) (p. 6). Technical Document No. 36. All India Coordinated Research Programme on Biological Control of Crop Pests and Weeds, Bengaluru.

Somasekhar, N., Praseas, J. S., & Ganguly, A. K. (2012). Impact of climate change on soil nematodes—Implications for sustainable agriculture. *Indian Journal of Nematology, 40*, 125–134.

Sood, R., Bhatia, S., Gounalan, S., Patil, S. S., & Patnaik, B. (2007). Seroprevaence of Boviine Viral Diarrhoea virus in India: A survey. *The Indian Journal of Animal Sciences, 77*, 667–671.

Sridhar, V., Chakravarthy, A. K., Asokan, R., Vinesh, L. S., Rebijith, K. B., & Vennila, S. (2014). New record of the invasive South American tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in India. *Pest Management in Horticultural Ecosystems, 20*, 148–154.

Subramaniam, S., Pattnaik, B., Sanyal, A., Mohapatra, J. K., Pawar, S. S., Sharma, G. K., Das, B., & Dash, B. B. (2013). Status of foot-and mouth disease in India. *Transboundary and Emerging Diseases, 60*, 197–203. http://doi.org/10.1111/j.1865-1682.2012.01332.x

Tanwar, R. K., Prakash, A., Panda, S. K., Swain, N. C., Garg, D. K., Singh, S. P., Satya Kumar, S., & Bambawale, O. M. (2010). Rice swarming caterpillar (*Spodoptera mauritia*) and its management strategies. In *Technical Bulletin 24*. NCIPM.

Thangavelu, R., Devi, P. S., Chrismala, P. M., Mustaffa, M. M., van den Bergh, I., Smith, M., Swennen, R., & Hermanto, C. (2011). Cross infection and genetic diversity of *Fusarium oxysporum* f. *sp. cubense*, the causal agent of *Fusarium* wilt in banana. *Acta Horticulturae, 897*, 353–362.

Thind, T. S., Goswami, S., Thind, S. K., & Mohan, C. (2009). Resistance in against metalaxyl in citrus orchards. *Indian Phytopathology, 62*, 536–538.
Tripathi, S., Bhati, R., Gopalakrishnan, M., Bohra, G. K., Tiwari, S., Panda, S., & Garg, M. K. (2020). Clinical profile and outcome of patients with Crimean Congo haemorrhagic fever: A hospital based observational study from Rajasthan, India. *Transactions of the Royal Society of Tropical Medicine and Hygiene, 114*, 650–656.
Vass, K. K., Das, M. K., Srivastava, P. K., & Dey, S. (2009). Assessing the impact of climate change on inland fisheries in River Ganga and its plains in India. *Aquatic Ecosystem Health and Management, 12*, 138–151.
Vennila, S. (2016). Information and communication technology for effective integrated pest management. *Current Science, 110*, 287–288.
Vennila, S., Lokare, R., Singh, N., Ghadge, S. M., & Chattopadhyay, C. (2016). *Crop pest surveillance and advisory project of Maharashtra—A role model for an e-pest surveillance and area wide implementation of integrated pest management in India* (p. 56). ICAR National Research Centre for Integrated Pest Management.
Vennila, S., Paul, R. K., Bhat, M. N., Yadav, S. K., Vemana, K., Chandrayudu, E., Shabistana, N., Murari, K., Ankur, T., Rao, M. S., & Prabhakar, M. (2019). Impact of climate variability on recent and future status of Jassid infestation in groundnut at Kadiri, a hot arid region of A.P. State. *Journal of Plant Protection, 47*, 66–68.
Vennila, S., Prasad, Y. G., Prabhakar, M., et al. (2011). Spatio-temporal distribution of host plants of cotton mealybug, *Phenacoccus solenopsis* Tinsley in India. In *Technical Bulletin No. 26* (p. 50). National Centre for Integrated Pest Management.
Vennila, S., Ranjit, K. P., Bhat, M. N., Yadav, S. K., Vemana, K., Chandrayudu, E., Shabistana, N., Murari, K., Ankur, T., Rao, M. S., & Prabhakar, M. (2018). Abundance, infestation and disease transmission by thrips on groundnut and their weather based predictions for Kadiri region of Andhra Pradesh. *Journal of Agrometeorology, 20*, 227–233.
Viswanathan, R. (2020). *Fusarium* diseases affecting sugarcane production in India. *Indian Phytopathology*. http://doi.org/10.1007/s42360-020-00241-y
WHO. (2020). *Emergencies preparedness, response*. Available on https://www.who.int/csr/en/
Yadav, M. P., Singh, R. K., & Malik, Y. S. (2020). Emerging and transboundary animal viral diseases: Perspectives and preparedness. In *Emerging and transboundary animal viruses* (pp. 1–25). http://doi.org/10.1007/978-981-15-0402-0_1

Transformative Agroecology-Based Alternatives for a Sustainable and Biodiverse Future

Ravi Prabhu, Shiv Kumar Dhyani, Devashree Nayak and Javed Rizvi

1 Background: The Imperative for a Transformative Shift in Indian Agriculture

Globally food systems are at a crossroads and new directions are needed. At the first UN Food Systems Summit, Secretary General Guterres stipulated that a transformation of food systems is necessary so that they support the health and well-being of all people and at the same time protect our planet (UNFSS, 2021). The High-Level Panel of Experts on Food Security and Nutrition (HLPE, 2019) showed that a profound transformation is required in agriculture and food systems at all scales. Such a transformation must ensure sufficient food production while also safeguarding human and environmental health as well as socio-economic standards (Caron et al., 2018). It must be a systemic transformation—from paradigm through to practices.

Against this global backdrop we have a proud tradition of Indian agriculture that over six decades turned a country that was a net importer of food grains into a net exporter, removing the spectre of famine that appeared to hang over the country at independence (Nelson et al., 2019; Pingali, 2012). This massive increase in productivity has come at a price though, one that India is no longer willing to bear: increasing farmer indebtedness (NSO, 2021), groundwater depletion (Dangar et al., 2021), losses of soil fertility (Sharda et al., 2017), water and air pollution (Abdurrahman

R. Prabhu (✉) · S. K. Dhyani · D. Nayak · J. Rizvi
CIFOR-ICRAF, Nairobi 00100, Kenya
e-mail: r.prabhu@cgiar.org

S. K. Dhyani
e-mail: s.dhyani@cgiar.org

D. Nayak
e-mail: d.nayak@cgiar.org

J. Rizvi
e-mail: j.rizvi@cgiar.org

R. Chand et al. (eds.), *Indian Agriculture Towards 2030*,
India Studies in Business and Economics,
https://doi.org/10.1007/978-981-19-0763-0_7

et al., 2020; CWC, 2019; Ghosh et al., 2010), adverse impacts of synthetic fertilisers and pesticides, a focus on calories to the detriment of nutrition, are just a few of the now unacceptable costs (Brainerd & Menon, 2014, Sekhri & Shastri, 2020). The litany of problems affecting Indian agriculture is long and getting longer. Any call for a transformation of Indian agriculture that hopes to be successful, must distinguish between the types of agriculture we are dealing with, because Indian agriculture is not a homogenous entity. For our purposes here we will distinguish two broad clusters of practices: High External Input Agriculture (HEIA) and Low External Input Agriculture (LEIA).

HEIA: Characterised by high and often excessive consumption and dependence on external inputs; the national average of 133 kg/ha of fertiliser does not reveal the extent to which it leaches into hydrological systems or causes damages to soil biota and soil organic carbon accumulation (DES, 2020). According to DES (2020) over 75% of cropped area has synthetic fertiliser applied to it (ranging from about 78% of small and marginal farmers to about 63% of large land holdings) and about 43% of cropped area is treated with pesticides. Overuse of synthetic inputs in such systems, especially in irrigated systems, is a major contributor to driving land and water degradation, health impacts, farmer indebtedness and a number of other deleterious impacts, as explained above. While annual statistics are available for consumption and production of synthetic external inputs, no such statistics are available on impacts of overuse—a lacuna that needs to be filled. But at the same time these practices provide the bulk of India's food production, especially staples, oil seeds and certain horticultural crops. There is a growing consensus that these systems need to be made much less dependent on external inputs, much more efficient in their use of inputs. Two pathways are proposed for such transformation: a more capital intensive, external knowledge driven transformation for which terms such as precision agriculture, sustainable intensification etc. are used. This we see as an *incremental* change to an already relatively capital-intensive system that expects to deliver transformative results based on external injection of knowledge and more built-capital, we will not deal with this type of change here. The second pathway we see as being a more *transformative* change based on adherence to agroecological principles and knowledge, in order to radically reduce external inputs while sustaining productivity and reducing adverse impacts on the whole system. It relies on restoring or sustaining natural capital, especially contributions from biological diversity, while building on human and social capital at multiple scales and forms. As a result, this second pathway is much less built-capital dependent, as such it seeks to transform a HEIA into a LEIA. In between these lie approaches such as conservation agriculture and regenerative agriculture, which may take either pathway, depending on how they are interpreted.

LEIA: These include systems that traditionally depended less on external inputs of any kinds, as well as more 'modern' LEIA systems such as organic farming, natural farming, agroforestry etc., which may incorporate external inputs at low intensities. Between LEIA and HEIA we have various forms of regenerative agriculture, permaculture and integrated agricultural systems, although based on their intentions of building on natural capital and minimising external inputs they are also classified as LEIA. Sustainable improvements to LEIA systems would involve improving access and uptake of evidence-based agroecological knowledge, organisation, policy and institutional support, to support better use and delivery of ecosystem services, access to markets and price stability. In other words, the transformation pathway here focuses on strengthening human and social capital, without reducing the important contribution of natural capital, with much less emphasis on built-capital. Although changes proposed would be incremental as the systems remain LEIA, the impacts would, however, be transformational with respect to profitability, productivity, sustainability and resilience of these systems.

The transformative imperative in all cases requires acknowledgement that the full cost of farming must be internalised in some way, and this is a challenge that must be dealt with at nested scales from the field or stand of trees through farm, forest and landscape (and beyond). This means that we are not just dealing with proximate and directly visible challenges and opportunities but also with distant and often cryptic ones, including the sustainability of *input-sources*, such as for fertilisers or farm energy and *waste-sinks*, such as for greenhouse gas emissions or pesticide residues. In this context, understanding the impacts of the interactions of current and proposed policy is vitally important. These interactions can often have surprising and often countervailing impacts, for instance the Indian Forest Act (IFA) of 1865 which was amended twice, once in 1878 and then in 1927 forbade the cutting of indigenous timber species with the result that farmers lost interest in growing them, a situation that has begun to be rectified recently with the national agroforestry policy and recent amendment (2017) in Section 2(7) of IFA, 1927, bamboo is no longer a tree, this enables the livelihoods of forest communities as well as private grower. We use the term 'productive resilience' as the aspirational goal for the kinds of transformation we seek—lowering unsustainable inputs, rebalancing knowledge so that it is framed within agroecological principles, incorporating diversity, strengthening capacities for adaptation and innovation while at the same time not jeopardising food, nutrition and ecosystem sustainability.

Two further sets of challenges bear mentioning at this stage: women and youth empowerment.

Women are the backbone of Indian agriculture, but their role is seldom appreciated when it comes to benefits and ownership. While the longer term trend has seen a feminisation and ageing of the farming community, as men have migrated to cities in search of paid work, during the COVID-19 pandemic this migration was reversed because agriculture remains the safety net for the vast majority of the Indian population. However, we believe that agriculture, suitably transformed can be more than that, offering decent livelihoods and jobs for all, including women and youth. The average age of Indian farmers stands at about 50 years today according to the Input Survey 2011–12 (released in 2016) by the Union Ministry of Agriculture and Farmers' Welfare.

India has 600 million young people and about half of the population is under 25 years old (Census of India, 2011; UNFPA, 2014). India also follows the global trend where nearly 67% of rural youth (defined as the age group between 15 and 24 years and about 20% of the population (Youth in India, 2017)) live in agricultural high potential areas (Rural Development Report, 2019). But, despite the large numbers of youth, few are choosing agriculture as their livelihoods. Hence, transforming agriculture, upgrading and strengthening value chains and being extremely judicious in the deployment of built-capital versus human and social capital, it should be possible to offer young people an economically viable and satisfying future in farming and associated value chains. However, the ultimate test of success for any transformation of agricultural systems in India must be in terms of their emergent outcomes for the country. The challenge, therefore, will be to identify the kinds of metrics and performance evaluation system that gives true insight and guides sound policy and investment.

2 Paths to More Sustainable Agricultural Systems

2.1 Current Status of Transformative Agricultural Policies Across India

About 54.6% of India's total workforce is engaged in agricultural and allied sector activities (Census of India, 2011) and this accounted for 17.8% of the country's Gross Value Added (GVA) for the year 2019–20 (at current prices). Given the importance of the agriculture sector, Government of India has taken several steps for its development in a sustainable manner, foremost among them pertains to the steps taken to improve the income of farmers. Here, we highlight relevant parts and aspects of the vision statements, acts, plans, 'missions' and schemes of the Government that can help to accelerate agroecology-based transformative changes, the main ones of which are described in the next section. In Annexure 1, we identify the key initiatives that can be harnessed for an agroecology-based transformation.

2.2 Working with Nature and Ecology: Transformation Based on Agroecology

2.2.1 Agroecology as the Framing Paradigm for Transformation: Opportunities and Challenges

Agroecology embraces ecological principles, a set of practices and a social movement and has evolved over recent decades to expand in scope from a focus on fields and farms to encompass whole agriculture and food systems (HLPE, 2019). It now represents a transdisciplinary field that includes all the ecological, sociocultural, technological, economic and political dimensions of food systems, from production to consumption. It combines different scientific disciplines to seek solutions to real world problems, working in partnership with multiple stakeholders, considering their local knowledge and cultural values, in a reflective and iterative way that fosters co-learning, as well as the horizontal spread of knowledge from farmer to farmer or among other actors along the food chain. Agroecological principles and practices (Wezel et al., 2020) harness, maintain and enhance biological and ecological processes in agricultural production, in order to—reduce the use of purchased inputs that include fossil fuels and agrochemicals and to create more diverse, resilient and productive agroecosystems. Agroecological farming systems value, inter alia: diversification; mixed cultivation; intercropping; cultivar mixtures; habitat management techniques for crop-associated biodiversity; biological pest control; improvement of soil structure and health; biological nitrogen fixation; and recycling of nutrients, energy and waste.

According to HLPE 2019, there is no definitive set of practices that could be labelled as agroecological, nor clear, consensual boundaries between what is agroecological and what is not. On the contrary, agricultural practices can be classified along a spectrum and qualified as more or less agroecological, depending on the extent to which agroecological principles are locally applied (Sinclair et al., 2019).

Kerr et al. (2021) noted that agroecology has increasingly gained scientific and policy recognition as having potential to address environmental and social issues within food production, although concerns have been raised about its implications for food security and nutrition, particularly in low-income countries. A majority of studies (78%) in over 2,700 articles they screened, found evidence of positive outcomes in the use of agroecological practices on food security and nutrition of households in low and middle-income countries. Such agroecological practices included crop diversification, intercropping, agroforestry, integrating crop and livestock and soil management measures. They noted that, more complex agroecological systems, that included multiple components (e.g. crop diversification, mixed crop-livestock systems and farmer-to-farmer networks) were more likely to have positive food security and nutrition outcomes, a finding earlier reported by Asbjornsen et al. (2012).

From this we can return to the HLPE report and reaffirm the need to base transformative efforts around practices that:

(i) rely on ecological processes as opposed to purchased inputs;
(ii) are equitable, environmentally friendly, locally adapted and controlled; and
(iii) adopt a systems approach embracing management of interactions among components, rather than focusing only on specific technologies.

Given the diversity of practices and contexts and the need for inclusive and adaptive innovation the challenges to agroecology arise from the diversity of practices, claims about its effectiveness and the impacts on natural systems and consumer preferences and confidence. It seems likely that clearly identifiable sets of practices will need to be evidenced and supported for agroecology to receive the kinds of policy and investment support it deserves.

At the same time, the Committee on World Food Security (CFS) of the Food and Agriculture Organization of the United Nations has recommended that

> States (and regional and local authorities, as appropriate) in consultation with inter-governmental organizations, producer organizations, the private sector (including small and medium sized enterprises) and civil society… [in] the need for context-appropriate pathways to move towards sustainable agriculture and food systems… **encourage the adoption of agroecological and other innovative approaches** (CFS, 2021).

2.2.2 Natural Farming

NITI Aayog (2020) sees agroecology and natural farming as having potential to accelerate economic growth in India. Current estimates by NITI Aayog suggest that about 3.657 lakh ha across eight states in India are being cultivated using natural farming principles. About 5.09 lakh ha are under *Paramparagat Krishi Vikas Yojna* (PKVY) scheme, of which some 72% are under *Bhartiya Prakritik Krishi Padhati* (BPKP) or natural farming (see Annexure 1 for brief descriptions of these schemes). Here we will focus mainly on natural farming in Andhra Pradesh because it is the largest and most structured such transformative effort. Here, *Rythu Sadhikara Samstha* (RySS), a not-for-profit entity set up by the Government of Andhra Pradesh and financially supported by the Government of India and others, is engaged in scaling up a form of regenerative agriculture known as Andhra Pradesh Community Managed Natural Farming (APCNF). Based originally on Zero Budget Natural Farming (ZBNF) developed by Mr Subhash Palekar, APCNF has evolved as it has been adopted by innovative farmers who have adapted it to their needs and contexts across the state. This scaling effort started in 131 village clusters in 2016 and has since expanded to include over 7,00,000 farmers across the state in late 2021.

The origins of APCNF lie in the Society for Elimination of Rural Poverty (SERP), registered as a Society in the year 2000 in the state of Andhra Pradesh. As part of the objective to eradicate poverty and to improve livelihoods of the poor, Government of Andhra Pradesh set up SERP to facilitate poverty reduction through social mobilisation and improvement of livelihoods of rural poor in Andhra Pradesh. Naturally, SERP had identified agriculture as an important area of intervention because the majority of the poor were dependent on agriculture. Since SERP was involved with women's savings groups (Self-Help Groups), all the interventions were focussed on women while farming decisions were predominantly taken by men. At this time, one of the critical problems that was identified in agriculture was use of fertilisers and pesticides.

RySS aims by 2024–25 to cover 4000 g Panchayats (40% villages) and around 1.4 million farmers and farm workers (24% of all farmers and farm workers) in Andhra Pradesh. The major sources of financing are centrally sponsored Schemes of the Ministry of Agriculture, *Rashtriya Krishi Vikas Yojana* (RKVY), *Paramparagat Krishi Vikas Yojana* (PKVY) and *Bharatiya Prakritik Krishi Paddhati* (BPKP). In addition, in 2020–21 the State Government took a loan from *Kreditanstalt für Wiederaufbau* (KfW) Development Bank, Government of Germany, to expand the coverage of the programme. The programme outlay until 2024–25, from all these sources will amount to about INR 2000 crore.

APCNF is based on agroecological principles. It is 'farming in harmony with nature' and on the principle of 'do good, prevent harm'. APCNF seeks to improve soil health and plant productivity by mimicking and catalysing natural processes, and leverages animal manure and natural remedies to completely replace chemical inputs. At the heart of this initiative are agroecological practices that minimise the use of synthetic fertilisers and pesticides, building instead on biological nitrogen fixation coupled with nutrient and biomass recycling from livestock and biodiverse plant associations in and around farmers' fields, to improve or maintain soil organic carbon, functional microbial diversity, water holding capacity and balanced pest-predator populations.

APCNF promotes the following principles in farmers' fields.

(1) Covering the soil with live crops to ensure the activity of living roots
(2) Diverse crops/trees (around 15–20 species)
(3) Minimal disturbance of soils
(4) Integrate animals into farming
(5) Bio-stimulants as necessary catalysts
(6) Increase organic residues in soils
(7) Preferably use indigenous seed
(8) Pest management through botanical extracts
(9) No usage of synthetic fertilisers or pesticides.

The APCNF protocols are primarily based on farmers' practices that were developed using their traditional wisdom in using natural resources and natural processes, enhanced by ZBNF practices and other innovations of various organisations engaged in agricultural improvement, especially in the non-governmental sector. The APCNF team along with the State Agricultural University - Acharya N.G. Ranga Agricultural University (ANGRAU), NGOs in the field of natural farming and progressive farmers practising Natural Farming had jointly prepared the initial set of protocols on Natural Farming in 2016. Recognising the importance of continued innovation and learning, APCNF has an established procedure to refine and revise crop wise protocols regularly after studying best farmers' cases across all crops and situations.

It may be noted that these natural farming principles and practices have many features, which are drawn from the integrated nutrient management and integrated pest management protocols of the Indian Council of Agricultural Research (ICAR) and the State Agricultural University. At the same time there are differences in terms of the non-use of synthetic chemicals. APCNF's principles, practices and the implementation are in line with the 10 elements of agroecology (FAO, 2018): diversity, co-creation of knowledge, synergies, efficiency, recycling, resilience, human and social values, culture and food traditions, responsible governance and circular and solidarity environment. Initial results (Table 1) from APCNF indicated the need for higher labour inputs and therefore employment. This is potential good news particularly if such labour is attractively compensated.

Rosenstock et al. (2021) concluded that

> APCNF drastically reduces emissions even as yields largely remain the same. As a result, the GHG intensity of APCNF is an average of 47% lower than that of conventional practices across all the crops, with four of the six crops demonstrating a nearly 60% reduction in GHG intensity.

A life cycle analysis of APCNF suggested that the processes employed required 50–60% less water and consequently less electricity (than non-APCNF) for all the selected crops in that study (CSTEP, 2019). For irrigated crops, APCNF required

Table 1 Results of Crop Cutting Experiments comparing APCNF and Non-APCNF farms in 2019. Particularly remarkable is the net improvement in farmers' income (IDSAP, 2021)

Crop	Season	Difference between APCNF and non-APCNF (per cent)		
		Yields	Gross revenue	Net revenue
Paddy	*Kharif*	5.85	13.14	65.73
	Rabi	−7.02	2.05	14.60
Maize	*Kharif*	−4.73	−10.97	−5.26
	Rabi	8.94	4.39	21.31
Jowar	*Kharif*	10.42	11.28	23.51
	Rabi	1.88	−2.51	73.62
Ragi	*Kharif*	23.26	18.08	49.36
	Rabi	−3.62	−11.23	−9.72
Bengal gram	*Kharif*	1.69	13.73	181.90
	Rabi	−9.47	−6.52	116.07
Black gram	*Kharif*	23.21	25.21	67.08
	Rabi	2.45	2.43	−1.92
Red gram	*Kharif*	6.20	19.64	361.43
Green gram	*Rabi*	14.62	31.15	31.52
Groundnut	*Kharif*	0.94	5.53	23.81
	Rabi	4.76	6.33	21.67
Sesamum	*Rabi*	32.78	28.44	32.57
Chillies	*Kharif*	8.98	11.77	39.58
	Rabi	−7.84	13.74	22.45
Onion	*Kharif*	9.36	24.67	43.06
	Rabi	−12.35	−18.54	13.27
Cotton	*Kharif*	−2.93	−3.11	165.65
Sugarcane	*Kharif*	−1.12	8.33	18.81
Turmeric	*Kharif*	9.70	10.26	26.20

45–70% less input energy (12–50 GJ per acre) and resulted in 55%–85% less emissions (1.4–6.6 Mt $CO2_{eq}$) than non-APCNF. It also has the potential to avoid residue burning by practising mulching. In a projection carried out by RySS for the decade 2021–31 the conclusion reached was that for each INR invested in conversion to APCNF, roughly INR 1.8 would be saved in electricity subsidies for irrigation and INR 3.7 in subsidies for synthetic fertilisers and pesticides. This 1:5.5 ratio is for financial subsidies only and does not count benefits that accrue due to lower greenhouse gas emissions, greater availability of surface and groundwater, lower pollution of air and water and improved biodiversity outcomes.

RySS has identified three important components to its theory of change in implementing the APCNF programme:

1. Transformation should happen in a democratic way wherein women collectives (SHGs and their federations) and other farmer institutions are involved in programme planning, implementation and monitoring;
2. Knowledge dissemination and handholding support is constantly provided through farmer-driven extension architecture led by resource persons embedded in the community;
3. Saturation of entire village, cluster, Mandal and the state (in that order) involves converting all villages, all farmers, all farms and all practices leading to a total transformation.

Essentially, these key pillars define the contours of the strategy, activities and the associated costs of implementation of APCNF model.

It is early days yet for Natural Farming in India, but there are some encouraging results—for yield, better income and better management of natural resources—to be had from across the country, with data being sparse. Recently the National Coalition for Natural Farming has framed its ambitions for the programme in terms of an integrated landscape-based systems approach, which promises to speak to the restoration of a holistic approach to agriculture in India (Fig. 1).

It is clear that despite promising results more evidence is required on how natural farming works, for whom it works best, where and with what impacts. To this end the Indian Council of Agricultural Research (ICAR), the Government of Andhra Pradesh and the International Centre for Research in Agroforestry (ICRAF) have agreed to develop a research programme that will contribute to ICAR's overall programme of research on the efficacy of natural farming in India.

2.2.3 Agroforestry

During FAO's first conference on agroecology, the following definition of agroforestry was offered (Prabhu et al., 2015): *a dynamic, ecologically based, natural resource management system that, through integration of trees on farms and in the agricultural landscape, diversifies and sustains production.* Agroforestry is the practice and science of the interface and interactions between agriculture and forestry, involving farmers, livestock, trees and forests at multiple scales. It is an effective land

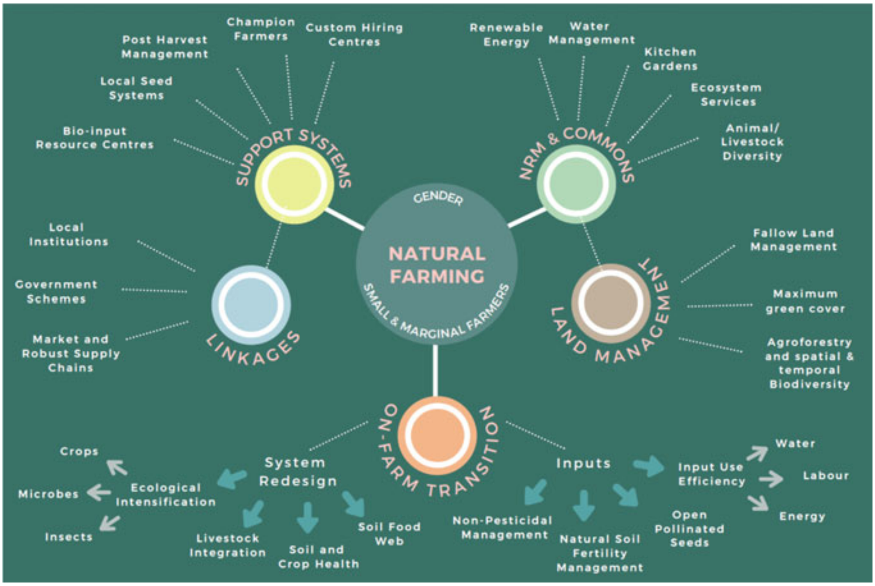


Fig. 1 Conceptual model developed by the National Coalition on Natural Farming to explain to participating partners how to intervene in the farming systems to achieve transformative impacts at landscape scale (Gupta et al., 2021)

use system, which contributes to food, nutritional and environmental security. The term agroforestry emerged in the late 1970s and in the five decades since, agroforestry has been understood and defined in multiple ways, often referring to a specific system scale of interest. However, though agroforestry as a science is a recent but the practice of combining crops, forest and fruit trees and domestic animals on the same unit of land in sequential or temporal dimension has existed in India for thousands of years. The socio-religious fabric of the people of the Indian subcontinent is interwoven to a very great extent with raising, caring for and respecting trees. Many examples of agroforestry practices are available. For example, the Taungya system, a method with its roots in Burma, aims to establish forest species in temporary combination with field crops. It was introduced into mainland India in 1856 and has been in regular cultivation since 1911.

There are many programmes recently initiated by Government of India focusing on agroforestry mainly to meet the growing demands and safeguarding natural resources. About 20 common agroforestry systems have been identified as being practised in different agroecological regions of India (Dhyani et al., 2009).

Although there is a sizable area occupied by agroforestry in the country, clearly more can be done. The total agroforestry area in India (if defined as more than 10% tree cover on agricultural area) was found to be around 28 million ha that is approximately 17% of the total agriculture land area. This is much less than the global average of 43%. The analysis further revealed that the agriculture land potential in

India towards the agroforestry suitability category (S1: High Suitability) is alone 75.6 million ha that are 2.7 times of total existing agroforestry extent. This has been recognised in India's Nationally Determined Contribution (NDC) targets for 2030. Where agroforestry is seen to play an important role in lowering the emission intensity of GDP by 33–35% below 2005 levels and to create an additional (cumulative) carbon sink of 2.5–3 $GtCO_2$ (UNFCC, undated). The assumption on which these targets are based is an anticipated increase in tree cover, which can only be achieved through adoption of agroforestry in a big way.

This is possible as the Task Force on Greening India (Planning Commission, 2001) had projected that an additional 28 million ha area of tree plantation through agroforestry can be achieved to meet the national goal of increasing forest cover on one-third of the total geographical area. For this purpose, 10 million ha of irrigated lands which are suffering from water logging, salinity and water erosion and another 18 million ha of rainfed lands have been earmarked for agroforestry development. A sizeable area will also be contributed from barren and uncultivable land, permanent pastures and other grazing land, culturable waste land and fallow land.

Anticipating this, in September 2019, India committed to restore 26 million ha of degraded land by 2030 to achieve Land Degradation Neutrality (LDN), as part of its global commitments during the 14th Conference of Parties to the United Nations Convention to Combat Desertification (UNCCD).

As Prabhu et al. (2015) have pointed out and in summary:

1. Optimising the contribution of trees to agricultural systems at nested scales will deliver multiple benefits to people and the planet
2. Fine scale variation and diversity of species, systems, life-forms, contexts and options are assets rather than hurdles
3. It is possible to go to scale in time because we have the tools, evidence and an understanding of the kinds of partnerships that will succeed, but challenges remain.

However, despite the significant development in the agroforestry sector in India, there are some constraints which slow down the growth and development of agroforestry to its full potential.

These are long gestation period and market uncertainties; insufficient support by financial institutions and extension services; unavailable improved planting material; no regulated price mechanism; unfavourable export and import policies; competition of trees on farm with crops for space, sunlight, moisture and nutrient; allelopathic effect by trees on crops; requirement of intensive labour, etc. The challenge in agroforestry, is therefore to support or induce productive resilience and support decent livelihoods in agricultural landscapes while countering rapid, pervasive change that is threatening to undermine the agroecological basis of the farming systems involved. This it holds promise of doing.

Table 2 Increases in yield and income with project varieties (World Agroforestry, 2021)

Project intervention	Yield (kg/ha)		Per ha increase in income (INR)
	Farmer's variety	Project variety	
Rice	1313	5017 (CR310)	67,228 @ INR 18.15/kg*
Grass pea	0–60	625	16,950 @ INR30/kg#
Eggplant	15,000–20,000	20,000–25,000	90,000 @ INR18/kg#
Tomato	10,000–15,000	15,000–20,000	1,60,000 @ INR32/kg#
Chilli	5,000–8,000	8,000–11,000	6,54,000 @ INR218/kg#
Okra	6,000–8,000	10,000–12,000	1,20,000 @ INR30/kg#

* Rice Minimum Support Price (MSP) of Odisha for 2019–2020 # https://agmarknet.gov.in, June 2020 wholesale price for Bolangir

Case Study from Odisha

To illustrate what a transformation to alternative, agroecology-based farming looks like we offer the following case study. The project entitled, "Enabling smallholders to produce and consume more nutritious food through agroforestry system" is operational in Bolangir and Nuapada districts of Odisha. The two districts in western Odisha, are dominated by resource poor farmers, who are technologically deprived and often migrate within and outside the state for their livelihoods, particularly during *rabi* and summer. The project aims to introduce and accelerate adoption of suitable agroforestry systems to enhance availability of nutritive food; generate employment and income to support the efforts of Odisha Government to reduce in-country migration; and create awareness about benefits of consuming diversified nutritious farm produce and build capacity of all stakeholders. The summary of the achievements to date are given below and in Table 2.

- More than 9,000 farmers have benefited [5,582 in Bolangir and 3,459 in Nuapada] in three years to date operating in 5,305 ha area in the 30 g panchayats of the two districts, covering 149 villages [108 in Belpada and 41 in Nuapada].
- The project is being implemented through a "System Farming Approach"—including bund plantation, intercropping [crop demonstration with agroforestry], boundary and backyard plantation, nutri-gardens and nursery establishment with adequate capacity development-interventions.
- More than 125,000 multipurpose plants such as teak, gamhar, bamboo, jackfruit and drumstick var. PKM-1, fruit plants- mango var. Amrapali, guava var. VNR-Bihi, Apple ber, custard apple var. Balanagar, aonla var. NA7, lemon -Konkan lemon, papaya (Pusa Dwarf, Pusa Nanha) etc. were planted by farmers.
- Out of the above, about 90,000 saplings planted with Pusa Hydrogel and SNF to help plants to sustain better during hard summer and to reduce the water requirement.
- Bund plantation in 4534 ha [2948 ha in Belpada and 1,586 in Nuapada].
- 6523 ha covered under crop demonstration intercropped with fruit plants.

- 7691 backyard farmers and around 7,000 migratory farmers provided with various inputs and encouraged to adopt agroforestry system to improve livelihood.
- Five biofortified seed production Farmer Producer Organisations established, which produced 64.30 tonne seed in 2020, and farmers are successfully linked with Odisha State Seeds Corporation (OSSC).
- More than 18,650 farmers were trained under capacity development programmes and 21 officers under exposure visits and training programmes.
- Fifteen (15) nutrition gardens, 36 village nurseries and 2 district nurseries for high quality planting material established to supply quality planting material of agroforestry species locally.
- In Paddy, Belpada project farmers could get additional income over the district average of INR 12,931 during 2019–20 and INR 8,439 during 2020–21, while in the Nuapada part of the project farmers could get additional gain over district average INR 9172 during 2019–20 and INR 6,163 during 2020–21. Besides this Bio-fortified varieties CR 310 and 311 contributed more than 10.3% protein in the diet. Thus, increasing per hectare availability of 515 Q of protein, 150 g zinc, 150 g iron enriching the nutrient profile.
- In rice -fallows, with grass pea introduction, a total of 752 ha was covered in two years with an average yield of 4.06 q/ha. In total, 1880 farmers covered in two years with 33.18% farmers as migratory farmers.
- Under backyard plantation, average income after consuming 30% produce of vegetables and 50% produce of fruits from first year plants is around INR 4,682 (INR 3,000 from vegetable and INR 1682 from fruit production, viz. papaya and Apple ber) per household.
- Hydrogel was introduced in plants and crops, on an average, in paddy (Ankit variety), yield increased by 14% over control.
- Water infiltration and NRM based Agroforestry: An area of about 200 acres at two sites identified and developed with NRM interventions in a participatory mode at Boirbhadi in Nuapada and Tara in Belpada—for increasing water infiltration and recharge of sub-surface irrigation water to have second crop during *rabi*.
- Mobile phone based monitoring: About 9,000 farmers project activities geotagged and uploaded.
- Under drought situation, farmers are becoming more dependent and eager to grow fruit plants as seen in the ongoing season.
- Agroforestry Assistant, a smartphone-based application (AFA)—The App provides comprehensive information on agroforestry systems, trees, crops, nursery and helpful in locating availability of planting material in nurseries. App beta version is uploaded on Google Play store and will be shortly released.
- Improving production and consumption of nutritive food.

As an illustration (Fig. 2) of the landscape approach of the project, consider how it addressed the availability of nutrients across the landscape in pursuing the following model:

Here, fruit trees—such as guava, apple ber and moringa—have started bearing fruit with 100 g of edible portions, which have enriched the food quality of farmers

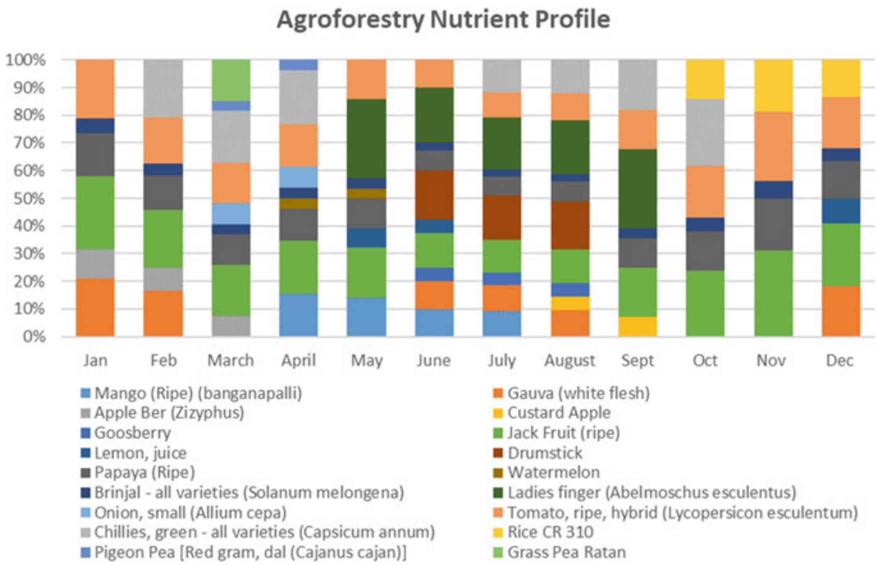


Fig. 2 Agroforestry nutrient profile (World Agroforestry 2021)

with 996 μg of vitamin A, 214 μg of vitamin C from guava; 46 mg of calcium and 62 μg of vitamin B complex from apple ber; and 358 μg of vitamin K, 350 μg of vitamin A, 0.73 mg of iron and 419 mg of potassium from drumstick fruit; all of which are essential for growth and building a strong immune system as well as reducing stunting in children. Selection of fruits and vegetables is done in a way to provide year-round nutritious food to participating farmers, as shown in the graph of agroforestry nutrient profile from the package of practices established through the Odisha Agroforestry Project.

The project is observing an early trend in reduction of migration, as the planted fruit trees have started fruiting, some of which was in sellable quantity, like papaya and Apple ber. In addition, with the introduction of fallow crop, now the migratory farmers are able to take crop in the winter, which in turn means source of regular income. With the issues faced by the migratory farmers during the COVID-19 pandemic, the trends and demand of farmers in the two districts are encouraging and create an avenue of transformation in their traditional agricultural practice by shifting to system-based farming approach, inclusive of agroforestry at a large landscape level.

2.2.4 Organic Farming and Other Approaches

Faced with degradation of soil and water resources, increase in pollution hazards and threats to environment because of the over-use of finite arable lands for agriculture and excessive chemical inputs a range of alternative approaches, including organic farming have been mooted. Besides, organic farming, some of the most promising practices in sustainable agriculture in India include the System of Rice Intensification, alternative wetting and drying regimes in rice production, conservation agriculture, integrated farming systems and forms of permaculture. Practices such as crop rotation and intercropping, cover crops and mulching, integrated pest management, vermicomposting, contour farming, rainwater harvesting and assisted recharge of groundwater can be found across many of them.

Under the National Action Plan on Climate Change (NAPCC), Government of India is implementing *Paramparagat Krishi Vikas Yojana* to promote organic farming practices. It is also encouraging the conversion of waste to compost by linking it with the sale of fertilisers and providing market development assistance. According to FAO (1999)

> Organic agriculture is a holistic production management system which promotes and enhances agroecosystem health, including biodiversity, biological cycles and soil biological activity. It emphasises the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, agronomic, biological and mechanical methods, as opposed to using synthetic materials, to fulfil any specific function within the system.

Government of India has elucidated its recommendations on how to implement organic farming (NHM, undated).

According to the Union Ministry of Agriculture and Farmers' Welfare (as of 7 December 2021), 3,809,589 ha is under organic farming in the country.

Though the area under organic farming in country is still small, it is increasing but there remains challenges. The most important challenge in the development of organic farming is the lack of awareness (Das et al., 2020) among farmers about it and its potential benefits. Markets tend not to reward organic produce with a price premium unless certified. But there are inadequate numbers of certifying agencies and input costs to grow organic products remain high. There is also an insufficient quantity of biomass of the required quality and inadequate infrastructure support for organic products in the country.

2.3 Designing Transformation Processes

In considering how to design a transformation process we turn to Charles Vlek (2009), who in his seminal paper on the precautionary principle, concludes with a quote from Roel Pieterman: "fear is a bad counsellor, and optimism is often necessary to maintain or restore self-confidence. Would hope be a better counsellor?". He calls for a "precautionary principled approach to uncertain risks". In other words, caution with the avoidance of paralysis. This is precisely the approach we propose here: Driving transformation of agriculture and food systems within a landscape-level, nested scale "structured learning" or "adaptive management" approach that considers whole systems, while seeking productive, resilient and equitable outcomes.

The goal is clear, but what is still missing are the milestones and signposts to monitor progress and minimise serious risks. We need safeguards as we deal with uncertainty. The poor treatment of uncertainty in current public policy and development and the widespread avoidance of the precautionary principle Vlek advocates are precisely what has brought us to the present situation, which is more similar to mining than to sustainable land use. Like miners, agriculture today tends to exploit soil resources and, when they are exhausted beyond use, lands are declared as 'wastelands' and we move on or begin very expensive restoration campaigns. We produce food at the cost of the environment and future generations. This must of course change—but we still lack agreement on the safeguards that will ensure that risks are managed in an acceptable manner.

Research has and must continue to deliver the safeguards we need for transformative policies and development. Safeguards and metrics by which to judge performance are needed to protect public and private policies and investments from the overly optimistic proponents of 'magic bullet' thinking and the pessimists who charge that all modern tools only lead to adverse outcomes.

We offer the mnemonic RENEWAL to capture the four key principles we think should drive the changes to publicly funded agricultural transformation agendas in food systems:

1. ***R**efocus and repurpose*: Agronomic efficiency considerations must be nested within broader LEIA perspectives. This particularly applies to international and national public investments and funding, since private sector investments are more focused on agronomic efficiency than transformation. An approach focused on "productive resilience" based on agroecology will require the achievement of multiple objectives at multiple temporal scales to ensure the system can continuously adapt to multiple drivers of change, especially those related to the climate crisis. As Table 2 illustrates, present research and education investments do not align well with an agroecological transformation. Three examples from research investments serve to illustrate what we mean:

    - Conventional (and now biotechnology-enabled) breeding programmes focus on bridging yield gaps in monocrop fields. In the hot, dry conditions of arid zones of the Sahel, there is overwhelming evidence that cereal crops like maize, millet and sorghum grow better under the shade of trees like *Faidherbia albida* than they do under the open sun. In arid Rajasthan, increases in the amount of nitrogen and phosphorus and other macro-and micro-nutrients are reported under *Khejri* (*Prosopis cineraria*) as compared to sites bare of vegetation (Shankarnarayan, 1984), and forage species produce higher biomass under *khejri* tree canopy due to a high fertility status (Singh & Lal, 1969). And yet breeding programmes simply ignore the opportunities of breeding for ecological synergy, despite the obvious adaptation benefits.
    - Although it is clear that soil biota play an enormous role in determining the fertility and indeed sustainability of farmers' fields, instead almost all the research on improvement of fertility is focused on fertiliser inputs.

- With respect to the relation of agriculture with food systems, applied research about agricultural, or global, value chains would pay particular attention to governance, in helping to elucidate the balance of power, decision-making and access to information among the different actors in food systems, from producers/farmers to consumers, as well as to efficiency in terms of identifying market opportunities (Béné et al., 2019).

2. ***N****est and include* ***W****idely*: The interdependence of species and knowledge systems must be included within agricultural and food system boundaries, not batted away as components to be added later. Whole landscape perspective investments in food systems transformation and research must include and nest landscapes, watersheds settlements, farms, fields and other land-uses. For instance, a study of improvement of one crop must include consideration of other varieties and crops planted within that landscape, and biological, social and economic interactions that result, the impacts of change on the whole system, especially with respect to the productive resilience of the system and its ability to adapt to changing climate and demographics. This suggests that a landscape perspective is essential to properly inform decision pathways.
3. *Strengthen* ***A****daptive Learning*: Current agricultural transformation approaches are predicated on the identification and development of breakthrough technologies but ignore the fact that any intervention in a system is likely to generate unexpected ripple effects. Adoption of a systems perspective and a more structured learning approach promoting adaptive innovation practices and learning loops would prevent potentially useful technologies being treated as 'silver bullets'. The metrics and frameworks for this are currently underdeveloped: Land Equivalent Ratios, Total Factor Productivity, Full Cost Accounting and many more approaches and (sustainability) metrics have been proposed, but no new national and widely structured learning system for policy and development adaptation has emerged so far.
4. ***L****evel playing fields*: Differentials in power and investment capabilities in power structures and political economy support the status quo and prevent a change in paradigm (Kramer et al., 2020). Recent literature, e.g. the study on financial flows in food system research that go to sub-Saharan Africa by the International Panel of Experts on Sustainable Food Systems (IPES-Food) (Biovision & IPES-Food, 2020), has begun to bring to the surface the perverse impacts of this political economy on flows of resources to publicly funded research. While private sector investment will continue to support the agronomic efficiency paradigm, as it supports most directly their profit motives, it is important that the public sector focuses on public goods aspects such as promoting nutrition through diversity or integrated pest management, benefits of and systems for multispecies agriculture, permanent canopy systems like agroecology, agroforestry, permaculture, natural farming and mixed and integrated energy efficient systems, circular bioeconomy and nature-based solutions. The bias towards a few crops and commodities and a 'production paradigm' is obvious in India's premier publicly funded agricultural research system (Table 3), this can be seen as indicative of an under-investment in systems research.

Table 3 Focus of agricultural researchers at ICAR and in Higher Education by major thematic area

Thematic research focus	ICAR	Higher education
	Share of FTE researchers (%)	
Crop genetic improvement	14.9	11.7
Crop production (agronomy, fertiliser)	10.6	11.0
Crop protection	9.7	8.8
Other crop-related themes	1.5	1.3
Genetic improvement of livestock	2.7	5.2
Livestock health	3.8	13.1
Livestock management	1.5	7.6
Pastures, forages and animal nutrition	2.4	5.5
Other livestock-related themes	2.2	2.9
Fisheries-related themes	4.7	9.5
Soil	1.6	2.5
Water	1.3	2.9
Agricultural engineering	2.2	1.2
Biodiversity, germplasm conservation	7.0	1.7
Farming systems	2.2	2.1
Food safety	1.5	1.2
Emerging areas (biotechnology, nanotechnology)	5.5	2.4
On farm postharvest research	6.0	2.5
Socioeconomic and policy research	13.0	4.3
Other themes	5.8	2.6
Total	100	100

FTE full time equivalent (Stads et al. 2016)

The World Bank's *Harvesting Prosperity* report, recommending establishing the institutional autonomy of research institutions, ensuring stable and diversified funding and promoting public–private partnerships as well as regional and international links to align R&D efforts. UNEP's *TEEB for Agriculture & Food: Scientific and Economic Foundations* recommends a new way of assessing, valuing and—where appropriate—monetising all capitals (produced, natural, social and human) involved in eco-agri-food systems will provide the true costs of our food (TEEB, 2018).

3 What India Needs to Achieve by 2030

Agriculture is the backbone of the country with about 54.6% of India's total workforce engaged in agricultural and allied sector activities (Census of India, 2011) and more than 65% of the citizens living in rural India. It is the source of food, feed, fibre, fuel and the livelihood of Indian people. The Green Revolution in India introduced of high yielding varieties of some key crops (rice and wheat, for example), led to an expansion of irrigation facilities, heavier dependence on fertilisers and pesticides, farm mechanisation, credit facilities and buttressed by price support, and other rural infrastructure facilities ushered in higher farm incomes in some parts of the country. The results were not even and higher dependence on expensive external inputs has also led to higher farm indebtedness, in many cases cripplingly so (Nelson et al., 2019). The Green Revolution's almost singular focus on increasing agricultural productivity is proving to be a poverty trap, especially for smallholder farmers, evidenced by rising indebtedness as explained earlier. In the two decades between the year 2000 and 2020 the proportion of the undernourished in the population barely decreased from 18.6 to 14%, and some indicators, such as under-5 child wasting actually increased according to the Global Hunger Index.[1] So clearly production and productivity increases, while necessary, are not sufficient to tackle poverty and malnutrition, even if we ignore the massive environmental impacts listed earlier.

In the foreseeable future, agri-food systems will be under an unprecedented confluence of pressures, not only to meet nutrition, poverty and environmental expectations such as reversing the rapidly depleting availability of water, soil degradation, deforestation, land degradation and threats to agrobiodiversity, as explained earlier. But because rising income, demographic changes, changing dietary patterns and increased demand for a more varied, high quality diet will exert further pressure on the food systems. Climate change, with rising temperatures, increasing frequency of extreme weather events, shifts in precipitation regimes and hydrology will have uneven and varied impacts across the country, exacerbating the situation further (see PSA, 2019, for example).

In addition to these effects of the COVID-19 pandemic- a global health crisis that is already having devastating impacts on the world economy, are also being felt by the food and agriculture sector in short term and will certainly have long term implications. Such 'shocks' to our agricultural systems—regardless of their origin—are predicted to rise as global systems enter states of increased fragility, this calls for agricultural and food systems designed to be much more resilient than at present.

In our view solutions to these challenges require multi-scaled and nested responses, involving harnessing of agroecological science and context specific innovation and adaptation throughout agriculture and the food system. Producers such as farmers, especially small and marginal farmers, agricultural labourers, fishers and pastoralists must be at the heart of this human and social capital focused transformation, because without them any hope of productive resilience based on context specific adaptation will be lost. It is important also to focus on strengthening capabilities across the entire value chain, so that net incomes rise but not at the cost of the environment. Therefore, addressing the needs and aspirations of all value chain actors, starting with the primary producers is a matter of national priority.

[1] https://www.globalhungerindex.org/india.html, accessed October 3, 2021.

India's agriculture, which is currently growing at 2.9% per annum, must grow faster, but improved productivity is just one target among many. We suggest the following principles are required in any search for an alternative, summarised further in Table 3:

- **Ensuring that the welfare and advancement of farmers and food system actors meets expectations**: Even using the rather limited indicator of cash income, it is apparent that income earned by a farmer from agriculture is crucial to address agrarian distress (Chand et al., 2015; Chand, 2016) and so any transformation of the system must promote farmers' welfare and at least meet expectations of parity between income of farmers and those working in non-agricultural professions.
- **Better access to quality seeds and planting material, along with improvements to supply chains for these**. It is estimated that the direct contribution of quality seed alone to the total production is about 20–25% (http://seednet.gov.in) depending upon the crop and it can be further raised up to 45% with efficient management of other inputs. This includes judicious exploitation of hybrid technology, because managed well and in the appropriate circumstances, hybrids are a powerful ally for transformation of food systems, especially if the benefits are extended to so-called orphan crops. In this context biotechnology too has a great potential in improving efficiency and profitability of agriculture through identification of promising varieties of under-invested crops, disease resistant planting material, hybrid seed production, rapid and accurate diagnosis of diseases, rapid breeding of new varieties, etc. Recently 35 crop varieties developed by the Indian Council of Agricultural Research (ICAR) to address the twin challenges of climate change and malnutrition were released. These climate-resilient crops include a drought tolerant variety of chickpea, wilt and sterility mosaic resistant pigeon pea, early maturing variety of soybean, disease resistant varieties of rice and biofortified varieties of wheat, pearl millet, maize and chickpea.
- **Capacity and capability strengthening**: This is especially true in research, rural advisory services and outreach for hitherto neglected crops and farming systems that are more climate resilient and benefit farmers and consumers. The paradigm for education, training and research must shift from being top-down and productivity driven to being inclusive also of farmer innovation and systems resilience driven. Indeed a salient feature of any sustainable agriculture system of the future will be its ability to support innovation that drives context specific adaptation in the face of drivers of global change that are only picking up momentum.
- **Shifting to better adapted species and practices**: The development and identification of disease resistant and climate resilient crops and crop varieties, with enhanced tolerance to fungal/insect attack, heat, drought, flooding, chilling and salinity stresses are essential in order to sustain and improve crop yields to cope with the challenges of biotic/abiotic stresses. Similarly, as biofertilisers are emerging as means for reducing chemical footprints in agriculture, the biopesticides have huge role to play in sustainable management of crop pests and pathogens. ICAR developed 41 validated biofertilisers and 31 microbial formulations were made available to farmers of the country in recent years.

- **Shifting to more resilient forms of agriculture that still meet productivity thresholds**: such as agroforestry, horticulture, permaculture, natural farming and other agroecological approaches. An expansion of horticultural crops, for example, allows for resilient growth that takes advantage of India's long growing-season, diverse soil and climatic conditions comprising several agroecological regions, and can be particularly impactful in farming systems that build on diversity, such as agroforestry and permaculture. The potential contribution of horticulture has been recognised in the report of the committee on doubling farmers income (DACFW, 2018). Between 2000 and 2016, horticulture growth rates of 5.8% occurred owing to technological back-up, investment and policy environment. Past trend shows that target of production of 316.41 million tonnes envisaged for 2020–21 is easily achievable, as production of 314.67 million tonnes has already been achieved in 2018–19.
- **Managing agricultural landscapes for more than food production**: This will require developing new metrics for evaluation of impacts and effects, valuing and supporting diversity in farming systems, protecting soil fertility and its regeneration through the farming system, promoting cyclical agriculture and bioeconomy and reforming agriculture research and education (Table 4).

Table 4 The major targets for change and notional difficulties in achieving them depending on starting conditions

Target for change	Relative degree of difficulty	
	HEIA	LEIA
Shifting to farming systems that are better adapted and adaptive to climate change, based on agroecological principles	Variable	Low to medium
Diversification including towards higher value and higher nutrition content crops	High	Low to medium
Improving tree cover, biomass and soil-organic carbon and fertility across Indian agriculture	Medium to High	Low to medium
Concomitant improvement in productivity	Medium	Medium
Resource use efficiency especially with respect to water	Medium to High	Low to medium
Increase in cropping intensity	Medium	High
Landscape approach that factors in contributions from forests, common lands and waste-lands in the provision of ecosystem services	Medium to High	Medium to high
Shifting cultivators from farm to non-farm occupations, and	High	Low
Improvement in terms of trade for farmers or real prices received by farmers	High	High
Basing policies and investments on a full or true-cost accounting approach	High	High

4 Policy Changes/recommendations

The Government of India is aware of the agrarian crisis and the need for a transformation of the agricultural systems that determine India's food security and condition the well-being of almost half its population. If we are to change the paradigm within which Indian agriculture takes place, one where productivity gains are framed within a 'duty of care' towards achieving resilient outcomes for ecosystem services as well as commodity production, then we follow FAO and HLPE (2019) in identifying principles, as they have done for agroecology, rather than attempting any list of specific policies.

The *first principle* to be followed for any transformation of Indian agriculture in a densely populated and highly interconnected country like India is to embrace the concept of stewardship—which embodies the 'duty of care', a duty that recognises that care must extend to our relationships towards nature and society as a whole, in more ways than our agricultural systems presently recognise—as the paradigm within which change can take place.

The *second principle* is to recognise that farmers must be viewed and rewarded as stewards of the land and all of its ecosystem services, not be rewarded as just producers of food. In other words there needs to be a recognition that farmers who practice agriculture while conserving water, biodiversity or reducing pollution or greenhouse gases are providing a valuable service—at present this is taken for granted and they are only 'rewarded' for the commodities they produce.

The *third principle* to be adopted is to recognise the need for constant, context specific adaptation. This will call for encouragement of innovation at all scales and reducing barriers for the dissemination and adoption of innovations that can drive context specific adaptations.

Application of these three principles will facilitate the shift from HEIA types of production systems to LEIA or to an improvement of existing LEIA systems. Without drastically reducing or optimising inputs, transformation processes will likely find themselves on a slippery slope—with productive resilience and sustainability remaining elusive. Transformation challenges must be framed around systems, not technologies. Only through adopting a whole systems approach at landscape and nested scales, can we ensure that we work with nature and people, not against them. Prabhu et al. (2021) have suggested that agricultural transformations must seek to approximate a stewardship economy. In other words, farmers who are successful in sustainably delivering ecosystem services must be rewarded for those services, along with any rewards they receive from markets for the commodities they produce. This recognises that markets have so far failed to adequately reward the delivery of ecosystem services and attempts to commodify such services have hitherto proved inadequate to act as incentives for a more balanced stewardship of the land. Repurposing subsidies that currently have perverse outcomes is only one way to approach this market failure.

A prerequisite for achieving such transformation is the revision of the metrics we use to evaluate performance. Metrics that are blind to system performance must be discarded in favour of those that are not. We need comprehensive performance metrics, covering all the impacts of agriculture and food systems as the basis for rational decision-making. The performance of particular practices needs to be measured in relation to their purposes within a whole systems framing, not against narrow objectives. This may involve measuring quantities like crop yield, soil organic carbon content, or income from sale of products with consideration of the variability of performance across contexts. Practices are integrated within farms or livelihood systems, making the total factor productivity of farm enterprises or smallholder livelihoods a key integrated metric at household level. At landscape scale, the concept of land equivalent ratio can be applied to ecosystem services to derive a multifunctionality metric that sums the effects of agriculture on all provisioning, regulating and cultural ecosystem services weighted by their relative societal value, in the place they are provided. For whole food systems, an ecological footprint represents an integrated metric that accounts for what people consume and how it is produced, processed, transported and used.

Finally, it will require an omnibus policy review to ensure that the 'sustainable whole' we so desire for Indian agriculture is much more than the sum of its existing and proposed parts. To guide the review and transformation process we offered RENEWAL and some key targets (Table 3). Based on this review, and understanding the need for context specific innovations, we should be able to develop transformation plans and approaches that are inclusive and likely to deliver productive and resilient outcomes. Many of the elements of these plans have already been identified in previous sections. What remains now is to take up the work before the crisis is further exacerbated. A transformation of farming and food systems that builds in the hopes and aspirations of India's youth and women is the beacon that any reform must follow, even as it seeks to meet the Sustainable Development Goals.

Acknowledgements Parts of this paper were developed with inputs and insights from Alexander Mueller, Vijay Kumar Thallam, Sunil Londhe, Patrick Worms, Fergus Sinclair and Thomas Zschocke to whom the authors owe a debt of gratitude.

Annexure 1

Key initiatives of the Government of India relevant to agricultural transformation:

1. ***Atmanirbhar Bharat Abhiyaan* (ABA) (self-reliant India)** is the vision of new India announced by the Hon'ble Prime Minister Shri Narendra Modi on May 12, 2020. In agriculture, ABA aims to strengthen Infrastructure, Logistics, Capacity Building, Governance and Administrative Reforms. The components of the ABA- Agriculture are:

    a. **Agriculture Infrastructure Fund (AIF)—**From the year 2020–21 until 2029–30 the fund will aim to create infrastructure at the farm gate.

b. **The National Beekeeping and Honey Mission (NBHM)—**INR 500 crore from 2020–2021 to 2022–2023 is allocated for three mini missions that will promote and develop scientific beekeeping in the country

2. **Farmer Producer Organisation (FPO)**: Farmer-Producers' Organisations can now be incorporated/ registered either under Part IXA of Companies Act or under Co-operative Societies Act of the concerned States and formed for the purpose of leveraging collectives through economies of scale in production and marketing of agricultural and allied sector.
3. **Forecasting Agricultural Output using Space, Agro-Meteorology and Land Based Observations (FASAL)**: The objective of the Scheme is to provide multiple-in-season forecast based on Agromet, Econometric and Remote Sensing based methodology. Multiple forecasts of 11 major crops are envisaged at National/ State/District level depending on status of technology available.
4. **National e-Governance Plan in Agriculture (NeGPA)**—Its aim is to achieve rapid development in India through use of Information and Communication Technology (ICT) for timely access to agriculture related information for farmers. In agriculture, availability of real time information at the correct time is a continuous challenge. National e-Governance Plan in Agriculture (NeGPA) was initially launched in seven selected States namely, Assam, Himachal Pradesh, Jharkhand, Karnataka, Kerala, Madhya Pradesh and Maharashtra in the last quarter of 2010–11. This Scheme has subsequently been extended in the 2nd Phase to cover all the States and 7 UTs from 2014 to 15.

a. **MKisan-Use of basic mobile telephony**: The Department has developed a portal—mKisan (mkisan.gov.in), where around 5.2 crore farmers are registered and experts/ scientists of different departments like India Meteorological Department (IMD), Indian Council of Agricultural Research (ICAR), State Governments, State Agriculture Universities send information to farmers in 12 local languages on a regular basis. More than 2,462 crore SMSs have been sent through mKisan since its inception in 2013.
b. **Farmers' portal** (www.farmer.gov.in): Farmers' Portal is a one stop shop for farmers where a farmer can get relevant information on a range of topics including seeds, fertiliser, pesticides, credit, good practices, dealer network, availability of inputs, agromet advisory etc. This centralised repository is the backbone of all mobile apps and SMS advisories. This portal provides information across all stages of crop management right from sowing of seeds till post harvesting. There is now a dedicated TV Kisan channel to provide round the clock information on agriculture to all stakeholders.
c. **Development of Mobile Apps**: Various mobile apps have been developed for farmers. Such as *Kisan Suvidha* that provides information on critical parameters—weather, input dealers, market price, plant protection, expert advisories, Soil Health Card, cold stores and godowns, crop insurance, government schemes, etc.

5. **Mission for Integrated Development of Horticulture (MIDH)**: This mission supports the holistic growth of the horticulture sector covering fruits, vegetables, root & tuber crops, mushrooms, spices, flowers, aromatic plants, coconut, cashew and cocoa. MIDH consists of 5 schemes on Horticulture:

    a. National Horticulture Mission (NHM),
    b. Horticulture Mission for North East and Himalayan States (HMNEH),
    c. National Horticulture Board (NHB),
    d. Coconut Development Board (CDB),
    e. Central Institute of Horticulture (CIH), Nagaland.

6. **National Food Security Mission (NFSM)**: Currently, NFSM is being implemented in identified districts of 28 states and 2 Union Territories (UTs) viz. Jammu and Kashmir and Ladakh in the country. It focuses on Rice (also with a special action plan and linked to the Bringing Green Revolution to Eastern India scheme for rice-based systems), Wheat, Pulses, Coarse Cereals (including maize and barley), Nutri-Cereals (including jowar, bajra, ragi and other millets—also with a special action plan), Oilseeds and Oilpalm and last but far from least: **Tree Borne Oilseeds**
7. **National Mission for Sustainable Agriculture (NMSA) & *Pradhan Mantri Krishi Sinchayee Yojana* (PMKSY)—**with some key centrally sponsored schemes:

    - **Rainfed Area Development (RAD)**: This adopts an area-based approach for development and conservation of natural resources through promoting Integrated Farming Systems (IFS).
    - **Sub Mission on Agro-Forestry (SMAF)**: The Sub-Mission on Agroforestry (SMAF) has been launched in 2016–17 to encourage and expand tree plantation on farmland, with the motto of "Har Medh Par Ped", along with crops/cropping system. At present, the scheme is being implemented in 20 States.
    - **National Bamboo Mission (NBM)**: 14 Ministries/Departments are associated in various aspects as per their allocation of business. The scheme is being implemented in 23 States.
    - **Integrated Nutrient Management (INM) and Organic Farming: Soil Health Management (SHM)**: SHM aims at promoting Integrated Nutrient Management (INM) through judicious use of chemical fertilisers
    - ***Paramparagat Krishi Vikas Yojana* (PKVY)**: The PKVY Scheme facilitates marketing of organic produce is implemented in a cluster mode with min. 20 ha size but more ideally in cluster sizes of 1,000 ha in plains areas and 500 ha in hilly areas.

    The following sector-based initiatives are worth mentioning here additionally:
    - Soil and Land Use Survey of India (SLUSI)
    - National Rainfed Area Authority (NRAA)

- **Mission Organic Value Chain Development for North Eastern Region (MOVCDNER)**: The scheme aims at development of certified organic production in a value chain mode to link growers with consumers and to support the development of the value chain starting from inputs, seeds, certification and creation of facilities for collection, aggregation, processing, marketing and brand building initiatives in eight states. It incorporates the National Centre of Organic Farming (NCOF) and the Central Fertilizer Quality Control and Training Institute (CFQC&TI).

8. ***Pradhan Mantri Kisan Maandhan Yojana* (PM-KMY)**: PM-KMY is an old-age pension scheme for all Small and Marginal Farmers (SMFs) in who hold land in the country, aiming to provide an assured monthly pension of INR 3,000/- irrespective of gender, on attaining the age of 60 years.
9. **National Crop Insurance Programme (NCIP)** The insurance schemes currently under implementation are the Pradhan Mantri Fasal Bima Yojana (PMFBY) and the Restructured Weather Based Crop Insurance Scheme (RWBCIS).

   a. **Coverage of Women Farmers under PMFBY**: out of the total coverage under the scheme approximately 15–16% women farmers were enrolled under the scheme every year. There has been 0.7% increase in the enrolment of Loanee women farmers and a significant increase in the enrolment of Non-Loanee women farmers amounting to approximately 56% increase from *kharif* 18 to *kharif* 19 demonstrating favourable attitude among women farmers towards PMFBY.
   b. **Coconut Palm Insurance Scheme (CPIS)**: The Coconut Palm Insurance Scheme (CPIS) has been implemented since the year 2009–10 in selected areas of Andhra Pradesh, Goa, Karnataka, Kerala, Maharashtra, Orissa and Tamil Nadu.

10. ***Gobardhan* scheme**: Galvanising Organic Bio-Agro Resources Dhan (GOBAR-DHAN) scheme is under the Ministry of Jal Shakti. The scheme is implemented under the Swachh Bharat Mission Gramin-Phase 2, by the Department of Drinking Water and Sanitation under the Jal Shakti ministry. The scheme aims to augment income of farmers by converting biodegradable waste into compressed biogas (CBG).
11. ***Rashtriya Krishi Vikas Yojana* (RKVY)**: RKVY scheme was initiated in 2007 as an umbrella scheme for ensuring holistic development of agriculture and allied sectors. The scheme incentivises States to increase public investment in Agriculture and allied sectors.

References

Abdurrahman, M. I., Chaki, S., & Saini, G. (2020). Stubble burning: Effects on health and environment, regulations and management practices, *Environmental Advances, 2*, ISSN 2666–7657 (available at https://doi.org/10.1016/j.envadv.2020.100011).

Asbjornsen, H., Hernandez-Santana, V., Liebman, M. Z., Bayala, J., Chen, J., Helmers, M. J., Ong, C. K., & Schulte, L. A. (2012). Targeting perennial vegetation in agricultural landscapes for enhancing ecosystem services. *Renewable Agriculture and Food Systems*. https://doi.org/10.1017/S1742170512000385

Béné, C., Oosterveer, P., Lamotte, L., Brouwer, I. D., de Haan, S., Prager, S. D., Talsma, E. F., & Khoury, C. K. (2019). When food systems meet sustainability: Current narratives and implications for actions. *World Development, 113*, 116–130. https://doi.org/10.1016/j.worlddev.2018.08.011

Biovision Foundation for Ecological Development & IPES-Food. (2020). Money Flows: What is holding back investment in agroecological research for Africa? Zurich, CH: Biovision Foundation for Ecological Development & Brussels: International Panel of Experts on Sustainable Food Systems. Retrieved August 31, 2020, (available at http://www.ipes-food.org/_img/upload/files/Money%20Flows_Full%20report.pdf).

Brainerd, E., & Menon, N. (2014). Seasonal effects of water quality: The hidden costs of the green revolution to infant and child health in India. *Journal of Development Economics, 107*, 49–64. https://doi.org/10.1016/j.jdeveco.2013.11.004

Caron, P., Loma-Osorio, G., Nabarro, D., Hainzelin, E., Guillou, M., Andersen, I., Arnold, T., Astralaga, M., Beukeboom, M., Bickersteth, S., Bwalya, M., Caballero, P., Campbell, B. M., Divine, N., Fan, S., Frick, M., Friis, A., Gallagher, M., Halkin, J. -P., & Verburg, G. (2018). Food systems for sustainable development: Proposals for a profound four-part transformation. *Agronomy for Sustainable Development, 38*. https://doi.org/10.1007/s13593-018-0519-1

Census of India. (2011). 2011 Census Data. *Chapter 2 Population Composition*. Accessed October 10, 2021 at https://censusindia.gov.in/2011-common/censusdata2011.html

CFS. (2021). Making a difference in food security and nutrition. The CFS Voluntary Guidelines on Food Systems and Nutrition. Forty-seventh session committee on food security, February 8–11, 2021, FAO, Rome.

Chand, R. (2016). *Why doubling farmers' income by 2022 is possible* (p. 15). Indian Express.

Chand, R., Saxena, R., & Rana, S. (2015). Estimates and analysis of farm income in India: 1983–84 to 2011–12, *Economic and Political Weekly, L*(22), 139–145.

CSTEP. (2019). *Life cycle assessment of ZBNF and Non-ZBNF*. A study in Andhra Pradesh. Center for Study of Science, Technology and Policy. Accessed on October 10, 2021 at https://apcnf.in/wp-content/uploads/2020/05/LIFE-CYCLE-ASSESSMENT-OF-ZBNF-AND-NON-ZBNF-A-STUDY-IN-ANDHRA-PRADESH.pdf

CWC. (2019). *Status of trace & toxic metals in Indian rivers*. River Data Compilation-2 Directorate, Central Water Commission, Department of Water Resources, River Development & Ganga Rejuvenation, Ministry of Jal Shakti.

DACFW. (2018). *Report of the committee on doubling farmers' income*. Department of Agriculture, Cooperation and Farmers' Welfare, Ministry of Agriculture & Farmers' Welfare. Accessed October 10, 2021 at https://agricoop.nic.in/en/doubling-farmers

Dangar, S., Asoka, A., & Mishra, V. (2021). Causes and implications of groundwater depletion in India: A review. *Journal of Hydrology, 596*, ISSN 0022–1694, (available at https://doi.org/10.1016/j.jhydrol.2021.126103).

Das, S., Chatterjee, A, & Pal, T. K. (2020). Organic farming in India: A vision towards a healthy nation. *Food Quality and Safety, 4*(2), 69–76, (available at https://doi.org/10.1093/fqsafe/fyaa018).

DES. (2020). *Agricultural statistics at a glance 2019*. Directorate of Economics and Statistics, Department of Agriculture, Cooperation and Farmers' Welfare, Ministry of Agriculture and Farmers' Welfare.

Dhyani, S. K., Kareemulla, K., & Ajit, H. A. K. (2009). Agroforestry potential and scope for development across agro-climatic zones in India. *Indian Journal of Forestry, 32*, 181–190.

FAO. (1999). *Organic agriculture*. Item 8 of the Provisional Agenda. Commission on Agriculture 15th Session, Rome, January 25–29, 1999. Accessed on October 10, 2021 at (available at http://www.fao.org/3/X0075e/X0075e.htm).

FAO. (2018). *The 10 elements of agroecology*. Guiding the transition to sustainable food and agricultural systems. FAO, Rome. Accessed on 10/10/2021 at (available at https://www.fao.org/documents/card/en/c/I9037EN/).

Ghosh, N. C., Scientist, F., & Singh, R. D. (2010). *Groundwater Arsenic contamination in India: Vulnerability and scope for remedy*. National Institute of Hydrology, Roorkee – 247 667, Uttarakhand, India. Accessed October 10, 2021 at (available at http://cgwb.gov.in/documents/papers/incidpapers/Paper%208%20-%20Ghosh.pdf).

Gupt, S., Agrawal, P., & Ameen, M. (2021). *Comprehensive pilots*. National Coalition for Natural Farming. Accessed October 10, 2021 (available at https://drive.google.com/file/d/1NyptXPEN82NywhPXm9isaz2lkpab2aPQ/view?usp=sharing).

HLPE. (2019). *Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition.* A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome

IDSAP. (2021). *Impact assessment of APCNF (Andhra Pradesh Community Managed Natural Farming) Consolidated-2019–20 Report*. Institute for Development Studies AP, Andhra University, Visakhapatnam Accessed online 10/10/2021 (available at https://apcnf.in/wp-content/uploads/2021/09/CESS-IDS-2019-2020-Report.pdf).

Kerr, R. B., Madsen, S., Stüber, M., Liebert, J., Enloe, S., Borghino, N., Parros, P., Mutyambai, D. M., Prudhon, M., & Wezel, A. (2021). Can agroecology improve food security and nutrition? A review. *Global Food Security, 29*,100540, ISSN 2211–9124, (available at https://doi.org/10.1016/j.gfs.2021.100540)

Kramer, A., Weigelt, J., Müller, A., & Blasingame, S. (2020). *From the bottom up: Creating an enabling environment for sustainable land management*. A community-driven investment guide for the UN decade on Ecosystem Restoration (TMG Guide). Berlin: TMG Research gGmbH. Retrieved September 27, 2020 (available at https://globalsoilweek.org/wp-content/uploads/2020/05/Investment-Guide.pdf).

Nelson, A. R. L. E., Ravichandran, K., & Antony, U. (2019). The impact of the Green Revolution on indigenous crops of India. *Journal of Ethnic Foods, 6*, 8. https://doi.org/10.1186/s42779-019-0011-9

NHM. (Undated). *Organic farming system—an integrated approach for adoption under National Horticulture Mission.* National Horticulture Mission, Government of India—Department of Agriculture and Cooperation Ministry of Agriculture, New Delhi. Online: (available at https://midh.gov.in/technology/Organic_Management_NHM.pdf).

NITI Aayog. (2020). *Agroecology and natural farming could accelerate inclusive economic growth in India.* Posted On: 01 JUN 2020 2:49PM by PIB Delhi. Accessed October 10, 2021 (available at https://pib.gov.in/PressReleasePage.aspx?PRID=1628285)

NSO. (2021). *Situation assessment of agricultural households and land holdings of households in Rural India, 2019*. National Statistics Office, Ministry of Statistics and Programme Implementation, Government of India. Accessed October 10, 2021 (available at http://mospi.nic.in/sites/default/files/publication_reports/Report_587m.pdf).

Pingali Prabhu, L. (2012). Green Revolution: Impacts, limits, and the path ahead. *PNAS, 109*(31). 2302–12308 (available at https://doi.org/10.1073/pnas.0912953109).

Planning Commission. (2001). *Report of the task force on greening India for livelihood security and sustainable development*. Accessed October 10, 2021 (available at https://niti.gov.in/planningcommission.gov.in/docs/aboutus/taskforce/tk_green.pdf).

Prabhu, R., Lawry, S., Colmey, J. (2021) *Creating a new relationship with nature through a 'stewardship economy*'. Forest News. CIFOR. Accessed on October 13, 2021 (available

at https://forestsnews.cifor.org/74803/creating-a-new-relationship-with-nature-through-a-stewardship-economy?fnl=en).
Prabhu, R., Barrios, E., Bayala, J., Diby, L., Donovan, J., Gyau, A., Graudal, L., Jamnadass, R., Kahia, J., Kehlenbeck, K., Kindt, R., Kouame, C., McMullin, S., van Noordwijk, M., Shepherd, K., Sinclair, F., Vaast, P., Vågen, T. G., Xu, J. (2015). Agroforestry: Realizing the promise of an agroecological approach. In: FAO. *Agroecology for Food Security and Nutrition: Proceedings of the FAO International Symposium* (pp 201–224).
PSA. (2019). Report on policies and action plan for a secure and sustainable agriculture. Principal Scientific Adviser to the Government of India. (available at https://static.psa.gov.in/psa-prod/publication/Report%20of%20Policies%20and%20Action%20for%20Agriculture.pdf) Accessed October 10, 2021.
Rosenstock, S., Mayzelle, T. M., Nictor, N., & Fantke, P. (2021). Climate impacts of natural farming: A cradle to gate comparison between conventional practice and Andhra Pradesh community natural farming. *Journal of Agriculture and Allied Sciences.* https://doi.org/10.31220/agriRxiv.2020.00013
Rural Development Report. (2019). Creating opportunities for rural youth. *International Fund for Agricultural Development*. 294 p.
Sekhri, S., Shastry, G. K. (2020). *The curse of plenty: Early Childhood roots of the rise in chronic disease.* Working Paper. Accessed October 10, 2021 (available at http://academics.wellesley.edu/Economics/gshastry/sekhri%20and%20shastry%202020.pdf).
Shankarnarayan, K. A. (1984). Influence of Prosopis cineraria and Acacia Nilotica on soil fertility and crop yield. In K. A. Shankarnarayan (Ed.), *Agroforestry in Arid and Semiarid Zones* (pp.59–66). Central Arid Zone Research Institute (CAZRI) Publication No. 24.
Sharda, V. N., Ojasvi, P. R., Mandal, D. (2017). *Mitigating land degradation due to water erosion.* NAAS Policy Paper 88. National Academy of Agricultural Sciences.
Sinclair, F., Wezel, A., Mbow, C., Chomba, C., Robiglio, V., & Harrison, R. (2019). *The contribution of agroecological approaches to realizing climate-resilient agriculture (Background Paper).* Rotterdam & Washington, DC: Global Commission on Adaptation. Retrieved August 31, 2020, from (available at https://cdn.gca.org/assets/2019-12/TheContributionsOfAgroecologicalApproaches.pdf).
Singh, K. S., & Lal, P. (1969). Effect of Prosopis cineraria and Acacia arabica trees on soil fertility and profile characteristics. *Annals of Arid Zone, 8*, 33–36.
The Economics of Ecosystems and Biodiversity (TEEB). (2018). *Measuring what matters in agriculture and food systems: A synthesis of the results and recommendations of TEEB for Agriculture and food's scientific and economic foundations report*. Geneva: UN Environment.
UNFCCC. (Undated). *India's intended nationally determined contribution.* Accessed online on October 10, 2021 at (available at https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/India%20First/INDIA%20INDC%20TO%20UNFCCC.pdf).
UNFPA. (2014). *A Profile of Adolescents and Youth in India.*
UNFSS. (2021). *Nearly 300 commitments from civil society, farmers, youth and Indigenous peoples and member states highlights Summit's inclusive process to accelerate action.* UN Food Systems Summit (available at https://www.un.org/en/food-systems-summit/news/nearly-300-commitments-civil-society-farmers-youth-and-indigenous-peoples-and Accessed October 10, 2021)
Vlek, C. (2009). A precautionary-principled approach towards uncertain risks: Review and decision-theoretic elaboration. *Erasmus Law Review, 2*, 129–170. 10.553/ELR221026712009002002003.
Wezel, A., Herren, B. G., Kerr, R. B., et al. (2020). Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. *Agronomy for Sustainable Development, 40* (available at https://doi.org/10.1007/s13593-020-00646-z).
World Agroforestry. (2021). *A road less travelled by migratory farmers of Odisha: Innovative agroforestry practices.* Department of Soil Conservation & Watershed Development, Government of Odisha and World Agroforestry (ICRAF), New Delhi, India (available at http://outputs.worldagroforestry.org/cgi-bin/koha/opac-detail.pl?biblionumber=43589; https://worldagroforestry.org/publication/road-less-travelled-migratory-farmers-odisha-innovative-agroforestry-practices)
Youth in India. (2017). *Central statistics office, ministry of statistics and programme implementation.* Government of India. 86p.

Science, Technology and Innovation

R. B. Singh, R. S. Paroda and Malavika Dadlani

1 Introduction

India has been successful in building a massive ecosystem of science, technology and innovation (STI) since independence in 1947. Also, globally, STI continuum has been the main driver of agricultural growth, development and transformation of national socio-economic and agroecological milieus, and evolving dynamically to meet the fast changing development goals. Today, in the midst of the unprecedented COVID-19 pandemic, the world is challenged to meet the new and emerging health and nutrition demands along with the United Nations' Sustainable Development Goals—Agenda 2030 (UN, 2015). In this scenario, an effective STI system will be needed to disruptively transform Agriculture-Food Systems to achieve the veritable goal—leaving no one behind—especially youth and women.

The foremost challenge to the STI in India and other agriculturally-important developing countries is the increase in number of hungry and malnourished people. One-third of the humanity is malnourished and nearly one-fourth of the world's children are stunted—annually costing about 6–10% of GDP. Nearly one-fourth of the world's hungry, one-third of the world's stunted children and half of the world's wasted children are from India (Table 1: FAO, 2018).

In India, STI-led Rainbow Revolution transformed the country from 'ship-to-mouth' status to the 'Right-to-Food Bill' situation, with formidable foodgrain export and buffer stocking, making it the second largest agrarian economy in the world.

R. B. Singh (✉)
National Academy of Agricultural Sciences, New Delhi, India
e-mail: rbsingh40@gmail.com

R. S. Paroda
Trust for Advancement of Agricultural Sciences, New Delhi, India

M. Dadlani
Indian Society for Seed Technology, New Delhi, India

R. Chand et al. (eds.), *Indian Agriculture Towards 2030*,
India Studies in Business and Economics,
https://doi.org/10.1007/978-981-19-0763-0_8

Table 1 Number of undernourished people, 2017 (million)

Geographic entity	Number of undernourished people	Number of children under 5 wasted	Number of children under 5 stunted
World	821	51	151
India	196	26	47
China	125	1.6	6.9
Asia	515	35	84
Africa	257	14	59

Source www.fao.org/state-of-food-security-nutrition-in-the-world

Accounting for 18% of the world's population, with only 2.3% of the world's land and less than 4% of global freshwater, the country's STI effort must be geared to produce ***More from Less for More*** without further damaging the agroecological system and accentuating water and carbon footprints.

STI for Development (STI4D) must break the co-existence of food surplus and wastage, and high incidences of hunger and malnutrition; check the high inequities, trade and market distortions; halt unabated depletion of natural resources; stop the accelerated emergence of infectious diseases and aggressive pests; and, of course mitigate the ever-aggravating climate change volatilities posing major challenges to the Indian agriculture today. Another major challenge is to break the asymmetry of low and poorly planned investment in agricultural research, education and technology generation and transfer. This, despite the fact that investment in agriculture is at least three times more effective than in other sectors in alleviating hunger, under-nutrition and poverty (World Bank Group, 2020). Hence, moving beyond research and production as usual, an unusual science-technology-innovation continuum must be adopted to meet these challenges, and create zero hunger India (Singh, 2015). Ramesh Chand (2019), Member, NITI Aayog, emphasized the importance of advancement in science-led technology, enhanced role of private sector, liberalized output and active land lease market and increased input use efficiency along the value chain for transforming Indian agriculture.

Committed to demand-driven and technology-led revolution to transform agriculture, this chapter discusses the following sub-themes of science, technology and innovation (STI) towards transforming agriculture-food system to meet the veritable development goals: (i) paradigm shift in agricultural research to address new challenges, (ii) frontier technologies, IPR issues and their application, (iii) indigenous technical knowledge in agriculture, (iv) innovative technology dissemination options, (v) innovations outside agriculture influencing agriculture, (vi) rejuvenating agricultural education system and (vii) pathways from research to innovation for impact.

2 Paradigm Shift in Agricultural Research and Technology to Address New Challenges and Opportunities

While STI have continuously been transforming the agriculture-food-systems in the past, keeping in mind short, medium and long-term perspectives, the following major paradigm shifts in agricultural research are needed for making these more efficient, knowledge-based, inclusive and sustainable, in providing solutions to the new and emerging challenges, and capturing uncommon opportunities.

2.1 Smallholder Farmers at the Centre Stage

Smallholder and marginal farmers, accounting for nearly 86.25% of Indian farmers, 47.38% of the cultivated land and over 50% of the total agricultural production, are vital not only for India's agrarian economy (10th Agriculture Census 2015–16), but also for achieving alleviation of hunger and poverty. Over 50% of the smallholders, referred to as sub- marginal farmers, possess less than 0.5 ha land. Despite their higher per unit productivity, the extremely small and fragmented holdings are economically non-viable, swelling the ranks of hungry and poor. The biodiverse, predominantly crop-livestock integrated farming in India is the key to ensure resilience to climate change and sustainability of smallholder farming agroecologies. Recognizing that access of smallholders to technology, land, other production resources, credit and capital is limited, a holistic pro-smallholder approach and robust policy initiatives are called for. Augmented by new farm reform policies (aggregation of land through contract farming, diversification of cropping system and remunerative markets as per new Farm Bills, 2020, GoI), effective technologies and innovations are aimed at mitigating vagaries of climate change and enhancing farmers' net income, while encouraging entrepreneurship and off- farm and non-farm employment.

2.2 Nutritional Security to Be a Key Goal of Agriculture

Keeping in view the high incidence of hunger and under-nutrition in India vis-à-vis a fact that the country accounts for 20% of obese people in the world (Ahirwar & Mondal, 2019), ASTI (Agriculture Science, Technology and Innovation) needs to shift focus on achieving comprehensive nutritional security than just food security. This may be achieved through genetic improvement, bio-fortification, enhanced protein and other quality factors and/or value addition through post-harvest innovations. Decentralized research approaches will be needed for diverse ecologies, food preferences and market options, which call for region-specific prioritization of research, with due consideration to various socio-economic parameters. For extenuating the emergence of new infectious diseases and aggressive pests, that can often be transmitted along the entire agriculture-food system, from microbe to man, a 'One Health' concept comprising healthy soils—healthy plants—healthy animals—healthy people—healthy environment, would be the preferred approach (Singh, 2019).

In the post-Green Revolution period, agricultural research in India gradually moved from crop-based to farming system-based agriculture integrating horticulture, livestock, poultry and fisheries as essential components to achieve sustainable food and nutritional security and to maximize farm income. For the economic and nutritional security of a largely vegetarian population, dairy animals are of prime importance; and to improve their productivity and climate resilience, a two-pronged approach will be required—strengthening the availability of superior germplasm and enhancing fertility through biotechnological augmentation of reproduction (NDRI, Vision 2030, ndri.res.in/design/document/vision/pdf). Besides expanding the area and production by introducing better production technologies and genetically improved varieties of horticultural crops and breeds of livestock including the small meat animals, particularly in the northeastern region (NER), and poultry and fishes, the present focus needs to be demand-driven, changing from the 'Farm to Fork' approach to the 'Fork to Farm' one to ensure efficient marketing and better price for the farmers (Paroda, 2019a).

The efforts to make this happen comprise inter-disciplinary collaborations in developing innovative production and processing technologies, including nutraceuticals and fortified nutri-foods; cold chains involving refrigerated van using conventional and non-conventional energy sources, and necessary policy support to agro-industries, and all will play critical roles. COVID-19 pandemic generated considerable public awareness about the nutritional benefits of many indigenous herbs and seed and non-seed spices. Wild food plants (WFPs) have been a vital component of food and nutritional security for centuries. Recently, India and several other countries reported on the widespread and regular consumption of WFPs, particularly by rural and indigenous communities and in urban areas also. These would open new business opportunities for small farm holders. However, technological advancements and better extension would be required for better shelf life, food safety and value addition of these products. Hence, Research, Science, Technology, Innovation (RSTI) framework would need to play a bigger role encompassing six-dimensions of food security: availability, access, utilization, stability, agency and sustainability. Considering that the majority of the events in agricultural sector are influenced by events occurring in (i) bio-physical and environmental, (ii) technology, (iii) innovation and infrastructure, (iv) economic and market, (v) political and institutional, (vi) socio-cultural and (vii) demographic domains (FAO, 2020), a paradigm shift is needed to create an agricultural RSTI system, which is demand-driven, but farmer-centric, decentralized and structured on a bottoms-up, participatory, inter-sector and multi-disciplinary approach to provide variable solutions to diverse problems along the entire value chain.

2.3 Value Chain Management and Prevention of Food Losses

Scientific enrichment and management of value chain for agricultural commodities are urgently needed as these are globally changing rapidly in response to disruptive changes in agricultural and food standards influenced by dynamic public and private requirements on food quality, safety, ethical and environmental aspects. WTO notifications on new Sanitary and Phyto Sanitary (SPS) measures are fast changing, which ought to be internalized in national regulations. It is hoped that food processing industries (FPIs) will grow fast, especially in rural areas, and national system will provide integrated solutions to support the knowledge management, trade, collaborative ICT solutions, innovations, risk management and regulatory measures to all stakeholders along value chains.

Recalling that “a grain saved is a grain produced” and “unsafe food is no food”, “zero wastage of food” is one of the five pillars of the Global Zero Hunger Challenge Programme. According to the UNDP, up to 40% of the food produced in India is wasted and 50% of all food across the world meets the same fate, never reaching the needy. In India post-production losses, especially of perishables and semi-perishables like milk, meat, fish, fruit and vegetables, range from 18–25% amounting to INR 50,000 crore (INR 500,000 million) annually (*The Economic Times*, 28 Feb 2019). About 50% of these losses are preventable using suitable post-harvest processing technologies. Keeping in view the growing market of processed foods, the future ASTI has to offer innovative options to increase better nutrition and profitability through processing and value addition all along the value chain besides generating new employment opportunities.

2.4 Climate Smart Agriculture (CSA)

Indian agriculture-food system economy is greatly prone to climate change consequences. As India is projected to be one of the most negatively impacted countries by the climate change (Table 2), the ASTI efforts are needed to negate the impacts of climate volatilities, and also to create CSA endowed with sustainably enhanced productivity, resilience to climate change stresses (adaptation) and mitigation of climate change. A paradigm shift to imbibe interdisciplinary, participatory and international collaborative approach can address the multiple challenges caused by climate change while sustaining the desired economic growth (Aggarwal et al., 2018; Singh, 2013, 2014).

Table 2 Projected changes, considering 2013–14 as the baseline, in agricultural productivity from climate change at 2050

Country	Percentage change
Australia	−17
Canada	−1
United States of America	−4
China	−4
India	−25
Brazil	−10
European Union	−4
Least developed countries	−18

Source IPCC, 2014

2.5 Greening the Growth

The ASTI systems developed during the Green Revolution and Post-Green Revolution eras could not be judiciously adopted, leaving serious yield gaps, low total factor productivity and declining benefit-cost ratios. With mere 36–40% water use efficiency, India is predicted to become 'water scarce' before 2030 (NITI Aayog, 2018). With widespread deficiency of NPK and the increasing deficiencies of Zn, Bo, Fe, Mn and S, the nutrient use efficiency is only around 36–40% for N and about 15% for P. Similarly, constant mining of K is distorting mineralogical makeup, resulting in an irreversible deterioration of soil health, which already suffers from low organic carbon content. Achievement Gap Advisory Panel (AGAP) Report (UNAID, 2014) cautioned that with the business as usual only 59% of India's demand of food and agricultural production will be met by the year 2030. Obviously, a major paradigm shift adopting a soil, water and biodiversity-centric approach, harnessing veritable physiological and biochemical attributes, is required to increase and sustain agriculture-food system productivity and growth that conserves natural resources and mitigates climate change, moving from Green to Evergreen Revolution to Evergreen Economy (Singh, 2011; Swaminathan, 2007).

2.6 From Subsistence to Commercial Agriculture

Recalling the country's pledge of Doubling Farmers' Income by 2022/23, a USD 5 Trillion Economy by 2024/25 and Alleviating Wide Inequalities (farmers' average income being one- fourth of that of non-farmers), farming must be treated as an enterprise. Good post-production technologies, robust entrepreneurship initiatives and establishment of agro-industries in rural areas should foster economic and employment security and attract youth in agriculture-food systems, thus harvesting India's huge demographic dividend and achieving agrarian transformation.

2.7 From Green Revolution to Gene Revolution

The classical plant breeding uses deliberate interbreeding (crossing) of closely or distantly related species to produce new crops and varieties with desirable properties. Plants are crossed to introduce traits/genes from a particular variety into a new genetic background. In this, highly heritable oligo genes and exploitation of additive and dominance gene effects and interactions, led to the development of short stature, input-responsive, high yielding varieties (HYVs), often resistant to common diseases and pests, which ushered in the Green Revolution in the country especially in wheat, rice, maize, pearl millet and sorghum. Molecular breeding including transgenics and marker-assisted selection (MAS)-based gene pyramiding, brought incremental as well as transformational genetic gains in the last 20 years.

Genomics and gene editing must be adopted as preferred technologies for precision breeding (Vats et al., 2019). However, to do so, a science-based policy and well defined guidelines need to be placed on priority. In the new era of genomics, phenomics, proteomics and other omics – molecular breeding, the availability of high quality reference genomes of crop plants accelerated the discovery of genes, quantitative trait locus (QTLs) and DNA markers linked to the traits of agronomic importance. This is now being routinely applied in MAS of crop varieties, including those of horticultural species, for increased selection efficiency. The genomic selection approach will be further enriched by technologies haplotype-based breeding, single cell sequencing, Drop Synth technique for synthesizing large genetic libraries etc. Innovative approaches, such as apomictic F1 seed production, now a distinct possibility, can revolutionize the exploitation of hybrid vigour. As horticulture attains high importance, genomics of coconut, mango, banana, aonla, pointed gourd, tuber crops etc. need greater attention. In view of diminishing water availability, development of improved varieties/hybrids for dryland/arid horticulture along with appropriate cultivation technology will be a priority.

In livestock, genome editing has high prospect of enhanced prolificacy and reproductive performance, improved health, increased feed utilization and growth rate, carcass composition, improved milk production and or composition and increased disease resistance (Bharati et al., 2020). For instance, in pigs, resilience to African swine fever virus, a deadly disease, was achieved through gene editing. Further, using CRISPR/Cas, the generated pigs, were completely protected against porcine reproductive and respiratory syndrome (PRRS) infection. Using this technology in several livestock breeding populations, frequencies of favourable alleles were greatly increased while deleterious alleles removed. Gene-edited livestock (pigs, goats and cattle), developed jointly by three USA and one UK universities, for the first time, were rendered "surrogate dads", meaning that the sperm they produce holds only the genetic material of donor animals, paving the way for breeding elite livestock with certain desirable traits to boost food production (*The Times of India*, 19 September 2020).

2.8 Digital Solutions and Artificial Intelligence (AI) for Evergreen Revolution

Using Big Data Analytics, we can create decision support systems at various levels, including weather forecasting and efficient management of water, pest and nutrient. Linked with satellite imagery, this can also help in the future predictions of produce and price. Importance of ICT for marketing, sales and pricing as seen in the response to e-NAM, is expected to attract and retain youth in agriculture. Comprehensive and reliable data resources are conducive to augment AI that can bring a paradigm shift by developing smart farming practices using IoT (internet of things) to address the uncertain issues with utmost accuracy that will enable farmers to do more with less, and also provide new business opportunities to youth as well. AI can also be used for high throughput plant phenotyping, monitoring of natural calamities and crop residue burning.

2.9 Attracting Youth and Empowering Women in Agriculture

Globally, there is an increasing concern about the generational gap in agriculture, the farmers are getting old, as the youth is not inclined to practice agriculture. Nations with motivated youth engaged in diverse, secondary and specialty agriculture, supported by enabling policies, have progressed well. India, with a median age of 29 years with largest population of youth (356 million between 10 and 24 years age group) in the world (United Nations, 2014) has only 5% of the rural youth engaged in agriculture though over 60% of the rural people derive their livelihood from faming and allied activities. Hence, a paradigm shift is needed from 'Youth as a Farmer' to *'Youth as Value Chain Developer and Agripreneur'*. Zonal platforms for Motivating and Attracting Youth in Agriculture (MAYA) may be established in different parts of the country to facilitate this shift.

The principle of 'Leaving no one behind' though requires closing the gender gap, the female farmers, representing more than a quarter of the world's population, remain invisible in policy and decision making at every level of agricultural development. They neither have equal rights nor access to assets, information, inputs and services. In addition, women face excessive work burden, much of which remains unrecognized and unpaid (ICAR, 2012; FAO, 2018; Paroda, 2018). The World Bank and FAO recognized that had women enjoyed same access to productive resources as men, they could easily boost production by 20–30% raising the overall agricultural output in developing countries by about 4% (Paroda, 2019b). Therefore, integrating a gender perspective into STI policies is necessary to effectively address the gender inequity and related socio-economic challenges.

2.10 Towards Precision Agriculture

Precision agriculture, which exploits modern tools, technologies and innovations, including genetically enriched seeds, nanotechnology, artificial intelligence (AI), drones, sensors, robots etc. is the way forward to achieve environmentally sustainable Evergreen Revolution. The approach recognizes site-specific differences within fields and adjusts management actions accordingly adopting the concept of *"doing the right thing in the right place at the right time"*. Moving forward, this will be the new normal, addressing: (i) increased land and labour productivity by means of gender neutral technologies, (ii) intensification, diversification and off-farm employment, (iii) institutional arrangement to equitable rights and (iv) balanced agroecological settings compatible with minimum risk (Gatzweiler & Von Braun, 2016).

2.11 Measure to Manage—Ensuring Effective Implementation Pathways

India is off-track in meeting the SDG 1 and SDG 2 of Agenda 2030, primarily owing to inadequate governance and implementation of the concerned projects/programmes, resulting in wide gaps in technology adoption, yield and income (Singh, 2019). The availability of comprehensive and quality data would help create science-based indicators Hunger Index, Human Development Index, Social Progress Index (SPI), Science Index etc. for effective monitoring and evaluation of intended outcomes and impact pathways as well as for ranking Agricultural Universities and institutions. Efficacy of the pathways from research to innovation for impact, as envisaged in the last section of the paper, should be assessed by using these indicators. The proposed system should be institutionalized to fix differentiated responsibility and accountability to help in adopting need-based mid-course corrections and alternative pathways to meet the targets.

3 Frontier Technologies, Intellectual Property Issues and Their Application

For accelerating agricultural GDP growth, reorientation of Agricultural Science, Technology and Innovation (ASTI) is required to focus on greater use of new science and scaling of innovations (Fan, 2013). The tackling of second generation challenges such as factor productivity decline, depleting natural resources, higher incidence of diseases and pests and increasing cost of inputs, in addition to the rising concerns of post-harvest losses, nutritional quality and safety of food, climate change, declining profits and above all the turbulence caused by COVID-19 pandemic, the use of frontier disruptive technologies and situation-specific innovations will be required to build diversified, secondary and specialty agriculture (TAAS, 2013). Establishment of appropriate regulatory machinery is needed for IPR and the ethical use of new technologies such as CRISPR/Cas-based gene editing, or release of second generation GMOs.

3.1 Innovations for Sustainable Agriculture and New Gains

The new argument is that there is a need to shift away from cereal-centric Green Revolution technology to diversified farming systems, which are more climate resilient and sustainable (Economic Survey, 2019). This needs to be supported by appropriate policies and programmes. Unlimited opportunities in unexplored frontiers of science exist to make new gains from application of STI for sustainable agricultural development. Important among these are: (i) improved plant varieties using precise molecular breeding and GM technologies; (ii) improved livestock breeds and fish culture; (iii) conservation agriculture; (iv) farm mechanization and precision agriculture; (v) solar power for small farm operations; (vi) integrated nutrient management (INM) and integrated pest management (IPM); (vii) more use of genuine biofertilizers and biopesticides; and (viii) post-production technology around value chain. The benefits of frontier technologies when scaled in a mission-mode are immense for increasing income of small holder farmers (Jat, 2017). Establishment of 'Climate Smart Villages', has resulted in adoption of climate resilient technologies resulting in increase in area of direct seeded rice (DSR) particularly in Haryana, Punjab, Odisha, Andhra Pradesh and Karnataka, which would also reduce burning of crop residues. Apart from institutional innovations and right policies, specific actions are needed for: (i) strengthening scientific manpower through more investment in R&D and by forging viable partnerships with other players in the public and private sectors, (ii) revisiting rules and regulations for speeding transfer of technology, including paid extension and (iii) fostering partnership with private sector for rapid commercialization of available technologies.

3.1.1 Genetic Resource Management and Crop Improvement

The importance of rich genetic resources in crop variety improvement cannot be over emphasized. Germplasm enhancement/pre-breeding using wide gene pools and molecular breeding techniques are to be given higher credence in evolving high yielding, nutritive, biotic and abiotic stress resistant, widely adapted and climate resilient crop varieties/hybrids suited for diverse agroecologies. Immediate steps are needed to characterize and evaluate the vast germplasm repository available in national institutes and use the same for genetic improvement. Hybrid technology capable of offering greater climate resilience, better yield and quality, is to be fully exploited to increase crop productivity. Newer approaches for hybrid seed production, including use of doubled haploidy, apomictic and two-line F1 seeds, should be actively promoted to render hybrid seed more affordable.

Cultivation of genetically modified (GM) crops, covering around 191.7 mha globally (http://www.isaaa.org/resources/publications/annualreport/2018/pdf/ISAAA-Accomplishment_ Report-2018) benefitted farmers through increased production and reduced use of costly inputs. India too has gained considerably through the release of Bt cotton, covering around 11 m ha benefitting millions of farmers (Reddy et al., 2014). It reduced the use of pesticides by almost 40% and doubled productivity, making India a leading cotton export nation fetching around USD 3 billion annually. Necessary policy decisions are needed for the release of GM varieties in soybean, rapeseed-mustard, maize, rice, potato, brinjal, tomato, etc., of course, without compromising bio-security, to sustainably enhance productivity, nutritional security and farmers' income (NAAS, 2011, 2016). Dispelling existing mistrust among some segments of the society on the regulatory system that deals with GM crops, requires transparent steps to establish a robust system to regulate GM and genetically edited crops. Science-based regulatory committees, such as the Review Committee on Genetic Manipulation (RCGM) and Genetic Engineering Appraisal (Approval) Committee (GEAC), should be chaired only by expert scientists.

Ensuring timely availability of quality seed of improved varieties/hybrids of crops to farmers to increase seed replacement rate (SRR) should be a national priority, for which both public and private sectors and farmers' organizations are to work in tandem. To ensure this, more realistic state-wise and crop-wise five-year rolling seed plans must be developed with adequate provision of breeders' rights and incentives.

Biofortification of staple crops is an urgent necessity to address the widely prevailing nutritional deficiency, especially among women and children. Varieties of QPM maize and protein rich wheat, biofortified rice and millets with high iron and zinc and anthocyanin rich buck wheat, need to be popularized to ensure household nutritional security. On 16 October 2020, the Prime Minister, Shri Narendra Modi, dedicated 17 biofortified varieties of eight crops, rich in one or more nutri-components such as Zn, Fe, Ca, lysine, tryptophan and protein, to the nation on the 75th anniversary of the Food and Agriculture Organization (FAO). Crop diversification through potential non-conventional crops, viz. underutilized pseudo-cereals, legumes and small millets, which have high nutritional value, resistance to diseases, drought and cold, potential to grow in marginal areas etc. are to be promoted as *Crops for Future*.

3.1.2 Natural Resource Management

Conservation agriculture (CA), an innovation for sustainable intensification, is presently practised in only about 10.3 m ha in the rice–wheat cropping system in Indian part of Indo- Gangetic Plains (IGP) (Kumar et al., 2018). Shortage of farm labour and concern for water scarcity have already raised the area under direct seeded rice (DSR) to 25% in Punjab in 2020 (Amid pandemic, direct seeding of rice helps

Punjab farmers, *The Outlook*, 12 June 2020), reaffirming its scientific value. Being particularly suitable for rainfed farming, CA would help in arresting soil degradation, improving soil organic C content, conserving water and efficient use of nutrients, besides building resilience against climate risks, reducing the costs of cultivation as well as emission of greenhouse gases (GHGs). Hence, a mission on 'Conservation Agriculture for Sustainable Intensification (CASI)' would be a deciding step.

Organic agriculture (OA) currently occupies about 2.78 m ha which is about 3.85% of the total global area of 72.3 m ha (MoA&FW, 2020; Willer et al., 2020). To promote OA, there is need to develop specialized certified organic farming clusters in the *de-facto* organic eco-regions (hills, rainfed, dryland), such as the tribal belts of West- Eastern and North-Eastern Hill States (all kinds of produce), parts of Rajasthan (spices), Kerala (therapeutic rice, tuber crops, cashews, spices and condiments), Tamil Nadu and Karnataka (coffee, finger millet), Assam and hilly regions of West Bengal (tea), etc. Besides developing suitable varieties for organic production, there is a need to develop guidelines on standards and certification and to establish referral quality testing laboratories. For accelerated adoption of organic farming, "Modern Organic Agriculture Development Initiative (MOADI)" of the government is to be harnessed quickly.

Protected cultivation has the potential of increasing productivity and income by 3 to 5 times, and can encourage youth (including women) to become entrepreneurs. The current area in India under protected cultivation is around 50,000 ha, which has scope for at least to 4 times expansion (~200,000 ha) in the next five years (Paroda, 2019b). This requires to: (i) develop varieties of high value crops suited for protected cultivation, (ii) provide technical backstopping, (iii) promote the use of low-cost technologies and structures, viz. plastic mulch, low tunnel, walk in tunnel, naturally ventilated polyhouses, net houses and environment-controlled greenhouses, etc., and (iv) popularize soil less farming viz. hydroponic, aeroponic and aquaculture for high value agriculture.

Micro irrigation can help achieve more-from-less. Out of a total irrigated area of 64.7 m ha, only 7.7 m ha is presently covered under micro-irrigation, with a potential to double in the next decade to grow 'More Crop Per Drop'. For intensively irrigated (North-West), water congested ecologies with sub-optimal water use (Eastern India) and rainfed agro-ecosystems (south, west and central India), a five pronged strategy would be helpful: (i) precision water management practices (micro-irrigation, laser levelling, automation), (ii) reduced water wastage by discouraging flooding, (iii) cropping systems optimization and diversification, (iv) induction of solar pumps and (v) on-farm rain-water harvesting. Hence, efficient water management technologies (conservation agriculture, raised bed-and-furrow irrigation, precision land levelling, micro-irrigation, fertigation, plastic mulching and field bunding), water pricing and ban on flood irrigation could help in doubling the water productivity. Further, crop intensification, recycling of wastewater and managing blue water could help increase water availability for agriculture.

Increase in nutrient use efficiency (NUE), needs integrating the climate smart technologies with customized, slow release and liquid fertilization, integrated nutrient management (inorganic fertilizers with biofertilizers, vermicompost, organic fertilizers, etc.), linking fertilizer use to soil health status and switching over to fertigation system in a phased manner. This necessitates institutionalization of fertilizer research in public-private partnership and a "Fertilizer Subsidy Policy Reform" through rationalized nutrient-based subsidy (NBS) linked to soil health card and direct benefit transfer (DBT). Farm mechanization and innovative use of new technologies like bioinformatics, GIS, remote sensing, robotics, use of drones, artificial intelligence and precision farming offer viable options to bring efficiency in agriculture by increasing cropping intensity, attracting youth and reducing cost of production and drudgery of agricultural workers (especially women) (Paroda, 2019b).

3.1.3 Integrated Farming for Sustainability

India is rich in livestock (with 15, 58, 18, 7 and 5% of world's cattle, buffalo, goat, sheep and poultry birds' population, respectively) and fishes (6.3% of global fish production), which contribute significantly to India's agrarian economy under diverse production systems. Therefore, sustainability of future agriculture would require integrated farming practices, leveraging on the principle of cyclic resource use.

Besides establishing sufficient semen banks for the livestock and production centres for fingerlings and juveniles of fish species, innovative and transformative technologies are must to make animal husbandry, poultry and fishing viable options for small farmers. Important among these are multiple ovulation and embryo transfer (MOET), ovum pick-up and in vitro fertilization in animal breeding; rapid molecular diagnostics for major diseases in livestock, poultry and fish; molecular tagging for traceability; innovative fishing vessels and fish farming and aquaculture technologies such as re-circulatory aquaculture system (RAS), integrated multi-trophic aquaculture (IMTA), pen culture and waste water aquaculture (Paroda, 2019b; TIFAC, 2019) in meeting the dual challenges of climate change and depleting natural resources, while fulfilling the demands of nutritious and safe food products. There is an urgent need to characterize and prepare a comprehensive database of all livestock and poultry breeds in the country for conservation, breed improvement and utilization, including the revival of hardy native livestock breeds.

3.1.4 Integrated Plant Protection Strategy

Annual crop loss due to pests and diseases ranges around 30 to 40%. (https://www.cabi.org/what-we-do/cabi-projects). Effective pest management measures, therefore, are a must, keeping in mind the growing concerns for pesticide residues for domestic and export markets and the long-term impact of pesticides in an ecosystem. The menace of spurious pesticides, which is estimated to be about 25%, needs resolution on priority. Cropping system- and location-specific technological innovations, including biological control methods are, therefore, needed for pest management. This also presents a strong case for adopting genetic manipulation technologies for biotic stress resistance in crop varieties through conventional breeding and GM technology. India established its credentials in molecular diagnostics and vaccine development for livestock and fishes. Similar lead is needed in locally developing green pesticide molecules. An active and viable public-private partnership will be the key in making successful market interventions and affordable pricing through competition.

3.1.5 ICT for Knowledge Dissemination and Attracting Youth in Agriculture

Real time access to knowledge and information is critical for keeping pace with emerging technological development. There is a large gamut of applications and e-Governance workflow systems that can harness the power of ICT in agriculture through appropriate policies and frameworks; need is to promote: (i) Factor Independent Mobile Device Apps, (ii) Internet of Things (IoT) for monitoring and automation of farming activities, (iii) Big Data Analytics and Dashboard for planning and monitoring the impact, (iv) Block chain in agriculture for transparencies and increased trust level, (v) GIS technology for mapping farming activities and (vi) Artificial Intelligence (AI) for monitoring and forecasting of agricultural commodity prices and global trends in agricultural trade. Further, post-production management, such as low cost primary processing, value addition, cool chains for perishable items, grading and packaging, online marketing through e-NAM etc. would all need efficient ICT support for increasing farmers' income.

Pluralistic and innovative extension approaches are critical for faster delivery of information and technology. Competencies of extension agencies especially youth (including women) as 'Technology Agents' need to be improved by systematic capacity building so as to enable them to respond better to emerging challenges. This achievement is possible only through better knowledge sharing, skill development and mentoring of youth, making them an integral part of "Plough-to-Plate Agri-Food System", promoting agri-preneurship through a dedicated "Agri-Youth Innovation Corpus Fund" for rural start-ups.

3.1.6 Innovative Post-Harvest Technologies for Extended Shelf Life and Value Addition

Innovative primary processing, dehydration and pasteurization technology at the farm gate, for extending shelf-life of farm produce, especially fruits and vegetables, milk and fish using solar power and low-cost storage facilities; advance processing technologies for value added and ready-to-use products and nutraceutical development, are some other vital areas that hold promise to increase value from agriculture both in domestic and export markets, as well as providing nutritional security.

3.2 IPR Issues and Their Application

Pre-requisites for adoption of cutting edge technologies, such as genetically modified and gene edited plant varieties, in agriculture, are the appropriate regulatory system and conducive policy support. Intellectual property (IP) protection for innovation, including Plant Breeder's Rights (PBRs) for varieties/hybrids, and prompt approval of the Biotechnology Regulatory Authority of India (BRAI) are vital in encouraging investments in second generation agricultural innovation.

The recent cases of infringement of IP for Herbicide Tolerant Bt (HTBt) cotton and illegal production and sale of seeds of such hybrids by several unauthorized seed companies brought forth the weakness of the regulatory system in protecting the IP of technology developers. In the cotton seed industry worth INR 2500–3000 crore (INR 25,000–30,000 million), nearly INR 400 crore (INR 4000 million) was accounted for by illegal seeds (Federation of Seed Industry of India, personal communication). Owing to this massive misappropriation of the IPR of HTBt, the government lost substantial tax revenue, farmers were denied seed quality assurance and after sale services in spite of paying 50% higher price per packet of seed, and the technology developer gained nothing from its huge investment.

On the other end of the spectrum, there are instances of potato farmers, breaching the contract with the technology (variety) developer, under the provisions of Section 39 of the Protection of Plant Varieties and Farmers' Rights Act (PPV&FRA), 2001, which allows them to grow, save, exchange, sell or sow the produce of a variety registered with the PPV&FR Authority. The Act does not differentiate between the seed and vegetatively-propagated planting material and their end use. Such concerns may need to be addressed through necessary amendments of the Rules.

Hence, protecting the rights of farmers, incentives to private sector on par with public sector; provision of exclusive rights for public-bred varieties/hybrids for specific regions/states; third party crop-auditing (reliable assessment of actual acreage under different varieties and payments of royalties based on it), and strict implementation of IP regulations are called for. Consequently, for wider adoption of frontier technologies and innovations, institutional and policy reforms such as harmonization of National Intellectual Property Rights (IPR) Policy, 2016, the PPV&FRA, 2001 and the national Biological Diversity Act (BDA), 2002 would pave the way (Saxena, 2017; Singh, 2019). This will ensure effective access and benefit sharing (ABS) by all those involved in the innovation chain and encourage more investment by the private sector in research and development (R&D). Ministries and statutory bodies concerned with IP protection may revisit existing laws/acts and remove grey areas by bringing in necessary amendments for making regulatory frameworks innovation-friendly and scaling disruptive innovations in agriculture.

4 Indigenous Technical Knowledge in Agriculture

Indigenous Technical Knowledge (ITK) has immense value in innovation and plays significant role in agricultural growth. The knowledge inherently acquired by the indigenous communities in different ecosystems is valuable for climate adaptation, natural resource management, processing/preservation, storage and medicinal value.

Traditional knowledge of farmers in conserving and identifying useful biological material, embodied in biotechnological innovations, offers an effective strategy for achieving sustainable food security (Blakeney & Siddique, 2020).

4.1 ITK: A Valuable Resource

The Inter-Governmental Panel on Climate Change (IPCC) highlighted the importance of ITK and indigenous crop varieties in adaptation, climate change monitoring and mitigation (IPCC, 2014). Traditional practices have helped better adaptation such as: (i) raising of short duration drought hardy and heat tolerant crops on marginal lands, (ii) conserving the seeds and use of local landraces with adaptive characteristics over generations, (iii) having knowledge for alternative food, feed, fibre, medicinal resources, etc. available locally in the forest or wild areas to rely when crops fail; (iv) practising traditional farming to conserve natural resources for better resilience and adaptation; and (v) using traditional knowledge to predict and forecast the extreme events and take precautionary steps to survive extreme vagaries of nature.

A well-recognized fact is that traditional varieties and landraces are genetically better equipped to withstand environmental stresses such as scarcity of water, less availability of nutrients and extreme temperature. Tribal areas across the country conserve rich diversity of plants and animals and provide a valuable source of rare germplasm for several species that can tolerate extreme weather and soil conditions and possess novel traits. Moreover, there are several nutri-crops such as minor millets, moth bean, cowpea, faba bean, taramira, lathyrus, etc. that have great relevance for adaptation to drought and high temperature. The traditional crop varieties are easily accessible as they come from farmers' own saved seeds and shared with the local communities, with women playing an important role.

4.2 Threats to Traditional Knowledge and Initiatives on Protecting ITK

ITK, generally transmitted verbally, in most cases is lost due to lack of proper documentation. It is, therefore, necessary that available ITK is documented, maintained to avoid dissemination loss, validated and refined to make agriculture more sustainable. The Convention on Biological Diversity (CBD) acknowledges the contribution of traditional knowledge in protecting species, ecosystems and landscapes. In India, both the BDA, 2002 and the PPV&FRA, 2001 have included necessary provisions for protection of ITK. The need for access and benefit sharing (ABS), an important instrument in using ITK, was included in these Acts. Perhaps PPV&FRA is the only national legislation in the world, which recognizes farmers as plant breeders. As a result, 1,649 farmers' varieties have already been registered as on 11 March 2020 (PPV&FR Authority, personal communication), although the work to mainstream them in the seed supply chain still remains. However, there exists no provision of incentives for ITK related to other sustainable agricultural practices like integrated nutrient management (INM), integrated pest management (IPM) and organic farming. The context of local knowledge systems in agriculture needs to be understood, tested and given legal protection for scaling.

4.3 Using ITKs and Farmers' Wisdom for Agricultural Sustainability

Indigenous people are custodians of traditional knowledge, have different perceptions and follow varied adaptation strategies to adjust with the ecosystem. There are several good examples of indigenous crops and local cultivation practices to sustain the vagaries of environment. These, integrated with scientific knowledge, can play important role in designing policy for climate change adaptation. Women are excellent source of both genetic and cultural information on plant and animal species, and play a crucial role in developing climate resilient models of agriculture.

Shifting of planting and harvesting dates, crop diversification, integrated crop-livestock-fish farming and cultivation of drought-resistant crops and varieties are some of the sustainable approaches to climate change adaptation. The practices of mixed farming e.g. *Satanaja* (7 crops in one field) and *Gyarahnaja* (11 crops in one field) are still prevalent in tribal belts and dryland areas to reduce the risk of crop failure. It is estimated that traditional multiple cropping systems provide 15–20% of the world's food needs. It ensures better yield stability and food diversity, and decreases the pest risk.

Crop rotation, an ancient practice, has recaptured the global attention to solve a variety of agroecological problems such as low WUE and soil erosion (Huang et al., 2003), and promote carbon sequestration (Triberti et al., 2016). It also has a potential to reduce the emissions of greenhouse gases (MoSTE, 2015; Theisen et al., 2017). Similarly, there are examples of ITKs relating to dietary innovations having health, therapeutic and medicinal values to humans and animals and *desi* (local) medicines made from organic and inorganic ingredients for pest and disease management (Sarkar *et al.,* 2015).

While the value of ITKs cannot be undermined in this land of *Vedas*, scientific validation through experimental verification, refinement and logical integration will pave the way to sustainable agriculture. Many of these traditional techniques have great potential for meeting the future challenges while reducing use of chemicals which, if they are not used judiciously, can harm our food chain and environment (Kumar *et al.*, 2014).

The network of frontline research extension system developed by the ICAR, which operates through its 726 KVKs (Agricultural Science Centres) under 11 Agricultural Technology Application Research Institutes (ATARI), is considered to be a unique institutional model, majority of which function under the state agricultural universities providing a two-way platform between farmers and technology developers. These are also the primary centres for capacity building and adoption of new technologies, as well as for sharing information and planting materials.

5 From Science of Discovery to Science of Delivery: Innovative Technology Diffusion Options

Developing innovative technologies is only the halfway to meet the challenges in agriculture, their timely and targeted delivery completes the goal. In spite of increased investments in agricultural research and extension in the past decades, the impact on the livelihoods of small farmers had not been significant, as mostly the improved technologies did not reach them. Therefore, well-functioning agricultural extension and advisory services are essential for translating technological achievements into tangible gains (Babu et al., 2019).

The pathways to impact should include scientifically designed systemic systems for enhancing production and productivity, sustaining natural resources, identifying and managing major risks, building resilient communities, enriching value chains and eliminating waste, enhancing opportunities for agri-business, job creation, creating opportunities for women and youth, coordinating the knowledge product and integrating communications, linking farmers with remunerative markets and reorienting education and skill development.

Innovative technologies suggested in the previous sections will help increase the income of small and marginal farmers by enhancing the value of farm output and reducing the cost of operations. These would be integral to a sustainable model of profitable agriculture across the divergent scenario in the country. Effective diffusion of such innovations holds the key to achieve success in agriculture. It is also important that with the growing presence of pluralistic extension system with varied approaches, a robust research framework and methodology is put into practice (NAAS, 2017).

During the COVID-19 pandemic, several new multi-dimensional challenges emerged impacting food and rural livelihood security; these are going to affect the food and nutritional security of the country, and also the livelihoods of over 50% of the population depending on agriculture, directly or indirectly (*The India Today*, 4 May

2020). Transformational innovations in agriculture, therefore, have to be affordable, profitable, rugged and user-friendly and supported by an efficient diffusion strategy.

The Green Revolution showed the importance of an efficient agricultural extension and advisory services. Conventionally, agricultural extension is in the domain of public sector, comprising State Extension machineries including line departments and Agricultural Technology Management Agency (ATMA), ICAR institutes and SAUs including the KVKs. However, it still left big gaps between the technology development and dissemination on one hand and developing need based technologies on the other. As a result, it could cater to only about 15% of the total mandated area of extension system, leaving majority of small farmers deprived of all resources including information and appropriate technology. However, the scope of innovative technology development and their diffusion has undergone significant changes in the last 10 to 15 years, with the involvement of a range of service providers including the private sector, NGOs, farmer organizations, civil society and independent professionals. This was further boosted by a revolution in communication technology. Mobile-based agro-advisory models delivering information based on real time conditions, and farmers' participatory programmes undertaken by the private sector and NGOs are complementing the existing extension services for a better last mile penetration. These have brought forth some efficient and cost effective extension models such as Indian Farmers Fertilisers Co-operatives *Kisan Sanchar* Limited (IKSL); e-Choupal of ITC; and aggregated vegetable farming and seed production by small farmers by SFI and BAIF (Mittal et al., 2019).

There are several innovative technologies ready to be scaled up and scaled out (*see* Box below), where skilled intermediaries can act as effective links between the technology providers and farmers. However, for the available extension machinery, better coordination among different players and active participation of private sector and paid service providers are going to be vital. Indian farmers demonstrate high levels of ingenuity in devising grassroots innovations, and re- engineered innovative technologies using local resources, which are valuable in solving situation-specific problems in cost-effective manner. Therefore, farmer-led innovations also need to be assessed, validated, refined and out scaled to harness their full benefits and adopted in a participatory mode involving all stakeholders (Paroda, 2019a).

- Hybrid technology (maize, *bajra*, sorghum, rice)
- Biotechnology GM crops (soybean, mustard, maize, brinjal)
- Conservation agriculture (3.5–20 m ha)
- Protected cultivation (expand area from 50,000 ha to 2.00 m ha) Micro-irrigation (discourage flood irrigation) – atleast 10 m ha Bioenergy/biofuel (use of sugarcane and maize—initially 20%)
- Biofortified crops (QP maize, Fe and Zn rich rice, Fe rich *bajra*, Zn rich wheat)
- ICT for knowledge sharing, e.g. e-Choupal
- (Paroda, 2019b)

Since the customers are typically resource poor in agricultural sector, following the principle of making profit at the 'Bottom of the Pyramid', diffusion models need to target a large number of users who can use such innovations at a reasonable cost. Options are suggested here for effective diffusion of innovative technologies.

5.1 Integration and Coordination among Different Departments

Agricultural extension is primarily a State subject, though the Government of India provides both technical and financial support through ICAR and various other programmes, such as Agricultural Technology Management Agency (ATMA) scheme, which is operating in 676 districts, RKVY (National Agriculture Development Program), Technology Missions.

Some of the initiatives by the Ministry of Agriculture and Farmers' Welfare, like Attracting and Retaining Youth in Agriculture (ARYA), Value Addition and Technology Incubation Centres in Agriculture (VATICA), National Repository of Information for Women (NARI), *Mera Gaon Mera Gaurav* (MGMG), National Skill Qualification Framework, knowledge systems and homestead agricultural management in tribal areas, climate smart villages, web and mobile advisory services have helped in the faster adoption of sustainable innovations (Paroda, 2019a), and also laid focus on engaging women and youth. Similarly, several programmes by the Department of Biotechnology (DBT) and National Innovation Foundation (NIF) helped faster adoption of innovative technologies and promoting entrepreneurship.

Significant inter-regional and inter-state differences exist in agricultural productivity and livelihood security, seeking eco-geographically and socio-economically differentiated approach to bridge the gaps. Agriculture being a State subject, the States must play a leading role in meeting the challenges.

Effective integration is required among various government institutions and departments to identify technology gaps and offer most appropriate technologies, leveraging on government schemes and incentives. Revamping organizational set up, employing contractual skilled staff, preferably from the same locality, as technology agents and undertaking farmer-led participatory schemes should hold the key.

5.2 Public-Private Partnership

Unlike consumer goods, innovations in agriculture face a higher market risk if the product basket is limited. With a large portfolio of innovations, only a few successful ones can more than pay for failures; whereas with a small portfolio it may only incur loss, profitability, and their diffusion is typically left to the state and federal extension machinery. Government may consider a transparent policy of reasonable pricing of agricultural technologies including seeds, pesticide, fertilizers, machines and tools as well as services, if required. This may be decided on case to case basis involving all stakeholders, instead of blanket orders, ensuring a level playing field for all players, to encourage the best technology to spread fast. Agrinnovate India Ltd of ICAR - an interface with the private sector, can provide such a platform (Saxena, 2017). However, the requirements of smallholder farmers must critically be assessed through on-farm testing while planning for either up-scaling or out-scaling new innovations (Gulati et al., 2006; Swarup, 2017 and Pal et al., 2017).

Partnering of corporate houses with public institutions or local bodies at village/block level, be it a local Farmers' Group, Self Help Group (SHG), NGO, or a village level startup, needs to be encouraged for quick and effective dissemination of knowledge and technology transfer. Leveraging Corporate Social Responsibility (CSR) offers an effective option for popularization of innovative technologies. While others can run on business models of rural entrepreneurship, partnership between the state agriculture departments with private technology providers can result in quick diffusion of innovative technologies providing sustainable solutions (https://www.business-standard.com/article/pti-stories/cropin-/4 March, 2019). Strong partnership, complementarity among partners and capacity building of partners are the key to delivery.

5.3 *Local is Vocal*

Diversity in agricultural systems, crops and other farm products is an untapped resource for uplifting rural economy which needs to be showcased and made popular by linking farmers, especially women SHGs, with corporate sectors through innovative marketing strategy. For instance, traditional crops and varieties, having special quality attributes, special food preparations and household items can be brought main stream and popularized as unique local products through ethnic food festivals and branding, in line of *"One village One product"* movement championed by Japan and adopted by Thailand and Sub-Saharan Africa (www.odi.org/publications). As most of these local crops/ varieties are not only rich in nutrients, but by default, are also amenable to organic cultivation, necessary policy support and financial incentives for their cultivation and consumption would also help build nutrition security and promote local products in domestic as well as export markets.

5.4 Technology Parks, Custom Hiring Centres and Agri-Business Hubs as Active Platforms for Technology Diffusion

Establishing *Technology Parks* and agri-business hubs would serve as innovation platforms, and also encourage rural graduates, entrepreneurs and young professionals to start businesses and bring technological and managerial expertise to rural areas. Policy support and financial incentives can drive establishment of ancillary agri-businesses, startups and small scale enterprises (MSMEs), such as those based on post-harvest value added products, Agri-Clinics, Agri-Input centres, farm gate storage, sorting and grading houses and cool chain facilities. Since agriculture-based startups experience difficulty in finding venture capital, incentives and credit availability on easy terms (Saxena, 2017) can boost the scope of such businesses. As farm mechanization and precision farming are going to be indispensable in agriculture, Custom Hiring Centres (CHC) need to be established in every block and village under the Sub-Mission on Agricultural Mechanization (SMAM) scheme of GoI (Farm Mechanization in India, 2015. http://www.agricoop.nic.in/). Similarly, 'Uberization' or affordable rental of farm-friendly vehicles for quick transport of farm produce and inputs is a promising option. The CHCs and rental services could be vital in bringing the benefits of mechanization to small farmers, as well as in overall knowledge dissemination, and attracting youth in agriculture.

5.5 Innovation and Incubation Centres

Model Innovation Centres and platforms should be established at SAU campuses linking farmers, agriculture and agri-food professionals, agribusiness and entrepreneurs through digital communication channels to trigger new opportunities and harnessing best of the science and technology in serving farmers. This will provide an opportunity to young graduates to work as interns gaining hands-on experience that will jump start their careers. The incubators for start-up companies will help convert innovations into commercial businesses and boost the Startup India initiative.

5.6 Farmer-Led Extension

In the wake of COVID-19 pandemic, the country has experienced an unprecedented reverse migration of farm labour, most of whom have acquired new skills and knowledge while working in different regions and diverse farming systems. With some formal training, these farmers can be made *Technology Champions* for testing and lateral diffusion of innovative technologies. Support at state level is needed to engage these farmers to diffuse technology, while creating employment and checking migration.

Creation of self-managed Farmers' Groups in village clusters or blocks could be another effective model, where each farmer pays a small membership fee to benefit from knowledge bank, advisory services and innovation repository. These may be interlinked (but not compulsorily so) with 100 such groups in other clusters, blocks and districts. These will also have direct links with input dealers, market nodes, veterinary service providers, market aggregators, CHCs and financial institutions. Principally, following ATMA model, these can run like a commercial activity, with formal or informal aggregation at the base of functioning.

5.7 Innovation Agents—Role of Skilled Youth and Women in Agriculture

Like para-medics, there is need for a band of skilled technology providers as Innovation Agents, at village cluster levels covering services from knowledge share, input supply, market links, machine hire and/or use, care of farm machineries, maintenance of horticultural nurseries, technology support to the livestock, poultry and fisheries enterprises. Engagement of *Mausam Mitra* and *Mausam Didi* in the lines of *Kisan Mitra/Pashu Mitra* and *Kisan Didi/Pashu Didi* model of ATMA may also be considered to spread weather based Agromet Advisories in the rural areas.

5.8 New Models for Capacity Building

Application of many new innovations may require a new set of skills or up-gradation of the existing ones. Indian youth, including the rural population, are fairly tech savvy and eager to learn. The first and foremost requirement for adoption of innovative precision technologies is training of local youth for vocational skills. Short Diploma courses offered by institutions accredited by ICAR or AICTE and intensive hands-on training of farm technologies by the KVKs are the need of the hour. Though the traditional methods of training involving instructor-led approach works well, yet it has limitations of penetration and access, especially in COVID-19 scenario and reaching the far flung and difficult to reach areas. In these situations, use of Extended Reality (XR) simulation platforms could be an option. Effective linkages will be needed with the programmes supported by the Agriculture Skill Council of India (ASCI) for skill development of local youth and NAERS, including some of the private colleges and deemed-to-be universities. The existing network of KVKs spread across the country can be identified as nodal points for imparting hands-on experience, evaluation and up-gradation of local skill levels.

5.9 Agriculture Innovation Board

A National Agri-Innovation Board may be created for quick development of need-based technology, up-scaling and out-scaling of agri-innovations and their quick adoption, in the MoA&FW under the chairmanship of an eminent agricultural scientist with members drawn from other sectors and concerned ministries (Paroda, 2019a). The board should develop an Agricultural Knowledge and Innovation System (AKIS) for (i) accelerating knowledge flows and strengthening links between research and practice, (ii) strengthening all farm advisory services and fostering their interconnections within the AKIS, (iii) enhancing cross thematic and inter-disciplinary innovation and (iv) supporting the digital transition in agriculture. The Board could extend funding support in the form of venture capital – a must for agri-startups.

6 Non-Agricultural Disruptive Technologies Influencing Innovations in Agriculture

Massive cross-sectoral, interdisciplinary technological shifts are of common occurrence in the present scenario. Agriculture is no exception. Though, it is not considered an industry per se, agriculture contributes ~ 17% to the national GDP, directly feeding to several major industries, including FMCGs. It is also expected that for increasing the profitability in agriculture, mechanization, automation, use of resource conserving technologies, data management and ICTs will be the order of the day in the coming years. Hence, several technological innovations in non-agricultural sectors would be influencing the core agricultural innovations in the years to come. Some such examples are discussed here.

6.1 Blockchain Technology—from Crop Management, Marketing and Procurement to Certification and Traceability

Besides its huge application in the value chain for on line transactions, as Blockchain or Distributed Ledger Technologies (DLT) that permits entry and data check at every 'node point' and allows the use to be tracked, it can be extremely useful for establishing 'farm to fork' traceability in food commodities and in processes like Organic Food and Seed Certification, which are crucial in fixing the accountability in case of poor quality of a food product or unsatisfactory performance of a seed lot, respectively. Similar applications are envisaged in a number of other inputs and product quality management.

6.2 Application of Biosensors in Agriculture and Allied Fields

With growing concerns about air, water and soil pollution, effective diagnosis of pathotypes, rapid, precise and cost-effective analysis and monitoring of food and other agricultural products are assuming greater salience. Biosensors (analytical devices that convert a biological response into an electrical signal, including enzymes, antibodies, nucleic acids, microorganisms etc.), in this way are being used in medicine and healthcare. It may be considered for a wide array of application in agriculture and allied industries.

6.3 Use of Non-Fossil Fuel—a Win-Win Option

India is making rapid advancement in the use of non-fossil fuel for various purposes, mainly transportation, agriculture, domestic and industrial use. India has bred excellent sugarcane varieties both for tropical and sub-tropical regions, with high sugar recovery, and maize and sorghum varieties suitable for bioethanol production. Many engineering institutions, independently and in collaboration with international institutions as well as industry partners (e.g. IIT, Madras and ExxonMobil, https://timesofindia.indiatimes.com, 14 Oct 2019) are engaged in developing affordable technology for bioethanol production. Several pre-treatment processes are already perfected to bring down the production cost of biofuels (Chundawat, 2020), and more refined technologies are in the offing. By adopting a viable technology, India can easily substitute 20% or more of its fuel use by bioethanol. This will reduce our C footprints, and also offer better remuneration to farmers cultivating biofuel crops.

6.4 Solar Power for Sustainable Agriculture

Use of renewable energy sources, particularly solar power is vital in agriculture. Though these are being promoted for a very long time, their use is limited and localized due to the high initial investment and lack of affordable and efficient power storage system (power grid and batteries). The costs of panels have come down substantially, but India is still tech-dependent on other countries in affordable battery manufacturing. Solar powered pumps are already being promoted by the GoI through various schemes and incentives; and special scheme for farmers for the installation of solar pumps and grid-connected solar power plants targets to add 25,750 MW of combined solar capacities by the year 2022 (*The Economic Times*, https://economictimes.indiatimes.com/ Updated 23 August 2019). Advancement in this sector is going to directly impact almost all activities related to agriculture.

6.5 Waste Management and Agriculture

Urban waste management is one of the top priorities in India, both for controlling environment pollution and maintaining sanitation, as well as for creating wealth from waste. The S&T institutions under CSIR, ICAR, IITs, DRDO, private sector agencies and NGOs are working towards finding practical solutions (TERI, 2015). For India, which uses 70% of its water for agriculture and also faces poor soil health problem due to low organic C content, effective waste management (solid and water based) technologies could not only solve the civic woes, but also prove a boon to agriculture. Models developed by the IITs and other engineering institutions (viz. zero chemical Continuous Aerobic Multi-Stage Soil Biotechnology (CAMUS-SBT) for waste water treatment developed by IIT, B) are addressing the water needs in agriculture and sustainable ways to meet it (www.thebetterindia.com/210034/iit-bombay-wastewater-treatment- technology-sustainable-startup-india, Jan 20, 2020). Such technologies need to be spread fast with necessary policy support and public–private partnerships.

7 Rejuvenating Agricultural Education System (AES)

7.1 State of the Agricultural Education System

Agricultural education system in India is based on the Agricultural Universities (AUs), which are structured on the Land-Grant pattern of the USA—integrating teaching, research and extension. Starting with Govind Ballabh Pant University of Agriculture and Technology, Pantnagar in 1960, today sixty-three State Agricultural Universities (SAUs), three Central Agricultural Universities (CAUs), four Deemed Universities (DUs) and four Central Universities with Agricultural Faculty, together comprise the 74 Agricultural Universities of the country. Added to the above educational institutions, 106 ICAR institutes, 11 ATARIs, 726 *Krishi Vigyan Kendras* (KVKs or Agriculture Science Centres), 57 All India Coordinated Research Projects (AICRP) and 25 Network projects constitute the National Agricultural Research and Education System (NARES)—the largest in the world. The Agricultural Universities (AUs) and ICAR institutes have been harbingers of the Green and the Rainbow Revolutions, and generating the needed scientific manpower, teachers, technologies and transferring these to transform India from 'Ship-to-Mouth' situation to the 'Right-to-Food' status.

7.2 Asymmetries and Shortcomings in the AES

The Rainbow Revolution notwithstanding, India's agrarian progress during the past few years has slackened and serious asymmetries are noted in science-led growth of agriculture. This could partly be attributed to the decline in quality and responsiveness of agricultural education system in the country, resulting from the following shortcomings:

(i) Inadequate investment and declining financial resources in agricultural universities/colleges; opening of new institutions without matching resources and norms; unmindful splitting of agricultural universities, poor resource planning and poor coordination between Centre and States.

(ii) Disconnect among agricultural education, employment and industries' requirements; lack of adequate skill, entrepreneurship and experiential learning; overall poor employability of agricultural graduates.

(iii) Extensive inbreeding; low access of agricultural education to rural students, especially to the tribal and socially-deprived communities.

(iv) Inadequate academic rigour and contextualization of emerging challenges and opportunities; erosion of basic sciences from agricultural courses; poor quality and insufficient academic staff (inbreeding and unfilled faculty positions); widening disconnect between education, research and extension resulting in knowledge deficit; limited internalization of relevant international trends and developments; indifference of youth towards agriculture.

(v) Poor system of evaluation, monitoring, impact assessment, accountability and incentive systems; limited digitalization; and inefficient governance.

7.3 Alleviating the Asymmetries for Rejuvenating the System

Towards resolving the above asymmetries and rejuvenating India's agricultural education system, the following approaches and actions, mostly arising from the NAAS's XI National Agricultural Science Congress (NAAS, 2014; Singh, 2014) and the Fifth Deans' Committee Report (ICAR, 2016), should be adopted.

- Embrace agricultural education for development (AE4D) as an integral component of the national agricultural policy in creating a world-class agricultural university system attuned to face local, national and international challenges and opportunities.
- Build integrated, multi-faculty and multi-disciplinary institutions; Ensure and institutionalize transparent governance, autonomy, meritocracy, judicious allocation of resources and accountable systems of evaluation (measure to manage).
- Minimize inbreeding and promote institutional linkages, focusing on standards, norms and accreditation; strengthen basic and emerging sciences in agricultural education and research; nurture centres of excellence.

- Strengthen and streamline Centre-State partnership with differentiated but reiterative responsibilities.
- Revamp teaching/learning processes and pedagogy to attract best of talent for preparing the "Youth for Leadership in Agriculture".
- Institutionalize skill development, entrepreneurship and experiential learning programmes, and invest on non-formal education and vocational training in agricultural technologies
- Support development of active and long-term international cooperation, rejuvenate and replicate successful collaboration models and launch South-South, South-North and trilateral collaborations.

7.4 Quality Assurance in Education

Quality assurance in higher agricultural education, pursued by ICAR/DARE/SAUs, involves accreditation, framing of minimum standards for higher education, academic regulations, personnel policies, review of course curricula and delivery systems, support for creating/strengthening infrastructure and facilities, improvement of faculty competence and admission of students through All India Examination. The ICAR's Fifth Deans' Committee Report (ICAR, 2016) restructured the course curricula to underpin relevant practical skills, entrepreneurial aptitude, self-employment, leadership qualities and confidence among graduates and attracting and retaining youth in agriculture. Further, the Committee recommended that all degrees in the disciplines of Agricultural Sciences should be declared as professional course degrees, and sought to achieve global level of academic excellence. It also suggested norms for establishing new colleges.

In order to harness regional specialties and to meet region-specific needs, certain optional courses such as Coastal Agriculture, Hill Agriculture, Tribal Agriculture etc. were formulated. New degree programmes and courses were recommended in emerging fields like genomics (biotechnology), nanotechnology, GIS, precision farming, conservation agriculture, secondary agriculture, hi-tech cultivation, specialty agriculture, renewable energy, artificial intelligence, big data analytics, mechatronics, plastics in agriculture, dryland horticulture, agro-meteorology and climate change, waste disposal and pollution abatement, food plant regulations and licensing, food quality, safety standards and certification, food storage engineering, food plant sanitation and environmental control, emerging food processing technologies, sericulture, community science and food nutrition and dietetics.

The ongoing World Bank supported National Agricultural Higher Education Project (NAHEP), built on the preceding World Bank projects, particularly NATP and NAIP, is poised to—strengthen capacities of faculty and other staff at all levels, foster linkages of the national system with global knowledge economy, facilitate International Experiential Learning, promote learning-centred education and fortify partnership with private industries.

In compliance with the Student READY programme launched in 2015, the Committee has designed one year programme in all the UG disciplines comprising (i) Experiential Learning, including International Experiential Learning wherever feasible; (ii) Rural Agriculture Work Experience; (iii) In-plant Training/ Industrial Attachment; (iv) Hands-on Training (HoT) / Skill Development Training; (v) Students Projects; and (vi) the Agricultural Science Pursuit for Inspired Research Excellence (ASPIRE) programme.

7.5 Paradigm Shifts Needed for Rejuvenating Agricultural Education System

In the spirit of *Reform, Perform and Transform*, paradigm shifts are needed for rejuvenating India's Agricultural Education System and change from Land-Grant to World Grant system, as local and global are no longer independent. The new curricula, courses and contents should keep evolving, dynamically encompassing the new global initiatives, such as Global Green Economy; Knowledge Economy; Global Zero Hunger Challenge; UN International Year themes, etc. Reiterating the role of Agriculture (A) as an agent of change, it is suggested that agriculture, along with social sciences and humanities, be amalgamated with science, technology, engineering and mathematics (STEM), thus transforming ***STEM*** into ***STEAM***. India should move towards ranking of its universities, including AUs, for raising the level of knowledge domains, meritocracy and governance as per the indicators suggested by the National Academy of Agricultural Sciences (NAAS), making our students globally relevant.

Synergizing excellence and relevance, new approaches towards building qualified human resources, for instance, custom-designed Massive Open Online Courses (MOOC) and establishing Model Innovation and Incubation Centres, are being popularized in NARES. It also prepared a roadmap for mentoring, emphasizing the need for matching the experience and wisdom of mentors with the learning needs of mentees, thus building bridges across the hierarchy levels, empowering change management, enhancing work ownership and sharing of responsibility and expanding learning ecosystem and good practices. This is in line with the programmes of the Department of Science and Technology (DST), especially Innovation in Science Pursuit for Inspired Research (INSPIRE), and of the Ministry of Human Resources Development (MoHRD), particularly its support to the Global Initiatives of Academic Network (GIAN). Thus, rejuvenated agricultural education would transform the agrarian economy, and attract foreign students, rendering the Government's Study in India initiative a success.

The above transformational changes will be boosted by the New Education Policy (NEP) 2020, adopted by the Union Cabinet headed by the Prime Minister on 29 July 2020. The Prime Minister elaborated the aim of the Policy at the education conclave held on 7 August 2020 and led the pledge to implement it effectively, including allocation of Rupees hundred thousand crore to begin with. The NEP envisions an educational system that makes good human beings with skill and expertise contributing directly to transforming our nation sustainably into an equitable and vibrant knowledge society, by providing high quality education to all, making our students global citizens, thus rendering NEP as the foundation for New India. Retraining, up-skilling and retooling of teachers, students and related staff, bridging gap between education and research by adopting a holistic approach, strengthening of vocational education, autonomy to institutions and establishing a self-sufficient domestic ranking system for Indian educational institutions, are the main planks of NEP 2020. Consequently, the Ministry of Human Resource Development (MoHRD) has been renamed as the Ministry of Education (MoE, GoI, 2020).

8 Pathways from Research to Innovation for Impact

The UN Inter Agency Task Team (IATT, 2020) had underpinned that science, technology and innovation, the key means for achieving the Agenda 2030, must be coherently integrated to meet economic, social and environmental aspirations in line with the SDGs. The UN Guidebook for the Preparation of STI for SDGs Roadmaps has emphasized integrating STI and the SDG Plans with the National Plan. Emphasizing that, 'The Future is Now: Science for Achieving Sustainable Development', IATT suggested six key steps and three core inputs for developing STI for SDGs roadmaps, as elucidated in Fig. 1.

The UN, in collaboration with World Bank, other international organizations and multilateral donor agencies, is pilot testing the guidebook approach with India, as one of the initial five participating countries.

In India, the Office of the Principal Scientific Adviser, NITI Aayog and other concerned offices, underpinning the current policy and strategy frameworks, jointly prepared the STI for SDGs Roadmaps, emphasizing agriculture, energy, water, biodiversity and comprehensive food, nutrition, health, livelihood and environmental securities—One Health One World inter-linkages, multi-disciplinary and system approaches, inclusiveness, digitalization, climate smart agriculture and resilience to biotic and abiotic stresses. It underpins the essentiality of coupling of funding with technology transfer as also envisaged in the Multilateral Fund under the Montreal Protocol, Green Climate Fund, GEF and UNFCC, which are supporting the STI for SDGs global movement. The Roadmap suggests: (i) establishing a Technology Facilitating Mechanism, (ii) adopting new models for incentivizing innovations for global public goods and enhancing access to them and (iii) integrating STI cooperation into strategies for the achievement of the SDGs.

An Agri-Food system-based approach has been adopted for addressing the large and systemic challenges the country is facing. The food systems lens should secure that research and innovations in sub-systems are clustered, monitored and evaluated from the overall food systems viewpoint. It will identify leverage points for improving

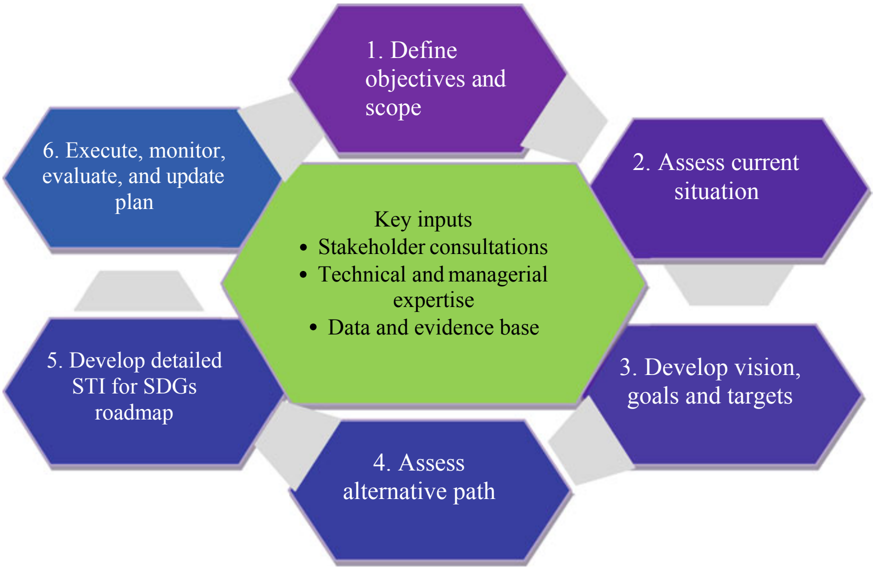


Fig. 1 Process flow of six key steps in the development of STI for SDGS roadmaps. *Source* Guidebook for the Preparation of Science, Technology and Innovation (STI) for SDGs Roadmaps (IATT, 2020)

a specific outcome without compromising other desirable outcomes. India's roadmap is designed to build inclusive food systems (IFPRI, 2020) to wipe off the Indian enigma of being food surplus and also home to about one-fourth of the world's hungry and poor, majority being smallholder and marginal farmers. This inclusive growth system should promote SMEs and participation of smallholders all along the value chain. Policies and regulations should be in place to ensure – land tenure security, access to credit, training, technical assistance and resilience-enhancing social protection. Income of the farmers thus enhanced will improve their access to education and information, which in turn will increase their inclusiveness in the food systems, breaking the inter-generational cycle of poverty, hunger and malnutrition.

Keeping in mind the frameworks and guidelines suggested above and ensuring policy coherence and enabling environment, including cooperative federalism, the following integrative pathways from research to innovations for impact are suggested.

- **Science-Technology-Innovation Continuum to be Farmer-centric and Demand- driven.** The cutting edge and innovative technology can bring agricultural transformation only if it addresses the problems of small and marginal farmers. While integrating basic and applied sciences, focus should be on being demand-driven (local being vocal) and adopting pluralistic delivery of innovations. Collaboration among all stakeholders is needed at the niche, regime and landscape levels in compliance with regulatory requirements. The implementing actors must explore various contextual conditions and work with potential adopters to situate new innovations within local socio-ecological practices. Along with capacity building and skill development, socio-political ambience should nurture local leadership to champion innovations (Shilomboleni and Deplaen, 2019).

- **No more 'Closed Jacketed' Approach.** Encourage Agri-food system-based multi-institutional, inter-disciplinary research, leading to rapid problem solving. Innovations to tackle COVID-19 pandemic have brought forward the advantages of dissolving boundaries in science to develop effective technologies leveraging expertise at various levels. This should be adopted as the norm by linking fundamental science to applied research; innovations at technology development and their diffusion; and partnership among the public and private sectors and civil societies. New initiatives of synergizing Science Social Responsibility (SSR) with Corporate Social Responsibility (CSR), can bridge the gap between private and public sectors. Agri-startups should help solve agribusiness problems, promote entrepreneurship and provide products, services, applications, etc. enhancing competitiveness.
- **Invest in Agri-Food Research and Development (ARD).** Studies showed that among all major components, investment in R&D gives the highest returns in agriculture, in socio- economic and ecological terms. In India, expenditure intensity in agricultural research has remained around 0.4% and in agricultural extension only around 0.16% for the past 15 years or so (Table 3). Against this, the intensity in USA and Australia is over 3.0%. Hence, in India both public and private funding need to be more than doubled as an immediate measure and a long-term strategy by bringing complementary convergence in funding from different sources and extending tax rebates, proportionate to the scale of investment. The National Education Policy, 2020 has proposed a common National Research Foundation (NRF), to minimize overlapping in funding, break barriers between various S&T Departments and create beneficial linkages. A similar approach is needed for ARD, with at least 0.2% of GDP invested, equalling about 1.0% of agricultural GDP as has repeatedly been recommended in the past.

- **Make the Education System Scientifically Sound and Professionally Competitive.** The agricultural education must maintain a Gold Standard ensuring that agricultural graduates from India are professionally well equipped to handle

Table 3 Expenditure intensity in R&D in India

Expenditure intensity in India (per cent)		
	Research	Extension
1983	0.25	0.10
1993	0.31	0.15
2003	0.39	0.14
2014	0.40	0.18
2018	0.39	N.A

Source NIAP, 2017–18

national as well as international challenges as enunciated in the NEP 2020 (GoI, 2020). The NARES should assess the manpower needs of the fast transforming, knowledge-intense agriculture to make necessary adjustments in curricula and skill development, emphasizing on experiential learning and exposure to national and international issues. More technological interventions are likely in the disciplines of ICT, digitalization, biotechnology, nanotechnology, agro-processing, precision agriculture and systems simulation, hence the associated manpower demand and shift in the pedagogy are to be brought in. Pluralistic approach and public-private partnership focusing on business/marketing/income orientation are needed for making the local extension sensitive to the challenges at micro level, strengthening the feedback mechanism and setting the right priorities. Promoting entrepreneurship and agri-startups, encouraging market-led extension strategies and intensive use of electronic media should be duly covered in the educational programmes.

- **Agriculture is Integral to Ecological Balance**. Agriculture being a risky (weather and market dependent) and low income occupation, makes farmers follow the cropping systems having assured market, resulting in serious depletion of resources, deterioration of soil health and ecological imbalance. Leveraging the growing preferences for nutri-foods, policy decisions, regulatory framework and incentives will be needed to reverse the trend. Steps taken by some state governments, such as discouraging certain crops or promoting others, or fixing the sowing dates for rationalizing water use, are showing promise. Long-term policies both for domestic and export trade, and support through subsidies linked to balanced use of natural resources and inputs can pave the way. Eco-friendly models of farming system, integrating natural, technical, economic and social aspects are needed to promote resource-use efficiency, sustainable intensification, climate smart agriculture, zero food waste/loss and enhanced food safety.
- **Small can be Bountiful**. More than 85% of farmers belonging to small and marginal categories primarily depend on agriculture for subsistence. Excessive fragmentation of farm lands, low factor productivity, vulnerability to climate change, poor value chain and lack of viable agro-industries are some of the key reasons for low profitability from agriculture in India, forcing millions to migrate to far off places in search of farm/non-farm employments. To reverse this trend by creating rural employment opportunities, an integrated approach is needed to aggregate small farms through reforms, digitization, need-based farm mechanization, creation of aggregation/collection centres, affordable transportation and market links. Shifting of some of the non-farm industries to rural areas also needs to be considered as a long-term strategy to – provide steady and equitable income to rural population, decongesting the cities and containing labour migration without affecting the economy. Dynamic retooling and retraining of the human resources would be essential.
- **Harnessing the Treasure of Traditional Knowledge**. An effective integration of traditional knowledge with modern agricultural technology will be desired for increasing the productivity while addressing the adverse impacts of climate change. To reap the benefits of ITK, we need sustained efforts in: (i) collection

and documentation of traditional knowledge relating to sustainable agricultural practices to build a National Database; (ii) a comprehensive policy framework to protect and utilize traditional knowledge and practices and facilitate better exchange, documentation and conservation of available agro-biodiversity; (iii) provisions for incentives and rewards to the saviours of ITK as well as access and benefit sharing (ABS); and (iv) translational research with focus on identification, validation and adoption of traditional agricultural practices. An apex body at the national level may be established to create wide awareness and acceptance of ITKs and to coordinate between various stakeholders for their adoption and mainstreaming.

- **Respect the Intellectual Investments in Innovations**. Generating new technologies and innovations to meet emerging challenges by the public and private sectors need to be encouraged through commensurate policies and necessary IPR regime. In this context, National Intellectual Property Rights (IPR) Policy, the Protection of Plant Variety and Farmers' Rights Act (PPV&FRA) and the Biological Diversity Act (BDA) of the Government of India need to be harmonized to ensure a win–win situation and to accelerate the pace of developing new innovations, and their quick access in the interest of farmers.
- **Take Technology to the Doors of Farmers**. Following Dr Norman E Borlaug's advice, a turnaround in the agricultural extension system will need to be brought in. There is a need to strengthen the existing extension system through partnerships with the private sector, NGOs, farmers' organizations, civil societies etc. imparting greater role to youth (including women) as Technology Agents and input providers. For showcasing and scaling of innovations, there is a need to establish technology parks and encourage farmer-led and paid extension work that is more efficient and accountable.
- **Scale-up and Scale-out**. Professionals, farmer producer organizations (FPOs), farmer producer companies (FPCs), self-help groups (SHGs), cooperatives and NGOs are to be effectively involved for scaling of innovations with an easy access to technology, policy and financial support and hand-holding from the research institutions. Thus, financing on easy terms, risk management and incentives from state administration will attract entrepreneurs to establish successful start-ups. Land reform act, including land tenure, rent contracts and land leasing should be streamlined to facilitate farms aggregation.
- **Empowering Women and Attracting Youth in Agriculture**. Urgent action is called at the national, regional and international levels to encourage women leadership at all levels and build collective advocacy to recognize their contribution towards agricultural development. For this the agricultural research for development (AR4D) agenda needs to be made gender-sensitive. Concerted efforts are needed to develop women friendly machineries, tools and technologies. It must be ensured that the institutions and legal support system promote women's ownership and equitable share in resources. To utilize India's human capital in agricultural development by attracting youth (including women), agri-education system needs to be reoriented towards farm innovations and agri-preneurship, by introducing high quality vocational/ non-degree courses and by providing funding

on easy terms to set up agri-business. Accreditation of skilled service providers in specialized fields will open up enormous scope of entrepreneurship and self-employment.

- **Build Back Better (and Differently)**. To overcome the unprecedented disruption caused by the COVID-19 pandemic, a holistic approach will be needed with agriculture at the centre stage of the national rebuilding process. To address the large and systemic challenges, inclusiveness and rapid conversion of knowledge into needed and commercial products will be the key to innovative and affordable solutions. Promoting the policy of Zero Hunger India, Make-in-India, *Swasth Bharat*, One Health, *Aatmanirbhar Bharat* and the like, technical and financial support to strengthen entrepreneurship, start-ups, Ministry of Micro, Small and Medium Enterprises (MSME) and other concerned Ministries and Departments will synergistically integrate to ensure social, economic and ecological sustainability towards building a green and strong India.

References

Aggarwal, P. K, Jarvis, A., & Campbell, B. M. (2018). The climate-smart village approach: framework of an integrative strategy for scaling up adaptation options in agriculture. *Ecology and Society, 23*(1), 14. Also available at https://doi.org/10.5751/ES-09844-230114.

Ahirwar, R, & Mondal, P. R. (2019). Prevalence of obesity in India: A systematic review. Diabetes and metabolic syndrome. *Clinical Research and Review, 13*(1), 318–321.

Babu, S. C., Joshi, P. K., & Sulaiman, V. R. (2019). Agricultural extension reforms: lessons from India. In S. C. Babu & P. K. Josh (Eds.), *Agricultural Extension Reforms in South Asia-Status, Challenges, and Policy Options* (pp. 41–60). Academic Press.

Bharati, J., Punetha, M., Kumar, B. S., Vidyalakshmi, G. M., Sarkar, M., Michael, J. D., & Singh, R. K. (2020). Genome editing in animals: an overview. In *Genomics and Biotechnological Advances in Veterinary, Poultry, and Fishes* (pp 75–104). Academic Press.

Blakeney, M., & Siddique, K. H. M. (Eds.). (2020). *Local Knowledge, Intellectual Property and Agricultural Innovation.* Springer Nature Singapore Pvt. Ltd, 247p.

Chand, R. (2019). *Transforming agriculture for challenges of 21st century.* Presidential Address, 102 Annual Conference Indian Economic Association, AURO University, Surat (Gujarat), 22p.

Chundawat Shishir, P. S. (2020). Ammonia-salt solvent promotes cellulosic biomass deconstruction under ambient pretreatment conditions to enable rapid soluble sugar production at ultra-low enzyme loadings. *Green Chemistry*. Also available at https://doi.org/10.1039/C9GC03524A

Economic Survey. (2019–20). *Economic Survey 2019–20*—Volume 1 (January 2020). Department of Economic Affairs, Ministry of Finance, Government of India, 286p

Fan, S. (2013). *Strategy paper on 'Ensuring Food and Nutrition Security in Asia: The Role of Agricultural Innovation.* Trust for Advancement of Agricultural Sciences, Pusa Campus, New Delhi, 11 January 2013, 20p.

FAO. (2020). Enabling agricultural innovation systems to promote appropriate technologies and practices for farmers, rural youth and women during COVID-19. Food and Agriculture Organization (FAO), Rome. Also available at https://doi.org/10.4060/ca9470en

FAO, IFAD, UNICEF, WFP and WHO (2018) *The State of Food Security and Nutrition in the World 2018. Building climate resilience for food security and nutrition.* Food and Agriculture Organization (FAO), Rome. Also available at www.fao.org/state-of-food-security-nutrition-in-the-world

Gatzweiler, F. W, & Von Braun, J. (2016). *Technological and institutional innovations for marginalized smallholders in agricultural development*. Springer International Publishing, Switzerland AG. ISBN 978-3-319-25718-1; XV, 435p.

GoI. (2020). *National Education Policy-2020*, Ministry of Human Resource Development (now Ministry of Education), Government of India, New Delhi.

Gulati, A, Joshi, P. K., & Landes, M. (2006). *Contract farming in India: An introduction* (e-book). International Food Policy Research Institute (IFPRI), National Center for Agricultural Economics and Policy Research (NCAP) and US Agency for International Development (USAID), New Delhi and Washington, DC.

Huang, M., Shao, M., Zhang, L., & Li, Y. (2003). Water use efficiency and sustainability of different long-term crop rotation systems in Loess Plateau of China. *Soil Tillage Research, 72*(1), 95–104.

IATT. (2020). *Guidebook for the preparation of science, technology and innovation (STI) for SDGs Roadmaps.* UN Inter Agency Task Team on Science, Technology and Innovation for the SDG, 66p.

ICAR. (2012) *Proceedings of first global conference on women in agriculture* (GCWA), 13–15 Mar 2012; organised by the Indian Council of Agricultural Research (ICAR), New Delhi & Asia Pacific Association of Agricultural Research Institutions (APAARI) at New Delhi.

ICAR. (2016). *Fifth deans' committee report*. Indian Council of Agricultural Research (ICAR), New Delhi, 807p.

IFPRI. (2020). *Global food policy report: building inclusive food systems-2020*. International Food Policy Research Institute (IFPRI), 1201 Eye Street, NW Washington DC 20005–3915, 110p.

IPCC. (2014). *Intergovernmental panel on climate change: summary for policymakers*. Fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

Jat, M. L. (2017). Outscaling natural resource management innovations. In *Paper presented to a dialogue on incentives and strategies for scaling-out innovations for smallholder farmers.* Trust for advancement of agricultural sciences, Pusa Campus, New Delhi, 30–31 Oct 2017.

Kumar, A. (2014). Integrated crop disease management in arid Rajasthan: A synthesis of indigenous knowledge with biocontrol. *Current Science, 107*(9), 1393–1399.

Kumar, V., Jat, H. S., Sharma, P. C., Singh, B., Gathala, M. K., Malik, R. K., Kamboj, B. R., Yadav, A. K, Ladha, J. K, Raman, A., Sharma, D. K., & McDonald, A. (2018) Can productivity and profitability be enhanced in intensively managed cereal systems while reducing the environmental footprint of production? Assessing sustainable intensification options in the breadbasket of India. *Agricultural Ecosystem and Environment*, *15*(252), 132–147.

Mittal, S., Mehar, M., & Hariharan, V. K. (2019). Information and communication technologies for strengthening extension services to reach the last mile in India. *Agricultural Extension Reforms in South Asia* 255–274.

MoA&FW (2020). Annual Report 2020. Ministry of agriculture and farmers' welfare, Govt of India, New Delhi.

MoSTE. (2015). *Indigenous and local knowledge and practices for climate resilience in Nepal, mainstreaming climate change risk management in development*. Ministry of Science, Technology and Environment (MoSTE) Kathmandu, Nepal.

NAAS. (2011). *Biosafety assurance for GM food crops in India.* Policy Paper 52, New Delhi, 15p.

NAAS. (2014). Proceedings of the 11th agricultural science congress, transforming agricultural education for reshaping India's future. In R. B. Singh, (Ed.), National Academy of Agricultural Sciences, New Delhi, 724 p.

NAAS. (2016). *Policy brief to accelerate utilization of GE technology for food and nutrition security and improving farmers' income*, Policy Brief 1, New Delhi, 12p.

NAAS. (2017). *Strengthening agricultural extension research and education—the way forward,* Strategy Paper No. 5, 2017. National Academy of Agricultural Sciences, New Delhi. 12p.

NIAP. (2017–18). *Annual Report*—2017–18. ICAR—National institute of agricultural economics and policy research. Indian Council of Agricultural Research, New Delhi.

NITI, A. (2018) *NITI Aayog Report on composite water management index (in 2018).* Government of India, New Delhi.

Pal S., Subhash, S. P., & Arathy, A. (2017). Upscaling agricultural innovations. In *Paper presented to a Dialogue on Incentives and Strategies for Scaling-out Innovations for Smallholder Farmers.* Trust for Advancement of Agricultural Sciences, Pusa Campus, New Delhi, 30–31 Oct 2017.

Paroda, R. S. (2018). Women's empowerment for agricultural development. In *Reorienting Indian Agriculture Challenges and Opportunities* (authored by Raj Paroda) (pp. 255–261), published by CAB International, Nosworthy Way, Wallingford, Oxfordshire OX10 8DE, United Kingdom.

Paroda, R. S. (2019a). *Urgency for upscaling agricultural innovations to meet sustainable development goals (SDGs).* Trust for Advancement of Agricultural Sciences, Avenue II, Pusa Campus, New Delhi, 23p.

Paroda, R. S. (2019b). *Report on policies and action plans for a secure and sustainable agriculture.* Committee Report submitted to the Principal Scientific Adviser to the Government of India, New Delhi, 198p.

Reddy, D. V. R., Ananda Kumar, P., Lava Kumar, P., Loebenstein, G., & Kameswara Rao, C. (2014). A Decade of Bt Cotton Technology in India—What has it Delivered and How Can it be Sustained? *Genetically Engineered Crops in Developing Countries* (pp. 145–160). Studium Press LLC.

Saxena S. (2017). *Incentives for patenting, innovation and partnership. Paper presented to a dialogue on incentives and strategies for scaling-out innovations for smallholder farmers.* Trust for Advancement of Agricultural Sciences, Pusa Campus, New Delhi, 30–31 Oct 2017.

Singh, R. B. (2011). *Towards an evergreen revolution—the road map.* National Academy of Agricultural Sciences, New Delhi, 61p.

Singh, R. B. (2013). *Climate smart agriculture towards an evergreen economy.* Presidential Address 20th AGM, 5th June 2013, National Academy of Agricultural Sciences, New Delhi, 32p.

Singh, R. B. (2014). Transforming agricultural education for reshaping India's future, presidential address., In *Proceedings NAAS 11th Agricultural Science Congress* (ed. R B Singh), Bhubaneswar, pp. 17–39.

Singh, R. B. (2015). *Zero Hunger India: The Challenge.* Dr. A. B. Joshi Memorial Lecture, National Academy of Agricultural Sciences, New Delhi, 44p.

Singh, R. B. (2019). *Agricultural transformation: The road to new India.* National Academy of Agricultural Sciences, New Delhi, 636p.

Sarkar, S., Padaria, R. N., Vijayragavan, K., Himanshu, P., & Jha, G. K. (2015). Assessing the potential of Indigenous Technical Knowledge (ITK) for Adaptation to Climate Change in the Himalayan and Arid-agrosystem. *Indian Journal of Traditional Knowledge, 14*(2), 251–257.

Swaminathan, M. S. (2007). *Agriculture cannot wait—new horizons in Indian agriculture* (ed. M.S. Swaminathan). Academic Foundation and National Academy of Agricultural Sciences, New Delhi, 550p.

Shilomboleni, H., De Plaen, R. (2019). Scaling up research-for-development innovations in food and agricultural systems. *Development in Practice, 29*(6), 723–734. Also available at https://doi.org/10.1080/09614524.2019.1590531.

Swarup, R. (2017). *Initiatives for Scaling Innovations in Agricultural Biotechnology, Paper presented to a Dialogue on Incentives and Strategies for Scaling-out Innovations for Smallholder Farmers.* Trust for advancement of agricultural sciences, Pusa Campus, New Delhi, 30–31 Oct. 2017. 23p.

TAAS. (2013). *Brainstorming on achieving inclusive growth by linking farmers to markets: Proceedings and Recommendations.* Trust for Advancement of Agricultural Sciences, Pusa Campus, New Delhi, 24 June 2013, 24p.

TERI. (2015). *Industrial and Urban Waste Management in India.* The Energy and Resources Institute, New Delhi.

Theisen, G., Silva, J. J. C., Silva, J. S., Andres, A., Anten, N. P. R., & Bastiaans, L. (2017). The birth of a new cropping system: towards sustainability in the sub-tropical lowland agriculture. *Field Crops Research,* (212), 92–94.

TIFAC. (2019). *Global technology watch group—sustainable agriculture. technology information forecasting and assessment council.* DST, Government of India, New Delhi, 112p.

Triberti, L., Nastri, A., & Boldani, G. (2016). Long term effects of crop rotation, manure and mineral fertilization on carbon sequestration and soil fertility. *European Journal of Agronomy,* (74), 47–55.

UNAIDS (2014) *GAP Report. United Nations Programme on HIV/AIDS (UNAIDS).* Geneva. ISBN 978-92-9253-062-4

United Nations. (2015). *Global sustainable development report* (p. 198p). United Nations.

United Nations. (2014). *World survey on the role of women in development.* United Nations, New York, 129p. Also available at www.unwomen.org.

Vats, S., Kumawat, S., Kumar, V., Patil, G. B., Joshi, T., Sonah, H., Sharma, T. R., & Deshmukh, R. (2019). Genome editing in plants: exploration of technological advancement and challenges. *Cells, 2019*(8), 1386. Also available at https://doi.org/10.3390/cells811/386.

Willer, H., Schlatter, B., Travnicek, J., Kemper, L., & Lernoud, J. (Eds). (2020). The World of organic agriculture. Statistics and emerging trends 2020. Research institute of organic agriculture (FiBL), Frick, and IFOAM-Organics International, Bonn.

World Bank Group (2020) *Agriculture Overview—World Bank Group.* Also available at https://www.worldbank.org/en/topic/agricultureoverview. Accessed 03 Nov 2020.

Structural Reforms and Governance Issues in Indian Agriculture

Seema Bathla and Siraj Hussain

1 Background

An examination of India's agricultural development since Independence brings to light the structural and institutional reforms that have been effected. The most significant advances were: consolidation of land holdings, public investment in agriculture and major and medium irrigation systems, improved prices and procurement policies and regulated marketing of agri-produce. In addition, the availability of institutional credit improved as a result of changes in the financial architecture comprising commercial banks, regional rural banks and cooperatives. The Food Corporation of India (FCI) enabled easy procurement of wheat and paddy at pre-announced minimum support prices (MSP), while the establishment of regulated wholesale markets facilitated the sale of produce under the Agriculture Produce Market Committee (APMC) Act, 1966. Stocking limits for cereals and pulses prescribed under the Essential Commodities Act (ECA), 1955 helped check hoarding. The government also enlisted agri-input companies to ensure uninterrupted supply of seeds, fertiliser, pesticides and other inputs to farmers at prices lower than their existing market rates, assuring them timely payment and compensation for any loss incurred.

The political unanimity for a state-led model of development and the proactive interventionist policy of the Centre transformed Indian agriculture. Two northern states—Punjab and Haryana—were pioneers in the adoption of the high yielding varieties (HYVs) of seeds, and allocation of sizeable area to wheat during the late

S. Bathla (✉)
Centre for the Study of Regional Development, Jawaharlal Nehru University, New Delhi, India
e-mail: seema.bathla@gmail.com

S. Hussain
International Council for Research on International Economic Relation, New Delhi, India
e-mail: sirajnoida@gmail.com

R. Chand et al. (eds.), *Indian Agriculture Towards 2030*,
India Studies in Business and Economics,
https://doi.org/10.1007/978-981-19-0763-0_9

1960s and the 1970s. In due course, a few southern states, notably Andhra Pradesh and Tamil Nadu, also witnessed higher innovation, private investment and production of paddy and diversified value-added products. The Green Revolution took agriculture on to a higher growth path and India achieved the overriding goal of food security and self-sufficiency, which significantly contributed to lessening hunger and rural poverty.

These achievements were followed by impressive successes in the White (milk) and Yellow (oilseeds) Revolutions during the 1980s. Unfortunately, by that time, productivity growth in agriculture had started to decelerate due to the reduction in public investment on major and medium irrigation projects, delays in the completion of existing projects and the emergence of anti-dam movements (Gulati & Bathla, 2001). The diminishing returns from public investment in irrigation also set in, along with an unsustainable use of natural resources. The government's efforts to support agriculture through subsidised inputs failed to accelerate the productivity of land and provide alternative occupations to rural households. Even during the economic reforms of the 1990s, agriculture remained a neglected sector with insignificant policy interventions. It was only towards the end of the 1990s, when the Centre gave handsome increases to the MSP of wheat and paddy and encouraged exports of rice and other commodities, that the terms of trade (agriculture price relative to industry price) became favourable to agriculture. India's comparative advantage was identified in cotton, groundnut seed, soybean seed, protein meals, spices and basmati rice. To realise the potential of these crops in the global markets and be compatible with the stipulations under the Agreement on Agriculture of the World Trade Organization (WTO), the government reduced farm protection by lowering tariffs as well as non-tariff barriers. However, as envisaged, an increase in exports could not help revive agricultural growth. Cereals exports became uncompetitive owing to increase in their support prices. The exports were also affected by price volatility in the global markets, transboundary threats, surge in imports and higher competition.

Agriculture continued to face serious challenges, including uneven regional growth, rising fiscal constraints, mounting subsidies, failing institutions that are responsible for managing public canals, increasing fragmentation of holdings, labour-intensive farming and depleting groundwater and solid nutrients. These were serious impediments for sustained agricultural growth and farmers' livelihoods (Singh, 2019). From the early 2000s, the Centre focused on structural changes through increased budgetary outlays towards major, medium and micro irrigation projects, rural infrastructure, fertiliser and power subsidies, various flagship programmes, including that on irrigation, and the initiation of income support schemes for farmers. The MSPs of food grains were hiked and far reaching reforms were initiated in the marketing of agri-produce, the major ones being allowing inter-state grain movement and contract farming under the aegis of the Model APMC Acts of 2003 and 2017.[1]

[1] The Model APMC Act of 2017 is termed as Agriculture Produce and Livestock Contract Farming and Services (Promotion and Facilitation) Act, 2017.

These measures, however, could not make uniform progress across states. In some, private investment increased and the transition began. In others, especially in the eastern regions—which also lacked public investment in irrigation, roads and other infrastructure and marketing support—stagnation continued. Implementation of the Bringing Green Revolution to Eastern India (BGREI) programme initiated during 2010–11 (now a sub-scheme of *RAFTAAR-Rashtriya Krishi Vikas Yojana*[2]) helped in the adoption of technology, building of assets, farm renovation, seed production and distribution, backed with the procurement of paddy at MSP. Agriculture growth did pick up in the eastern states, but they continued to face low levels of productivity and risks relative to other states due to variations in weather and commodity prices (Joshi & Kumar, 2016; Hoda et al., 2017).

The increase in output price barely corresponded with the rise in input costs and resulted in an agrarian crisis in many regions. The worst affected were smallholders and rural labourers who not only lack technical know-how and access to finance but also have low risk-bearing capacity to shift to non-farm activities. Consequent upon a steady decline in the net returns (income) of farmers in some states, a shift from a production-based agriculture policy towards an income-based policy framework has been suggested (Saxena et al., 2015; MoA&FW, 2018). Agriculture, with a 15% share in the national income, still absorbs more than 45% of the labour force, indicating limited success in achieving structural transformation. Binswanger-Mkhize and D'Souza (2012) maintained that India's structural transformation process is atypical, due to the slow pace of reallocation of labour from a low productivity sector, namely agriculture, to high productivity sectors. It is also characterised as "stunted", with the exiting labour moving primarily into the rural non-farm and informal sector instead of industry and services and also becoming increasingly 'casualised'.

The COVID-19 pandemic in 2020 has added a new dimension to the entire gamut of issues that the agriculture sector has been facing for long. Government intervention in this sector is considered necessary to boost production as well as to maintain supply in order to keep commodity prices at manageable levels. The Centre has spearheaded institutional reforms backed with a financial stimulus in order to reinvigorate private investment, infrastructure development and post-harvest technology. It also passed three Acts with the objective of addressing the structural weaknesses inherent in the sale, marketing and stocking of agri-produce being governed under the state-run APMC markets. In January 2021, the Supreme Court of India stayed the implementation of three laws. This was followed by a decision by the Central Government, in November 2021, to repeal them. Since agriculture is a subject in the State List of the Constitution of India, it is important to consider how the states should amend their existing policies and institutions and frame marketing reforms to raise the income levels of farmers, ensure sustainable agriculture and bring competition.

This chapter has done an in-depth analysis of four critical areas and attempted to unravel the governance issues under each:

---

[2] *Rashtriya Krishi Vikas Yojana* (RKVY), National Agriculture Development Scheme, aims to give a fillip to agriculture. It was rebranded as RAFTAAR, which is the Hindi word for speed and is the acronym for Remunerative Approaches for Agriculture and Allied sector Rejuvenation.

(a) Centre-state fiscal relations and shared responsibilities for agriculture development;
(b) public expenditure policy to compare spending on investment and subsidies in agriculture relative to other economic sectors and the relationship between public investment in agriculture and private (farm household) investment;
(c) interventions in the input and output subsidy regimes and the feasibility of replacing the existing price support system with direct income support to farmers; and
(d) reforms in agriculture pricing and marketing and the implications of the three new Acts.

The rest of the chapter is organised into four sections. Section 2 sets out India's federal structure, focusing on agriculture development and the Centre's role in the form of various schemes and grants and the governance issues in the agriculture sector. Section 3 analyses public spending on capital formation and input subsidies in agriculture vis-à-vis other economic sectors and their relation with private (farm household) investment and national income. It also examines possible ways to augment private investment in agriculture and rationalise input subsidies through alternate methods, including direct income support. Section 4 analyses state intervention in transactions relating to agriculture output, focusing on procurement of grains at MSP, and also explains the implications of the three new laws enacted in 2020 for state governments and the farmers. Finally, Sect. 5 sums up the key issues and suggests the way forward.

2 Agriculture Under a Federal Structure in India and Governance Issues

The power, functions and responsibilities of the Centre and the states are primarily governed by the Constitution of India. The subjects that each can legislate on and administer are set out in three lists—Union, State and Concurrent List. There is, however, an asymmetry in the fiscal relations, with the states having larger expenditure responsibilities than the Centre but lesser sources of revenue. Tiwari and Surya (2019) and Sahoo (2015) have highlighted the fact that the fiscal deficit and the revenue deficit of states have been growing due to an excess of their budget expenditure (excluding borrowings) over budget receipts and revenue expenditure over revenue receipts. A shortfall in the revenues over the requirements reflects the inefficiency of the respective governments to meet their regular or recurring expenditures.

States finance their expenditures through their own tax and non-tax resources, transfers from the Centre (their share in the net proceeds of the Centre's tax revenues set out by the Finance Commissions[3]), grants and transfers for implementation of

[3] The Finance Commission is a constitutional body set up by the President every five years mainly for the purpose of the distribution between the Centre and the states of the net proceeds of taxes

Centrally sponsored schemes[4] (CSSs) and borrowings. States have, over the years, been demanding a larger share in the tax revenue of the Centre[5] as well as greater flexibility and autonomy in the implementation of CSSs (as these come with conditions attached to them, failure to meet which results in withholding of funds). Successive Finance Commissions have tried to give more financial autonomy to the states; the Fourteenth Finance Commission increased their share in the pool of taxes from 32 to 42%. However, states continue to feel less empowered in decision-making (Singh & Singh, 2016; Patnaik, 2018).

Coming specifically to Centre-state relations in the primary sector, Singh (2008) adopted both the constitutionalist and issue-oriented approach.[6] Under both, the issue of fiscal federalism assumes importance as it has implications for the devolution of funds to states and possible ways to resolve the conflicts that may arise due to the criterion adopted to share revenues and the use of various types of taxes by different levels of government. The Constitution places the agriculture and allied activities and irrigation (including flood control) sectors under the jurisdiction of states (Items 14 to 17 in List II of the Seventh Schedule). However, the Centre plays a vital role in these sectors in many ways. Through the Union Budget, it provides financial outlays to the Indian Council of Agriculture Research (ICAR) to disburse funds to the State Agricultural Universities for research and development. It provides funds for inter-state rivers and fisheries outside territorial waters. The expenditure on fertiliser and food subsidies is borne entirely by the Centre, with the objective of real-time monitoring of commodity prices, production and other factors that may result in food insecurity. Similarly, it bears the entire cost of procurement of food grains at MSP and its distribution through fair price shops under the public distribution system (PDS). From 1970 to 1980, it executed 'Operation Flood' (White Revolution) to create a

---

and setting the principles which should govern the grants in aid of the revenues of the states out of the Consolidated Fund of India.

[4] CSSs form a major part of the Central assistance given to states to implement the development initiatives in certain priority areas. In 2016–17, the Centre approved merging the 147 CSSs and bring the number down to 66 for effective implementation and monitoring. The number has been further rationalised to 28 umbrella schemes of which ten are funded fully by the Centre and the remaining are funded in the ratio of 60:40 between the Centre and the states.

[5] The fund distribution among the states is based on a formula recommended by the respective Finance Commissions, with some changes in the percentage assigned under each category. For instance, the Fourteenth Finance Commission (2015–2020) recommended fund distribution on the basis of population (17.5%); area (15%); forest cover (7.5%); demographic changes (10%); and income distance between states (50%). The Fifteenth Finance Commission (2020–2025) has recommended inclusion of tax effort as another criterion under which states with higher tax collection efficiency should be rewarded.

[6] The constitutionalist approach underlines the fact that agriculture and related activities are subjects within the jurisdiction of states (List II of the Seventh Schedule of the Constitution). The Centre encroaches on states' sphere through the use of constitutional provisions—the Centre can overrule the states in matters of 'national interest'. This approach thus focusses on the degree of states' autonomy in agriculture vis-à-vis Centre's control by analysing the case of Punjab where agriculture was made a dominant economic activity during the 1960s to help attain national food security. In contrast, the issue-oriented approach identifies specific issues involving Centre-state relations, such as CSSs, pricing of agricultural commodities, input supply, credit and research and development.

nationwide milk grid. The National Dairy Development Board was permitted to retain money received from the sale of skimmed milk powder and butter oil gifted by the European Union through the World Food Programme.

Though the Centre implements several programmes to meet the national goals of food security, elimination of hunger, malnutrition and poverty, and financially supports states in such endeavours, the discontent of the states has endured. Almost every state is confronted with revenue deficits and resorts to borrowings, either from the Centre or from other funding sources to meet the revenue shortfalls. The fiscal burden of states has also been increasing due to farm loan waivers and initiation of income support schemes,[7] similar to that of the Central government's PM-KISAN.[8] A few state governments allocated between 9 and 43% of their agriculture budget to targeted income and investment support schemes (Tiwari and Surya 2019). This combination of expenditure on loan waivers and income support schemes has resulted in higher cutbacks, in particular on investments in agriculture and irrigation. Even if Central funds are available to the states, they come with certain conditions which states may not be able to fulfil and, hence, are unable to spend the allocated amount. For instance, under RAFTAAR, a few states have not spent the allocated amount under two heads—micro irrigation and machinery—perhaps due to lesser requirements by the farmers for these, indicating that states may be given some autonomy to redirect such expenditures (Bathla and Kannan 2020).

Based on the recommendations of the Fourteenth Finance Commission, the Centre increased the share of states in the net proceeds of its tax revenues. In 2015–16, the Centre initially decided to reduce its share in all the CSSs, which was in the range of 75–100%, to a uniform 50%, which meant that states would have to bear a higher share of the expenditure. Several schemes of the Ministry of Agriculture and Farmers' Welfare (MoA&FW)[9] were to follow this changed pattern of funding. However, following protests by state governments, the Centre constituted, in March 2015, a sub-group of ten Chief Ministers and one Lieutenant Governor on rationalisation of CSSs. On 17 August 2016, the Centre revised the sharing pattern based on the recommendations of the sub-group. The existing 66 CSSs were merged into 20 core schemes, six core of the core schemes and two optional schemes. The Centre's share of funding stayed at 100% in the core schemes. For the other two categories, the Centre bore 90% of the expenditure in the case of the eight north-eastern states and the Himalayan states of Uttarakhand, Himachal Pradesh and erstwhile Jammu and Kashmir; these states were to contribute 10% of the expenditure. In the case of all other states, the sharing ratio was fixed at 60:40 between the Centre and states

---

[7] Andhra Pradesh—YSR *Rythu Bharosa*; Haryana–*Mukhyamantri Parivar Samman Nidhi*; Jharkhand—*Mukhyamantri Krishi Aashirvaad*; Odisha—*Krushak* Assistance for Livelihood and Income Augmentation (KALIA); Telangana—*Rythu Bandhu*; West Bengal—*Krishak Bandhu;* Chhattisgarh—*Rajiv Gandhi Kisan Nyay Yojana*.

[8] Pradhan Mantri Kisan Samman Nidhi.

[9] These include Mission for Integrated Development of Horticulture, RAFTAAR, National Livestock Mission, National Mission on Sustainable Agriculture, Dairy *Vikas Abhiyaan*, Veterinary Services and Animal Health (Dairy Development Mission), National Rural Drinking Water Programme and Pradhan Mantri Kisan Samman Nidhi (PM-KISAN).

respectively. In another significant change, the funds for CSSs were now to be routed through the budgets of state governments instead of the earlier practice of the Centre directly releasing the funds to the implementing institutions.

In the case of irrigation water, during the Twelfth Five-Year Plan period (2012–17), the Command Area Development and Water Management Programme (CADWM) was implemented *pari-passu* with the Accelerated Irrigation Benefit Programme (AIBP). In the Union Budget of 2014–15, INR 89.92 billion was provided for AIBP. Since 2015–16, the programme is being implemented under the Pradhan Mantri *Krishi Sinchai Yojana* (PMKSY, Prime Minister Agriculture Irrigation Scheme)—*har khet ko pani* (water for every farm). The ongoing CADWM programme has now been restricted to the implementation of command area development works of 99 prioritised AIBP projects. In 2016–17, the Centre initiated an innovative model of funding the prioritised projects through extra-budgetary resources (EBR). A Long-Term Irrigation Fund (LTIF) was created in the National Bank for Agriculture and Rural Development (NABARD). NABARD provides loans, with a 15-year tenure, to cover the share of the Centre as well as the states. The Central share is provided to the National Water Development Agency (NWDA), which comes under the jurisdiction of the Ministry of Jal Shakti; loans for the state share are given to the state governments. Since April 2018, loans towards the Centre's share are entirely funded through EBRs in the form of fully-serviced Government of India bonds while the state's share (increased from about 10 to 40% of the project cost since 2015–16) is entirely funded through market borrowings by NABARD. NABARD extends loans to states at 6% per annum, and the Centre compensates the cost that NABARD incurs through interest subvention. The Union Budget for 2020–21 allocated INR 19 billion for payment of interest and INR 4.75 billion for payment of the principal for the NABARD loan to the NWDA.

While the Constitution places agriculture production and irrigation development (including flood control) squarely under the jurisdiction of states, it has taken a different approach to the marketing of agri-produce. Article 301 says trade and commerce will be free across all of India, while Article 302 gives Parliament the power to legislate on inter-state trade (See Box 1: Constitutional provisions on trade). The idea behind this is to break inter-state barriers in order to make the entire country as one market. The interpretation of this provision by the Centre is that freedom of trade is not confined to only inter-state trade, but also extends to intra-state trade and commerce. States, on the other hand, quote Article 304 to aver that the state legislature has powers to legislate on trade and commerce and can impose tax and restrictions on intra- and inter-state trade in the public interest.[10] In particular, state governments cited Article 304(b) to justify the restrictions on trading imposed through the Model APMC Acts (2003 and 2017) as these were considered reasonable and in public interest.

[10] Even during the initial period of lockdown due to COVID-19 (from 24 March to 3 May 2020), the movement of agricultural produce between two states—Karnataka and Kerala was stopped. The Government of Karnataka decided to block all 23 roads connecting with Kerala because Kasaragod in north Kerala was a hotbed of coronavirus cases.

Box 1: Constitutional Provisions on Trade

Article 301—Freedom of trade, commerce and intercourse:

"Subject to other provisions of this Part, trade, commerce and intercourse throughout the territory of India shall be free".

Article 302—Power of Parliament to impose restrictions on trade, commerce and intercourse:

"Parliament may by law impose such restrictions on the freedom of trade, commerce or intercourse between one State and another or within any part of the territory of India, as may be required in the public interest".

Article 304—Restrictions on trade, commerce and intercourse among States:

"Notwithstanding anything in Article 301 or Article 303, the Legislature of a State may by law -

(a) impose on goods imported from other States or the Union territories, any tax to which similar goods manufactured or produced in that State are subject, so, however, as not to discriminate between goods so imported and goods so manufactured or produced; and
(b) impose such reasonable restrictions on the freedom of trade, commerce or intercourse with or within that State as may be required in the public interest:

Provided that no Bill or amendment for clause shall be introduced or moved in the Legislature of a State without the previous sanction of the President".

However, increased grain production over the last three decades demanded a less restrictive marketplace. The APMC Act of 1966 and regulations restricted fair competition not just within the states but also within the wholesale markets, popularly known as *mandis*. Restrictions were imposed on the number of new licences issued to traders within a *mandi* and a separate licence was required for every *mandi*. So constricting was the implementation of the Act by most states that, over time, it prevented the entry of new market players within APMCs and even outside. APMCs also discouraged contract farming being brought under the Model Act of 2003 as companies have to register with *mandis*, pay market fee and levies without receiving any services and often face restrictions on stock holdings of produce.

In many places, the auction of produce was seen as opaque, resulting in denial of fair competition and prices to farmers. States earn substantial revenues from *mandi* fee/cess/taxes, which, in some cases, was fixed as high as 6.5% over and above the *arhatiya*'s (commission agents) commission of 2.5%, with little infrastructure and facilities being provided to the farmers (Acharya, 2017). All this explains why agri-markets continue to be less competitive and inefficient in terms of proper discovery of commodity prices, have low margins for producers and high margins for wholesalers.

The Centre, in several Union Budgets, proposed reforms to improve the marketing system. A few states, namely Punjab, Karnataka and Maharashtra, have amended their APMC Acts, encouraged contract farming,[11] and introduced direct farm-to-kitchen models, but clear-cut rules on these have mostly been missing.

A breakthrough came in June 2020 when the Centre promulgated three ordinances (which were later legislated into Acts by the Parliament in September 2020) with the objective of enabling one common market for agri-produce across the country, freeing farmers from stringent restrictions on selling their produce anywhere, enabling them to enter into contracts with processors, aggregators or other agencies for better prices, lowering their risks and enabling them to earn a higher income. Some state governments criticised these laws on the grounds that they were bypassed and that the laws would have the effect of (a) reducing or doing away with grain procurement at MSP, (b) reducing market fees earned from transactions and (c) putting agriculture in the hands of the private (corporate) sector. Details of these laws as well as the underlying implications of each are discussed in Sect. 4.

In sum, the Centre has never been disconnected from agriculture, as the Constitutional provisions would suggest. Agriculture serves certain national development goals and thus requires considerable handholding, especially during times of natural calamities and market risks. States, in turn, lack resources and are highly dependent on the Centre for funds and grants. Both have to work in tandem, even if there are conflicts in their respective agriculture policy agendas. Marketing is a key example, where states have built a monopoly and earn significant revenues from levies, taxes and cess on transactions in the wholesale/regulated markets without realising the adverse impact that this has on price stability, efficiency, farmers' income and the formation of supply chains. However, states also have their compulsions. With no revenues from tax on land and agriculture income, they have a high level of dependence on *mandi* fees and taxes. Their reliance on the Centre for financing of the agriculture and irrigation sectors will, therefore, continue in the future as well. The question of whether such interventions are seen as an assault on the federal structure and autonomy of the states will remain. The Centre follows the recommendations of Finance Commissions on the sharing of revenues with the states. However, the status of agriculture development differs across states and the Centre's one-size-fits all approach in its agriculture policies may not suit the specific needs of states. For instance, grants under CSSs have conditions attached to them and the states lack the flexibility to modify the spending in line with their requirements. Institutions such as the Inter-State Council and NITI Aayog should be involved in resolving disagreements, if any. In order to ensure proper spending of assigned grants, there needs to be more coordination within the existing institutional structure to prevent overlapping or duplication of schemes and their effective implementation.

In many ways, in the quasi-federal polity of India, governance poses unique challenges, not only at the level of implementation but also while enacting laws, both

[11] As of October 2016, 20 states amended their APMC Acts to provide for contract farming, whereas Punjab adopted a separate law on contract farming. In all, 14 states notified rules related to contract farming.

at the Centre and in the states. 'Governance' may be understood to be the traditions and institutions by which authority is exercised (Kaufmann et al., 1999). It may include the process by which governments are selected, monitored and replaced; a government's capacity to formulate and implement sound policies; and the respect of citizens and the state for the institutions that govern economic and social interactions. As per the United Nations Development Programme (2014), good governance is considered to be broader than institutions and includes the people, the state and the interactions between them. Good governance is important for promoting economic growth and improving developmental outcomes such as per capita income, literacy, conservation of natural resources and poverty reduction, among others. The mechanisms that promote good governance are transparency, democratic institutions and effective public services. Its processes may include the quality of participation (which includes the involvement of the most vulnerable sections of society and the poorest) and the accountability of institutions to the public and other stakeholders. Bad governance leads to corruption, poor and inefficient implementation of programmes, weak social norms and increased social and political conflict over the access to and use of resources (Keuleers, 2004).

Needless to say, the concept of governance and the indicators that measure it vary, depending on context and sector. Even though the government has repealed the three laws enacted by Parliament in September 2020, the need for marketing reforms still remains. Since agriculture impacts millions of people, farmers and consumers, good governance in the case of agri-marketing reforms would imply wide consultation with various stakeholders.

At the level of implementation, the main instrument of governance is the officers' cadre of the Indian Administrative Services (IAS). These officers are appointed by the President of India but they are allotted to a specific cadre (a state or Union Territories) and can work either in the states or come to the Central government on deputation. The IAS officers hold most of the important positions at both levels and are at the centre of the universally agreed target of 'good governance'. The Central government has the benefit of expert advice from the Department of Agricultural Research and Education (DARE) in the MoA&FW. This department is headed by an eminent agricultural scientist. The ICAR, which is entirely managed by scientists, researchers and other professionals in every field of agriculture and allied sectors, reports to DARE. It has 64 research institutions, 14 national research centres, four deemed universities, 13 project directorates and six national bureaus. The government, thus, has sufficient professional expertise, based on science and research, to advise it in the formulation of policies.

When judged by the broad governance parameters,[12] Indian governance since Independence largely measures up. By and large, political violence has not affected large parts of India and in spite of political instability in some states, mid-term elections, short tenures of chief ministers, defections from one party to another, etc., the agriculture administration has carried on. However, the effectiveness of government varies from state to state.

The actual implementation of policies at the district level is done by the officials of the respective state governments. There are qualified professionals appointed by the states in agriculture, horticulture, animal husbandry and poultry, fisheries, dairy, etc. Their work is coordinated by the district magistrate. At the state level, the departments are headed by secretaries. In most states, the work of departments is coordinated by the Agriculture Production Commissioner (APC) or Development Commissioner (DC) and the Chief Secretary. However, in most states, the secretary in charge of irrigation and power (electricity) does not report to the APC/DC, as these two departments get a large allocation of funds and they are considered more important than the departments of agriculture, animal husbandry, horticulture, fisheries, food and public distribution etc. The coordination between departments at the state level, therefore, becomes the responsibility of the chief secretary. However, the most influential role in the formulation of policies is played by the Department of Finance in both the Centre and the states. This department prepares the final budget, places it before the parliament or the state assembly and determines the allocation of funds across other ministries and departments.

Administrative reforms, which fall within the ambit of both the Centre and the states, can augment state capacity, which is imperative to bringing transformation in India's agriculture sector. A closer look at two key parameters of good governance—growth in gross domestic product in agriculture and allied activities (GDPA) and farmers' income—shows wide variations in these across states (Fig. 1). While some states have shown high growth in gross state domestic product in agriculture and allied activities (GSDPA) and farmers' income, several others have experienced only mild growth. Importantly, several subsidies are provided by the state government in addition to Central subsidies. Both have an influence on agricultural growth and farmers income. The Centre takes several policy decisions relating to MSP, procurement of produce, subsidies on crop insurance, fertilisers, food, interest subvention on credit and direct income support (PM KISAN), exports and budgetary grant for capital work on irrigation projects. These are highlighted in the subsequent sections.

[12] Kaufmann et al. (2009) shortlisted six parameters to assess good governance in a country. These are: voice and accountability; political instability and violence; government effectiveness; regulatory burden; rule of law and graft. Based on these dimensions, Debroy and Bhandari (2012) constructed an economic freedom index of Indian states to demonstrate how economic governance differs among them and is directly correlated with the well being of citizens. Similarly, at the sectoral level, Tortajada (2010) and Kannan et al. (2019) developed irrigation governance indicators to examine their impact on the public irrigation system and agriculture productivity.

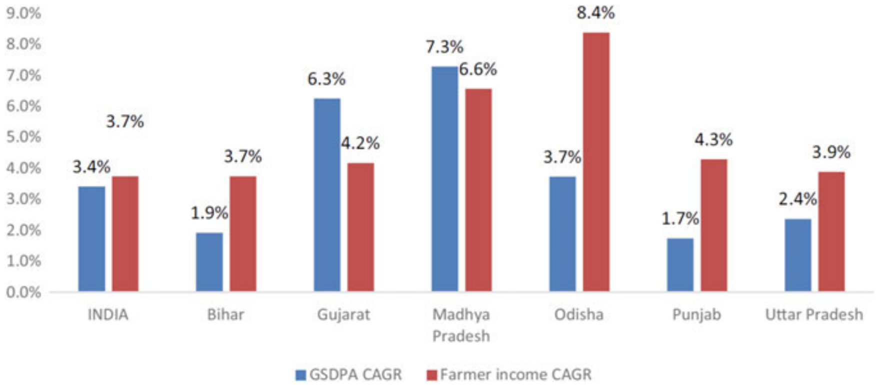


Fig. 1 Annual rate of growth in GSDPA and farmer income CAGR (%) 2002–3 and 2015–16. Chart depicting growth in GSDPA and farmer income 2021. *Source* Gulati et al. (2021). Compound Annual Growth Rate (CAGR) of GSDPA and farmer income between 2002–03 and 2015–16 based on data from NSSO, MoSPI) and NABARD. *Note* Growth rates are estimated as CAGR of terminal values of agricultural and allied-GDP and farmers' income for the years 2002–03 and 2015–16

3 Public Spending on Investments and Subsidies in Agriculture

Sen (2016) highlights the fact that despite an increase in the devolution of funds from the Centre, state budgets show fiscal deficits. Hence, states have to either adjust spending patterns between revenue and capital accounts, or bring modifications in the budgetary outlays across various activities, or resort to borrowing. This section looks at the long-term trends in public expenditure (on capital and revenue accounts) to gauge how far agriculture and irrigation have borne the brunt of the resource crunch that states face. Since public investment in agriculture and irrigation has a 'crowding-in effect' on private (farm household) investment, the section also examines trends in the latter. The analysis would be useful in understanding the expenditure policy in terms of directing resources towards the capital account (for asset creation) or revenue account (for provision of subsidies), and exploring ways to increase fiscal space for investments in agriculture.

As shown in Fig. 2 and Table 1, during the 1960–70 period, the average gross capital formation in agriculture and allied activities (GCFA), at constant 2011–12 prices, was INR 314 billion, which significantly increased to INR 566 billion during the 1980–90 period. It then remained somewhat stagnant for many years but increased from the early 2000s to reach INR 1,583 billion during 2000–09 and then to INR 2,639 billion during 2010–18. The change in stock (CIS) varies but roughly constitutes 5–9% in the total GCFA, which is at a reasonable level. The private GCFA—mainly by the farm households—witnessed a steady increase compared to public GCFA. The latter picked up from 2003–04, showed a declining trend during 2007–12 but again increased from 2013–14.

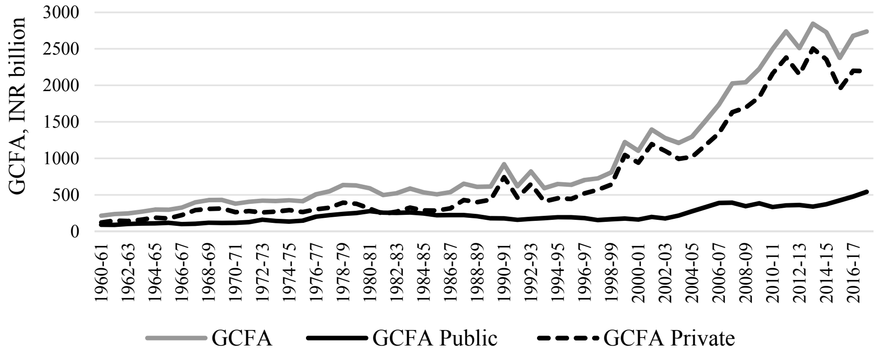


Fig. 2 Gross capital formation in agriculture & allied sector: 1960–61 to 2017–18 (at 2011–12 prices). *Source* National Accounts, various years, National Accounts Division, MoSPI http://www.mospi.gov.in/National Accounts Statistics

Table 1 Public and private GCFA, GDPA: 1960–61 to 2017–18 (at 2011–12 prices)

	INR billion				Annual rate of growth (%)			
Average	GCFA	GCFA Public	GCFA private	GDPA	GCFA	GCFA public	GCFA private	GDPA
1960–61 to 1969–70	314	106	209	4145	8.43	2.56	11.56	1.51
1970–71 to 1979–80	478	174	304	5215	5.97	8.97	4.37	1.74
1980–81 to 1989–90	566	234	332	6716	1.56	−3.96	5.43	2.97
1990–91 to 1999–00	770	175	595	9245	2.66	−0.15	3.38	3.34
2000–01 to 2009–10	1583	287	1296	11,926	7.89	11.28	7.22	2.57
2010–11 to 2017–18	2639	401	2238	16,450	0.39	6.68	−0.76	4.10

Source National Accounts, various years, National Accounts Division, MoSPI—http://www.mospi.gov.in/National Accounts Statistics

Note (1) GDPA (gross value added in agriculture and allied activities) is represented by GVAA (gross value added in agriculture and allied activities; (2) Data is converted into real prices at 2011–12 base using gross domestic product (GDP) and gross domestic capital formation (GDCF) deflators.

Comparing estimates on GCFA shows that both public and private GCFA have increased three times during the 2000s as compared to the 1990s. Private household investment accounts for a significant share (83%) in total investment. Although many private companies are making forays into agriculture, their share in total GCFA remains low and stagnant at almost 3%. Public GCFA mainly pertains to major, medium and minor irrigation systems and its share has consistently fallen from 33.76% during the 1960s to 15.19% during 2010–2018. A steady decline in the share of public GCFA in total investment has been explained by the bias in government expenditure towards the revenue account in the form of an increase in input subsidies and day-to-day expenses, inadequate funds and low priority towards spending on agriculture and rural development in comparison to that in other sectors (Chandrasekhar and Ghosh, 2002; Bathla, 2014).

As Table 1 shows, the annual growth rate of public and private GCFA declined between the 2000–01 to 2009–10 period and the 2010–11 to 2017–18 period. A slower increase in private investment during the 1980s and the 1990s has been attributed to deceleration in the rate of growth of public investment, unfavourable terms of trade and an inadequate flow of institutional credit (Bathla et al., 2020). A revival of private GCFA since the 2000s is explained by a big push in public GCFA, complemented with favourable terms of trade, weather conditions and adequate flow of institutional credit. Other factors may include an increase in the number of holdings due to fragmentation, diversification towards high-value crops, coupled with an increase in the demand for processed food (Chand & Kumar, 2004; Bathla 2014). Increased levels of investments on public and private accounts, complemented with other factors seem to have helped agriculture sustain a steady rate of growth close to 3% per annum for three decades (1980–2000s) (Chand & Parappurathu, 2012; Bathla and Kumari 2017). In the 2010–11 to 2017–18 period, India, for the first time, achieved a higher rate of growth at 4.10%.

Notwithstanding an impressive rate of growth in GCFA, its share in gross domestic capital formation (GDCF) has been declining. It was 16.56% in 1960–61, rising to 21.47% in 1968–69 and then decelerating for at least two subsequent decades. Although some improvement was observed in the share of GCFA in GDCF in 2001–02, at 11.89%, it fell to 6% again in 2017–18 (Annex Fig. 6). A significant fall in it can be attributed to public GCFA the share of which in public GDCF decreased from 16.4% in 1960–61 to 5.26% by 2017–18 (Annex Fig. 7). During the second half of the seventies, the government prioritised investment, which is visible in the form of a high share of public GCFA in public GDCF, at almost 20%.

A fall in the share of GCFA in GDCF may suggest that the latter, which constitutes almost 35% of GDP, has been increasing due to higher investments in the non-agriculture sectors relative to the agriculture sector. The share of GCFA in GDP improved from 6% in 1960–61 to 18% in 2013–14, which subsequently fell to 14% in 2016–17. This demonstrates that state governments accord less priority to agriculture and irrigation in comparison to this sector's contribution to national income. The state level agriculture orientation index (AOI) confirms the low priority given to agriculture. As Annex Table 3 shows, the index has improved in Chhattisgarh, Gujarat, Himachal Pradesh, Karnataka, Kerala, Punjab and Uttarakhand, but weakened in

Haryana, Jharkhand, Madhya Pradesh, Maharashtra, Rajasthan, Uttar Pradesh and West Bengal.

While this aspect merits attention, it needs to be noted that that the official estimates (National Accounts Statistics or NAS) on public GCFA relate to major, medium and minor irrigation systems and not agriculture. Investments in 'agriculture and allied activities' such as in crop and animal husbandry, soil conservation, forestry, livestock, storage etc., are not accounted for in the official statistics; instead, these are listed under the economic and functional classification in the System of National Accounts. A closer look at the magnitude of GCFA shows underestimation of investment in this sector. On average, public investment in agriculture-forestry-fishing was INR 107 billion during 2011–12 to 2017–18 and was much lower than the GCF in water supply (INR 146 billion) and transport and communication (INR 761 billion). It is somewhat higher than that in other economic activities such as mining, manufacturing, construction, electricity and gas etc. As shown in Annex Figs. 6 and 7 also, in relative terms, agriculture GCF accounted for 6% share in total GCF, almost the same (5.26%) as in the case of public GCFA i.e. irrigation investment in total public GCF during 2017–18.

Besides asset formation in irrigation and agriculture segments, the government incurs expenditure to support farmers and meet its own running expenses. The support is mainly to incentivise farmers to increase production, maintain price stability and ensure food security through input subsidies (the major ones being fertiliser, irrigation and electricity). Another significant expenditure is on account of procurement of wheat and paddy directly from farmers at the MSP, their storage and distribution at subsidised rates; this is the food subsidy for consumers. The NAS provides estimates on subsidy in agriculture and in other economic sectors, but does not provide disaggregated data on input and output subsidy.

Averaged for 2011–12 to 2017–18, at 2011–12 prices, data reveals that government expenditure on asset formation in agriculture was INR 508 billion (INR 107 billion in agriculture-forestry-fishing plus INR 401 billion in irrigation). However, the amount spent on subsidy in this sector is almost double at INR 964 billion. Table 2 shows that the agriculture and allied sector alone accounts for INR 964 billion (25.8% of the total subsidy of INR 3,733 billion across all economic activities) though it is somewhat close to the mining-manufacturing-construction sectors at INR 880 billion and lower than that given to 'other economic activities' at INR 1,079 billion. It is important to mention that these official estimates on subsidy may be on the lower side. The data collated from the budget and other sources indicate higher estimates of subsidy (fertiliser, power, credit, irrigation and crop insurance) at INR 1,290 billion, and food subsidy to consumers at INR 986 billion, averaged during 2011–12 to 2017–18 at 2011–12 prices.

Not only is the amount of farm input subsidy higher than public investment, statistics show that only 45% of capital expenditure in agriculture is actually utilised for asset formation. Other sectors, namely water supply, transport, communication etc., allocate more than 75% of capital outlays towards asset formation. This clearly indicates a relatively lesser public investment in agriculture and irrigation relative to other sectors, which is perhaps sought to be compensated by higher and increasing

Table 2 Magnitude of GCF and subsidy under various economic activities per year (INR billion, averaged 2011–12 to 2017–18 at 2011–12 prices)

Value of each sub sector under economic activity	Capital Expenditure (CE)	GCF	Subsidy	Percentage Share GCF in CE
General administration, regulation & research	387	31	3	7.98
Agriculture, forestry & fishing	235	107	964	45.72
Mining, manufacturing & construction	148	66	880	44.45
Electricity, gas, steam and other sources of energy	237	36	519	15.36
Water supply	183	146	1	80.14
Transport and communication	920	761	287	82.68
Other economic services	46	34	1079	73.80
Total economic activities	2,155	1,181	3,733	54.82
Annual rate of growth (%)				
General administration, regulation & research	11.61	37.20	16.29	
Agriculture, forestry & fishing	10.31	9.26	-0.74	
Mining, manufacturing & construction	26.43	27.57	-10.96	
Electricity, gas, steam and other sources of energy	5.94	10.43	16.41	
Water supply	18.57	20.71	NA	
Transport and communication	12.82	13.41	6.60	
Other economic services	1.51	11.57	9.05	
Total economic activities	12.59	14.83	2.28	

Source National Account Statistics, various years Statement S-4.2

expenditure on input subsidies. One favourable inference drawn from Table 2 is a positive and higher rate of growth in GCF compared to that of subsidies in each economic activity. Among all the economic sectors, only agriculture and mining-manufacturing-construction show a negative rate of growth in subsidies during the 2011–12 to 2017–18 period. General administration and energy sectors have the highest annual rate of growth at around 16% each.

3.1 Accelerating Public Investment in Agriculture and Irrigation

3.1.1 Estimating Public GCFA at Disaggregated Level

The NAS provides national-level estimates on public and private GCFA based on budget expenditure, the decennial *All India Debt and Investment Survey* (AIDIS) conducted by the National Sample Survey Organisation (NSSO) and other surveys. State-level estimates are available only for some. This should be estimated for all the states to enable a location-specific plan for future investment requirements in agriculture and irrigation and the dedicated budgetary outlays.

3.1.2 Increasing the Magnitude of Public GCFA, Efficiency and Governance

The quantum of public GCF in agriculture is much lower than in other sectors. More fiscal space must be given to agriculture and irrigation in the expenditure policy of governments because a majority of the population is dependent on agriculture for its livelihood. As per the report on *Doubling Farmers' Income* (MoA&FW, 2018), in order to double farm income by 2022–23, the required rate of growth in public investment (weighted agriculture, irrigation, rural roads-transport and rural energy) must be 14.17% per year (with 2015–16 as the base year). The rate of growth for private investment is estimated at 7.86% per year. As earlier shown in Table 1, the current rate of growth rate in investments is much lower at 6.68% and −0.76% respectively.

Further, attention needs to be paid to bringing efficiency in public canal irrigation and related infrastructure projects. These have long gestation periods and have not yielded satisfactory outcomes when assessed by the amount spent, net area irrigated, percentage of irrigation potential utilised and the gap in irrigation potential created and utilised (Gulati & Banerjee, 2017). Bathla et al. (2021) found that, on an average, public canals operate at about 59% technical efficiency, with wide interstate variations. Between capital and revenue expenditures, the low efficiency score is found mainly due to capital expenditure, which calls for faster completion of irrigation projects and their improved management and governance. Kannan et al. (2019) constructed a state-wise irrigation water governance index and found it had a positive impact on the performance of public (canal) irrigation systems, which, in turn, can significantly augment farm productivity.

3.1.3 Synchronising Public and Private GCFA Requirements

The thrust of government efforts continues to be skewed towards major and medium irrigation projects—and, of late, minor irrigation—while farmers' capital needs have moved beyond irrigation to machinery, implements, livestock, land improvement and non-farm businesses. Annex Table 4 shows that during the triennium ending (TE) 2015–16, 72% of budgetary allocations (capital plus revenue) within irrigation was for major and medium irrigation, 20% for minor irrigation and the remaining for command area development and flood control. The share of these categories in capital expenditure is slightly higher, except for command area development where the share of revenue expenditure is 3.29%, and capital expenditure a low 1%. In the case of capital and revenue expenditure for agriculture and allied activities, crop husbandry accounts for the highest share, followed by forestry and wildlife, food storage and warehousing and soil and water conservation. Outlays on food storage and warehousing have increased over time due to higher grain procurement.

In contrast, farmers' asset preferences have changed significantly between 1981–82 and 2018–19. The NSSO AIDIS 2013 and 2019 show that expenditure on land improvement, machinery, tractors, irrigation structures and livestock together account for 80% of the rural household's investments (Fig. 3). As expected, farmers in the hilly regions tend to spend more on land improvement, livestock and buildings/barns and those in the less developed states have higher expenditure on irrigation. An increasing number of farmers are opting for micro-irrigation (drip/sprinkler), machinery, implements and tractors for increasing mechanisation, productivity and higher water use efficiency. This development is more pronounced in agriculturally developed states and, of late, is visible in the less developed states as well (Bathla et al. 2020; Bathla & Kumari, 2017).

This indicates that the government should favour investments that correspond to the requirements of farmers across the country, such as storage infrastructure, soil health and solutions for post-harvest losses and other bottlenecks. This also intensifies the 'crowding in' effect of public GCFA on private GCFA. For instance, there are

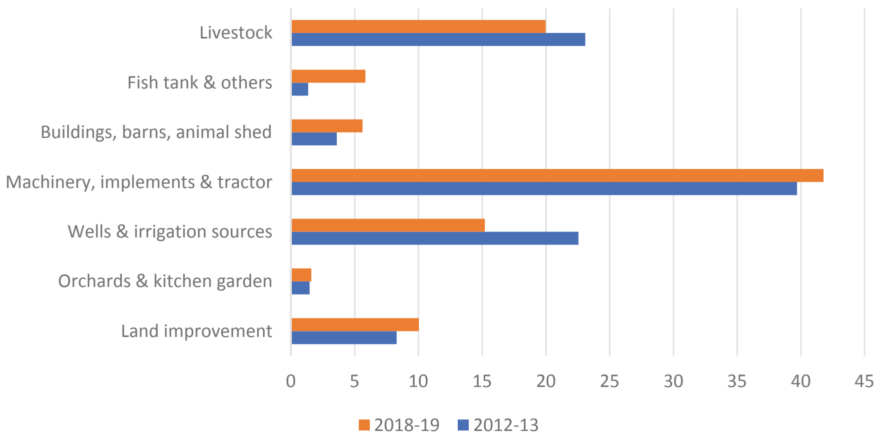


Fig. 3 Percentage share of components of private investment in agriculture by rural households, 2012–13 and 2018–19. *Source* NSSO AIDIS 2012–13 and 2018–19 (Schedule 18.2)

lesser outlays for animal husbandry, dairy development, fishery and bee keeping—activities that poor households mostly engage in. Governments can open veterinary hospitals, vaccine centres and training centres for farmers interested in allied activities. The public expenditure policy should be reassessed, primarily to address the mounting problems due to climatic changes, disasters, crop failure, depleting water resource and so on. Investment support to farmers for micro and minor irrigation is given through RAFTAAR. However, India needs much more investment in water recycling, bio-fertilisers and pesticides, weather information satellite mapping of crops, precision farming and so on. The use of artificial intelligence—drones, satellite imagery, robotics, sensors etc.—to diagnose diseases in plants and monitor storage conditions is also growing. Israel has used these latest technologies to shape its agriculture in the face of water scarcity and other geographical constraints. The private corporate sector must be encouraged to invest in agriculture—perhaps on the public–private partnership model similar to those in the power and airport sectors. Investments by start-ups in geographic information system (GIS), app-based weather advisories and other digital technologies should be scaled up by offering incentives.

3.1.4 Financial Inclusion and Outreach

Small and marginal farmers, who account for 86% of total holdings, have a less than 10% share in total investment, with the share of marginal farmers at a mere 1.9%.[13] In contrast, medium and large farmers account for 25.8% and 47.3% share in total investment respectively (Fig. 4). The marginal and small farmers have limited access to institutional credit and are unable to spend on asset creation (MoA&FW, 2015, 2018, 2019).

Furthermore, of the total investment made by farmers, 13.8% is through their own resources, 53.8% is through borrowings from formal (institutional) sources and the remaining 32.5% through borrowings from informal (non-institutional) sources. The share of borrowings from formal sources is much higher across all the land size holders except in the case of marginal farmers where it is only 39.6% (Annex Table 5). Data further shows that the percentage share of investment from formal sources is 63.4%, as compared to 36.6% from informal sources such as moneylenders, traders and input dealers. In the case of small, medium and large farmers, more than 67% of investment is through borrowing from formal sources; it is 59.4% for landless farmers and 47.9% for marginal farmers. The marginal and landless farmers depend more on informal sources for their investment needs. While they have to pay exorbitant rates of interest when they borrow from informal sources, the medium and large farmers

[13] Small and marginal holdings of up to 2 hectares (ha.) account for 86.21% of the 146 million land holdings which operated on an area of 157.14 million ha in 2015–16, an increase of 1.24% over 2010–11. The share of landholdings between 2 and 10 ha was 13.22% in total number of holdings, but had 43.61% of operated area. In contrast, the large holdings (>10 ha) were hardly 0.57% of total landholdings but had an operated area of 9.04% in 2015–16, little less than 10.59% reported during 2010–11.

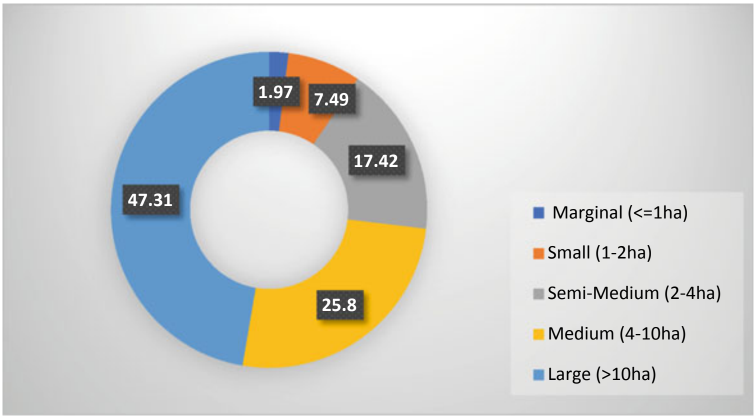


Fig. 9.4 Percentage share of private investment in agriculture as per landholding size, 2012–13. *Source* NSSO AIDIS 2013 (Schedule 18.2)

get subsidised loans from formal sources[14] (Kumar et al., 2017). The credit policy should aim at expanding financial inclusion, given that India has large inter-farm and inter-regional disparities along with a growing number of women farmers, tenants and labourers in agriculture and related activities.

3.1.5 Public Investment in Agriculture versus Input Subsidies

Public expenditure on input subsidies is more than double the investments made in agriculture and irrigation. Does higher public expenditure on input subsidies cut down public GCFA and incentivise farmers to make investments? A positive and significant impact of input subsidy and on private GCFA and productivity has been reported in Kannan (2012), Gulati and Chopra (1999) and Terway (2021). Figure 5 shows an increasing trend in investments and subsidies over the period from 1980–81 to 2017–18.[15] Increased budgetary outlays towards input subsidy lowered public GCFA for quite some time. However, both accelerated from the early 2000s, thus defying the argument that a hike in expenditure on subsidy lowers public investment. An increase in public GCFA also confirms a 'crowding in' effect on private GCFA, which became blurred from the 1980s to the mid-1990s. In fact, private GCFA and input subsidy have consistently shown an increasing trend up to 2008–09, followed by a decline. The estimated value of the correlation coefficient between public and private GCFA

[14] Institutional sources extend loans at a 7% rate of interest under the interest subvention scheme, which reduces to 4% in cases of early repayment.

[15] The primary sources of data on subsidies are Expenditure Budget; irrigation subsidy: Ministry of Statistics and Programme Implementation (MoSPI) and Reserve Bank of India (RBI); power subsidy: Power Division of the erstwhile Planning Commission, the Working on State Power Utilities and Electricity Departments, General Review Report (All India Electricity Statistics) and Tariff and Duty of electricity supply in India (Central Electricity Authority).

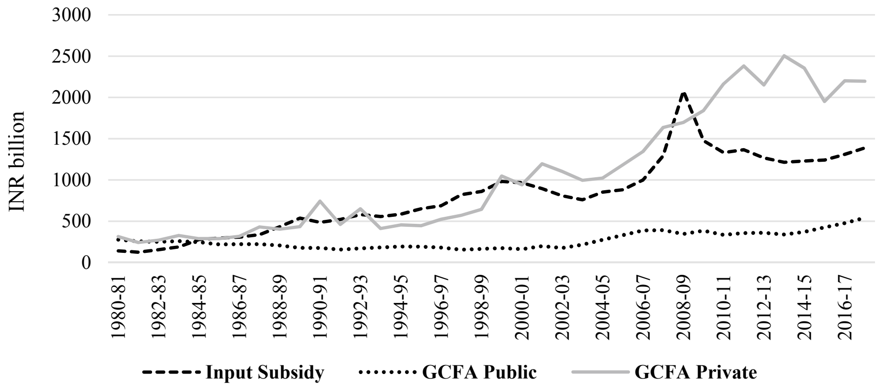


Fig. 5 Input subsidy, public and private GCFA 2011–12 prices**.** *Source* National Accounts and Union Budgets, various years. *Note* Input subsidy is the sum total of subsidy on account of power, fertiliser, irrigation and credit (including crop insurance). The data is converted into real prices using the wholesale price index at 2011–12 base

is 0.78, and that between private GCFA and input subsidy is 0.87. Going by this and other studies, the government should encourage private (household) investments by investing more, along with extending subsidised credit and subsidies on purchase of assets namely, micro irrigation, tractor and farm machinery. However, unabated rise in expenditure on subsidies has to be checked in order to improve expenditure efficiency and promote inclusive growth.

3.2 Reforming the Input Subsidy Regime

Public expenditure on agriculture has revived from the mid-2000s. Though spending on agriculture and irrigation accounts for nearly 11% of GDPA, only 3% of this is directed towards asset formation; the remaining 8% is for supporting inputs. The expenditure on input subsidy is INR 1,290 billion (at 2011–12 prices averaged during 2011–18), which is close to 1.5% of GDP. Within the total input subsidy bill, fertiliser and power had the majority share, at 45.6% and 30% respectively, followed by irrigation (16.4%), credit (5.07%) and crop insurance (2.69%). Tiwari and Surya (2019) confirmed that states, on an average, spent 6.5% of their budget on agriculture and allied activities during 2015–20. This constitutes 0.6% of budgeted capital outlay and 5.9% of the budgeted revenue expenditure. In some states, underspending (spending less than the allocated amount) in agriculture and irrigation was found to be to the tune of 8% and 16% respectively. Further, this underspending was more on the capital account, implying that states were unable to meet their development targets during that period or cut back expenditure in order to meet fiscal deficit targets.

The usefulness of input subsidy is often questioned on the grounds of the financial burden they impose on the exchequer.[16] Gulati and Narayanan (2003), Fan and Hazell (2000) have argued that input support might be useful in the short run, especially in regions where input use, productivity and farm income is low. Gulati and Terway (2018), Bathla et al. (2020) estimated that additional public spending on investment yields higher marginal returns as compared to additional spending on subsidies. The returns from fertiliser subsidy are found to be higher in less developed states, indicating that it should be targeted towards the disadvantaged, rainfed and low productivity states, which have a high proportion of small and poor farmers. Similarly, rationalisation in power and urea subsidy is a must in the north and north-west regions, in view of intensified cultivation of water-intensive crops, continuous depletion of groundwater and imbalanced nitrogen, phosphorous and potassium (NPK) ratio (Chand & Pandey, 2008; Sharma, 2013).

The broad consensus, therefore, is that if public policy continues with lopsided support in favour of select crops and irrigated zones, it will further reduce land productivity and returns to farmers—outcomes that are diametrically opposite to the intent (Gautam, 2015). Moreover, subsidies must cover the marginal cost in the long run. Rationalisation of subsidies in the name of efficiency, targeting and saving of public resources has to be based on the development level of a region and the prospects of private investment and growth in output there. Any recovery model, be it through *neem*-coated urea, use of solar pumps or direct income support in lieu of the existing price-based support system has to be inclusive, equitable and backed with a corresponding increase in public investment in agriculture.

In the case of the fertiliser subsidy, the Centre introduced the nutrient-based subsidy (NBS) scheme during 2010, under which the prices of P and K fertilisers were partially decontrolled under a fixed subsidy regime in which N (urea) was not included. As a result, subsidy on DAP (di-ammonium phosphate) and MOP (muriate of potash) is just about 25–30% of their cost of production or import, while that on urea continues to be in the range of 75% of its cost of production. Chand and Pavithra (2015) found excessive use of urea in several states, including Andhra Pradesh, Bihar, Haryana and Punjab, while in other states, notably Chhattisgarh, Kerala, Rajasthan and West Bengal, its consumption is much less than the norm for the crops grown. The authors pointed out that if urea prices are decontrolled, and the subsidy amount is transferred directly to farmers, the amount required would be INR 7,000 per hectare (ha.). The cash transfer estimated in Bathla et al. (2020) is somewhat lower at INR 5,250 per ha. at 2017–18 prices. Chand (2019) explored the possibility of merging all types of subsidies into one pack for distribution to farmers on a per acre basis. However, the main hurdles to this are assessing the exact magnitude of various subsidies given by the Central and state governments, estimating the amount of cash transfers in each state and devising a criterion for payment to farmers.

[16] An additional burden is that of loan waivers, which, according to the *Report of the Internal Working Group of RBI to Review Agricultural Credit* (RBI, 2019), may not address the underlying causes of farm distress, may destroy the credit culture, potentially squeeze investment and harm farmers' interest in the long run.

There are several other implications of switching over to direct income support, such as exclusion of tenants or sharecroppers and women farmers and the likely reduction in the consumption of fertilisers in some high consuming regions which could adversely affect productivity. We believe that if fertiliser prices are completely decontrolled, the price at which they will flow from factories to distributors and then to retailers will be higher by about 60% to 80%. Therefore, the requirement for working capital by distributors, retailers and other participants of the supply chain (private and cooperatives) will increase. Banks will then have to raise the working capital limits sanctioned at various levels for handling the same quantity of fertilisers. Since complete decontrol of urea prices at one go may not be possible, bringing urea under the NBS may be a better option. The subsidy will be capped at the current level, and an increase in prices may get reflected in retail prices. One consequence of complete decontrol will, however, be the closure of several uneconomic urea manufacturing plants.

Similarly, in order to reduce the subsidy bill on account of electricity used to extract ground water for irrigation, a formula needs to be devised to reward states that save energy (through the installation of metres or solar pumps) and to penalise the wrongdoers. The State of Uttar Pradesh has taken the lead in the installation of solar pumps. There is apprehension that if income support is substituted for subsidised electricity, farmers may grow less water-intensive crops because extracting groundwater will become more expensive. It may also alter the cropping pattern as per the irrigation water productivity (IWP). For instance, the IWP of rice in Punjab and Haryana is low as compared to several other states, especially Chhattisgarh. Income transfer can also spur investment in infrastructure in the eastern states which have higher IWP (Sharma et al., 2018). More research needs to be done on these issues and concerns raised.

On the issue of irrigation subsidy, the Fourteenth Finance Commission recommended the formation of Water Regulatory Authorities (WRA) for water pricing. The pre-requisite for this is an ex-ante assessment of the capacity and potential of different irrigation models, that is institutional arrangements, and ensuring the efficiency of departments engaged in the supply of canal irrigation water.

As in the case of support for inputs, the government incurs sizeable expenditure on the interest subvention scheme for agriculture. The subsidy on interest subvention on short-term crop loans in the budget estimates of the Union Budget of 2020–21 is INR 178.63 billion, which is way below the fertiliser subsidy of INR 799.98 billion. A sum of INR 136.41 billion has been allocated for subsidy on crop insurance. The expenditure of states has also escalated due to loan waivers since 2014–15.[17]

There are reports of beneficiaries not using loans given against gold for agricultural operations. The *Report of the Internal Working Group of RBI to Review Agricultural Credit* (RBI, 2019) has recommended that the scheme should be replaced with direct

[17] According to information given in reply to starred question no. 172 in the Rajya Sabha, Parliament of India, on 6 March 2020, the loan waivers announced by states varies from INR 1.29 billion in Chhattisgarh to INR 302 billion in Maharashtra. In Tamil Nadu, Maharashtra, Uttar Pradesh and Punjab, the loans of only small and marginal farmers were waived.

benefit transfer (DBT) for small and marginal farmers. The group has also recommended that tenant farmers, sharecroppers, oral lessees and landless labourers may also be covered as individual borrowers or through a self-help group/joint liability group (SHG/JLG) model with an overall limit of INR 300,000 per farmer. Since there is no record of tenants, sharecroppers and oral lessees, it would not be possible, in the first phase, to reach the DBT to them. If interest subvention is paid through DBT, farmers will have to avail loans from banks at market rates. In that event, the bank managers will also be more prudent while sanctioning the loans. Moreover, farmers will borrow only as much as is required for inputs. In the current situation, the extent of finance available is high for some crops and very low for others. This encourages the farmers to avail a loan for one crop and cultivate another crop. The working group also found that some states in the southern and western region have been availing agri-credit higher than their share in agri-GDP, while states in the central, eastern and northeastern regions get credit lower than their proportion of agri-GDP.

In sum, public expenditure on investment as well as on input subsidies can incentivise farmers to undertake investments. At the same time, states have budgetary constraints and tend to neglect asset creation in agriculture, relative to other economic sectors. However, spending on subsidies (done from revenue account) has been on the increase despite enormous fiscal constraints. It is, therefore, vital for states to allocate more resources towards the capital account—and, hence, capital formation—in their expenditure policy, bring in better governance in canal irrigation departments/systems and, at the same time, rationalise expenditure on input subsidies. Efforts should be made to ensure that support reaches the poorer states and farmers who are at the bottom of the income pyramid. The ongoing initiatives in fertiliser subsidy based on NBS can help to lessen the financial burden of the Centre. For reforms in the pricing of power, irrigation and other inputs, states have to be proactive in devising appropriate systems and assuring improved governance. Where shifting to cash transfers is concerned, each state should first examine its feasibility and then estimate the amount, intended beneficiaries (farmers, tenants/landless cultivators or both), possibility of changes in the cropping pattern and, hence, fertiliser application and its consequent impact on the environment.

4 Reforming Agriculture Price Policy and Marketing

4.1 Replacing Minimum Support Price with Income Support

Two institutions—the Commission for Agricultural Costs and Prices (CACP) and the Food Corporation of India (FCI)—were established in 1965 to formulate and implement agriculture and food policies. The MSPs of paddy and wheat and other selected crops are determined by the CACP based on the cost of production, demand and supply, movement of domestic prices, intercrop price parity and terms of trade between agriculture and non-agriculture sectors. The FCI was entrusted with the task of procuring wheat and paddy at MSP, maintaining the stocks to meet emergency needs and ensure price stability and distribution through the PDS and its network of fair price shops.

The CACP recommends MSP for 23 crops,[18] but its major focus has been on wheat and paddy for enabling procurement by the FCI and state agencies, mainly from Punjab, Haryana, Uttar Pradesh and Madhya Pradesh. After the global food crisis of 2006–07, procurement of wheat/paddy has expanded in other states as well such as in Andhra Pradesh, Telangana, Chhattisgarh, Odisha, West Bengal and Bihar. Procurement of pulses has picked up in the last five years; the National Agricultural Cooperative Marketing Federation of India Ltd (NAFED) procures and maintains the buffer stock of 2 million tonnes under the Price Support Scheme. The National Food Security Mission (NFSM) launched in 2006 also gave a fillip to food grain production and its procurement.

While the price support policy has incentivised farmers to increase investment and production and helped the government to maintain price stability and food self-sufficiency, its deleterious effects—regional bias,[19] mono-cropping and environmental degradation[20]—must not be ignored. In 2018–19, out of the total production of wheat, procurement was about 73% from Punjab and 80% from Haryana. In contrast, Bihar accounted for less than 1% share of procurement in total wheat production. Despite an improvement in the production and productivity of paddy in the eastern states, its procurement is sporadic and poorly organised. Furthermore, since procurement is confined to wheat and paddy, farmers in Punjab have largely moved away from maize, *bajra*, oilseeds and pulses. A similar situation prevails in Haryana and, lately, in Madhya Pradesh where, after an increase in the irrigated area, farmers have switched to wheat cultivation.

Another major outcome of the price policy is an excessive buildup of stocks (also called central pool stocks) from time to time. Procurement of wheat and paddy at

---

[18] The *kharif* crops include common and grade A variety of paddy, *jowar* (sorghum), *bajra* (pearl millet), *ragi* (finger millet), maize, *arhar* (pigeon pea), *moong* (green gram), *urad* (black gram), groundnut, sunflower seed, soybean, sesamum, nigerseed and cotton. The six *rabi* crops are wheat, barley, gram (chickpea), lentil, mustard and safflower. In addition, the CACP recommends support prices for sugarcane (called Fair and Remunerative Price), copra and jute. The sugar mills are bound by law to purchase sugar cane at this price. The difference between MSP and procurement price, however, became blurred over the years.

[19] Madhya Pradesh and Uttar Pradesh are two states where wheat is procured in large quantities. Andhra Pradesh, Chhattisgarh, Madhya Pradesh, Odisha, Telangana, Uttar Pradesh and West Bengal have also geared up their machinery for procurement of paddy. Bihar is the only major paddy producing state where procurement is still largely ignored. The NSSO AIDIS 2013 shows that the output price policy benefitted only 10% of farmers and that too in select states. Price distortions happen due to delays in procurement and other inefficiencies in regulated/wholesale markets because of cartels formed by wholesalers, inadequate storage and other infrastructure (Birthal et al., 2015).

[20] Assured MSP for wheat and rice has resulted in expansion of area under these crops in water-stressed regions at the cost of the environment. Punjab, for example, witnessed a massive depletion of the water table, at an alarming rate of 70 cms per year during 2008–12. Since farmers are not charged for the electricity used to pump groundwater and the canal network has also not expanded, the area irrigated by tube wells has soared and led to overexploitation of water in 80% of the blocks (CGWB, 2016).

MSP is open-ended, that is, government agencies are mandated to procure whatever quantity is offered by the farmers. The stock of rice and wheat has surpassed the buffer norms,[21] and this has put tremendous pressure not only on state finances but also on the storage capacity of FCI and state warehouses. The Centre has, on several occasions since 1999–2000, resorted to open market sale of grains for domestic consumption and exports. While revising the buffer norm in 2015, the government decided that if the stock of grain in the central pool was more than the revised norms, it will offload excess stock in domestic markets through open sale or exports.[22] Moreover, subsidising exports has become increasingly difficult because of WTO stipulations.[23]

The fixation of MSPs of wheat and paddy has also become highly politicised with states sometimes declaring bonus over and above the price recommended by the CACP. OECD-ICRIER (2018) found domestic price support in agriculture commodities to be negative in most of the years from 2000 to 2016, implying a price gap between their producer price and the reference (international) price. This indicates that India imposes an implicit tax on domestic producers through lower MSP, aggravated by regulations on trade, inefficiencies in agriculture markets and weak infrastructure. Farmers are also affected by a continuous increase in the input cost relative to output price, which results in lower net returns, and hence aspire for some safety net. On the demand of farmers, from the *kharif* season of 2018, the Centre fixed the MSP to ensure at least 50% return on overall paid out cost (A2 + FL).[24] In the *kharif* marketing season of October 2020–23 September 2021, a much higher procurement of rice at 59.84 million tonnes might result in central pool stocks of 78.61 million tonnes as on 31 August 2021, which may again exceed 100 million tonnes by the end of *rabi* procurement next year, sending the subsidy bill soaring.[25]

Should India move away from a system of price support to other fiscally sustainable alternatives that would also shield farmers' from price risk and maintain their income at a reasonable level? A high-level committee studied the grain policy and management and recommended several measures, which were never implemented (FCI, 2015). Chand (2019) suggested an "area-based income compensation" based on the difference between the market price received by farmers and the MSP for

[21] The current buffer norms of wheat and paddy are: 21.04 in million tonnes on 1 April; 41.12 million tonnes on 1 July; 30.77 million tonnes on 1 October and 21.42 million tonnes on 1 January.

[22] The Inter-Ministerial Group (IMG) recommended better management of food stocks as the economic cost of wheat in the central pool was higher than the prevailing international prices, making exports impossible without a subsidy being given.

[23] A communication from the United States of America to the WTO dated 9 May 2018 highlighted certain measures/notifications through which India provided market price support to rice and wheat.

[24] A2 + FL is actual paid out cost plus imputed value of family labour. The MSP for paddy (common variety) was increased by 12.90%. There was hefty increase in MSP of other crops as well (52.45% in the case of ragi and 45.11% in nigerseed). Since these crops are not procured by the Centre, there was no impact on central pool stocks.

[25] The food subsidy bill has soared to INR 1,403 billion in 2016–17, from INR 6.50 billion in 1980–81. The food subsidy bill (excluding market price support) constitutes 1% of India's national income averaged from 2011 to 2018.

various crops, popularly known as price deficiency payment system. The State of Madhya Pradesh initiated such a scheme under which farmers were compensated in cash when commodity prices fell below a certain level. The policy, however, was not successful (Gulati et al., 2018). Yet another suggestion is to adopt market-based instruments such as derivative market, that operate through options, forwards and futures in order to effectively cover the price risk of farmers.

Direct income support, implemented in Jharkhand, Karnataka, Odisha, Telangana and West Bengal seems transparent, less distortionary and equitable. According to Gulati et al. (2018), in this model, farmers sell grains in the market and the government provides income support in unfavourable situations. Assuming all farmers get INR 10,000 per ha., irrespective of the crops they grow and whom they sell to, the estimated cost at the national level will be approximately INR 1.97 trillion. The cost will be much lower if farmers who have sold their paddy and wheat at MSP to government agencies and sugarcane at Fair and Remunerative Price (FRP)/State Advised Price (SAP) to sugar mills are excluded from this system of payment.

India can also experiment with a system modelled on China's targeted price policy and direct compensation scheme. China followed a price support system, including buffer stock similar to India, and the country faced a situation of bulging grain stocks. The food grains purchased at the intervention price were much higher than the global prices. As part of reforms, the procurement price of wheat was reduced twice by USD 8.6 per tonne for 2018 and 2019. For 2020, the price has been retained at the 2019 price of USD 320 per tonne.[26] When market prices are high, China sells from its reserves in weekly auctions of grains, akin to the open market sales scheme followed in India. However, unlike India where the MSP is uniform across the country even though the cost of production differs widely across states, China follows a differential price policy across provinces. For cotton and soybeans, the target prices are fixed and combined with compensatory, direct payments to farmers, based partly on the area planted. In due course, China proposes to dilute the link between compensatory payments and production decisions on a historical production basis; by making them conditional on environmentally friendly cultivation practices (OECD, 2015). However, these measures have to be supported by land reforms, improvements in marketing, research, infrastructure, innovation, extension services and accessibility to good education and health care for productivity gains in the long run.

4.2 Legislation and Regulations in Agriculture Marketing

As noted in Sect. 2, agri-markets governed under the APMC Act restricted farmers, and traders to geographical zones and forced them to pay a cess on any transaction within or outside the marketing yard of the APMC. Stringent rules on intra and

[26] Source:http://www.fao.org/giews/food-prices/food-policies/detail/en/c/1238526/

inter-state trade together with improper price discovery and a long chain of intermediaries made markets uncompetitive and unfair to farmers for decades. Though the APMC Acts of 2003 and 2017 encouraged farmers to enter into contracts with private companies and retail chains to realise better prices, the monopoly of state-run *mandis* continued.[27] Contract farming could not take off due to the requirement of compulsory registration with *mandis,* payment of fees, levies and other market regulations, as well as coordination with farmers to build their confidence in the contractual arrangement.

On 5 June 2020, the Centre promulgated three ordinances—Farmers' Produce Trade and Commerce (Promotion and Facilitation) Ordinance, 2020, Farmers' (Empowerment and Protection) Agreement on Price Assurance and Farm Services Ordinance, 2020 and the Essential Commodities (Amendment) Ordinance, 2020. In September 2020, these were introduced as bills in Parliament and became laws after the President of India gave his assent. According to Chand (2020), these three laws were the most prominent structural reforms in the agriculture sector in the last few decades.

The Farmers' Produce Trade and Commerce (Promotion and Facilitation) (FPTC) Act, 2020 allowed sale and purchase of agricultural commodities outside the physical boundaries of APMC *mandis*. So far, such transactions attracted fees and other charges applicable to trading inside the APMCs. Only licensed traders were allowed to do business within these and such licenses were not freely available.[28] Instead of a license, anyone having a valid permanent account number (PAN) issued by the income tax department would have been allowed to purchase or sell agricultural produce in the trade area. More importantly, such transactions would not have attracted any market fee or other charges which are levied on transactions inside the *mandis*. In the trade area, there was also complete freedom to operate an online trading portal. This did not need to be linked to the e-NAM (electronic National Agriculture Market). However, the Central and state governments were free to frame rules for registration, code of conduct and procedure for trading on such platforms.

The Farmers' (Empowerment and Protection) Agreement on Price Assurance and Farm Services (FAPAFS) Act, 2020, brought uniformity in contract farming. Prior to its enactment, contract farming was governed under the AMPC Acts of individual states. The FAPAFS Act facilitated a written contract between the farmers and a sponsor (which could also be a company). The contract can mention the terms and conditions of quality, grade, time of supply and the price of the commodity being cultivated. The Act prescribed a minimum period of one year and maximum period of five years for such an agreement. It further stipulated that for any additional amount in

[27] A reply to Unstarred Question No 291 in the Lok Sabha of the Parliament of India on 19 November 2019 said that Andhra Pradesh, Assam, Chhattisgarh, Goa, Gujarat, Haryana, Himachal Pradesh, Jharkhand, Karnataka, Maharashtra, Madhya Pradesh, Mizoram, Nagaland, Odisha, Punjab (separate Act), Rajasthan, Sikkim, Telangana, Tripura, Tamil Nadu (separate Act) and Uttarakhand had made provisions in their respective APMCs to allow contract farming.

[28] In fact, even an autonomous society promoted by the small farmers' agribusiness consortium (SFAC) of the MoA&FW failed to secure a license to trade in Azadpur *mandi* of Delhi on the ground that it did not possess a shop in the *mandi*.

excess of the agreed price, the benchmark would be the prevailing price in the APMC *mandi* or an electronic portal like e-NAM. The contracts could be for any foodstuff, including edible oilseeds and oils, cereals like wheat, rice or coarse grains, pulses, fruits, vegetables, nuts, spices and sugarcane. Contracts could also cover poultry, piggery, goatery, fishery and dairy, intended for human consumption in its natural or processed form as well as cotton, jute and cattle fodder.

Importantly, the Act provided that the specifications of quality, grade and standards for pesticide residue and food safety standards can also be part of the agreement. Such specifications are especially important for contracts for export-oriented produce, specifically for perishables. Since Indian agriculture is dominated by small and marginal farmers, the Act protected their interests by clearly specifying that an agreement cannot involve any sale, lease and mortgage of the land. Moreover, no permanent structure can be raised on the land unless the sponsor agrees to remove it on the conclusion of the agreement, as per Section VIII of the FAPAFS Act.

The Essential Commodities (Amendment) Act (ECA) 2020, sought to deregulate the supply of food stuff, including cereals, edible oils, oilseeds, pulses, onions and potato by removing them from the purview of the ECA, 1955. The main objective of the 1955 law was to protect the interests of consumers by preventing hoarding of essential commodities by enabling the Centre to impose restrictions on their storage and movement. The Centre enabled the states to issue control orders through which they could impose such restrictions. The amended ECA limited the Centre's power to impose restrictions to only extraordinary circumstances like famine, war, extraordinary price rise and grave natural calamity. It allowed the Centre to impose stock limits in certain circumstances. In the case of perishable horticultural produce, stock limits could be imposed only if there is a 100% increase in retail price over the retail price in the preceding 12 months or the average retail price of the last five years, whichever is lower. For non-perishable produce, the restrictions could be imposed only if the price rise is 50% over the price in the previous 12 months or the last five years.

These laws had a multitude of far-reaching implications. The privately owned markets and non *mandi* transactions between farmers and consumers would have run parallel with the existing APMC markets. There was a provision to establish a state-level Contract Farming (Promotion and Facilitation) Authority to ensure implementation of the FPTC Act. The authority could levy facilitation fees and resolve any disputes that may arise. There was also a proposal to allow private entities and Farmer Producer Companies (FPCs)[29] to transact directly in the e-NAM and ease the supply chain. However, this freedom to trade could be subject to regulation as the government retained the right to notify any document other than a PAN card as a requirement for trading in the future. A system for registration of traders, modalities of transactions and the modes of payment to farmers has to be prescribed.

[29] Satyasai and Singh (2021) reported the success of FPCs in strengthening backward linkages with farmers and forward linkages with food processing units for value addition. With support from NABARD, the FPCs in the north-east region have facilitated higher income to growers through consolidation of produce, access to inputs and integration with processing units.

Furthermore, compared to physical trading where delivery is on the spot, trading on electronic platforms will require better oversight and regulations, as some agency or intermediary is needed to facilitate transactions between farmers and-or aggregators with the buyers.

State governments would have had to draw up a blueprint for the entry of the private sector in agri-markets and push for speedy implementation of regulations specified in the respective Acts. Appropriate institutional arrangements would have to be formed for aggregators, FPCs, SHGs, cooperatives and agri-start-ups that help in reducing the transaction costs of farmers and providing them grading and standardisation facilities. Such interventions have to be supported through adequate finance such as the support given by NABARD to the FPCs. The role of the Warehousing Development and Regulatory Authority (WDRA) would have been crucial.[30] As the notified warehouses and private online markets will be deemed markets for direct sale of produce, these can be regulated by the WDRA. On the flip side, there might have been no incentive for any warehouse to register with the WDRA, as all warehouses could have acted as market places without paying any fee or charges to APMCs. However, since business in trade areas was going to be deregulated entirely, it would have been necessary to make registration of warehouses with WDRA mandatory so that the privately-held stocks in warehouses are known to the government. This would have helped the government take informed decisions and intervene in markets to check hoarding of commodities and price fluctuations that could be detrimental to consumers' interests.

One important concern was that the warehouses and factory premises may have applied for de-notification and sub-market yards in order to take advantage of the zero tax structure. APMCs and the states may have had to bear some loss of revenue because of trade moving out of their jurisdiction as well as losing out on the market fee that was earlier levied on every transaction. Another issue was ensuring timely payment to farmers, which was earlier regulated by the APMCs. According to the FPTC Act, the payment will be made on the same day, but if procedurally required, it can be done in three working days. In this situation, the farmers will have to be given a receipt of delivery of produce in which the due amount will be mentioned.[31] Since the trade area is not under regulation, it is necessary to ensure that the farmer is either paid in cash or by electronic transfer into his/her bank account on the same day before the delivery of the produce. This will eliminate the possibility of disputes

[30] The WDRA was set up by the Central government in 2010 to ensure implementation of the Warehousing (Development and Regulation) Act, 2007. The WDRA was envisaged to create a digital, online, web-based ecosystem of electronic negotiable warehouse receipt (NWR), similar to the issuance of financial securities like equity shares/bonds. The WDRA has set up two repositories namely, M/s CDSL Commodity Repository Limited and M/s National E-Repository Limited, for the creation and management of e-NWR. The registered warehouses shall issue e-NWRs on any of the repositories for the stocks stored. WDRA has notified 123 agriculture and 26 horticultural commodities for registered warehouses to issue e-NWRS.

[31] In Nashik, the largest grape exporting district of Maharashtra, grapes have been out of the purview of APMC and the crop is sold by farmers outside the *mandi*s. There are reports in the media about traders defaulting on payment of millions of rupees.

between farmers and purchasers. For dispute resolution, the Act prescribed conciliation through a board appointed by the Sub-Divisional Magistrates (SDMs). Since SDMs and their officers also perform myriad other duties, it would be unrealistic to expect them to find time for settling disputes. Making same day payment mandatory will forestall disputes relating to payments. The farmers should be encouraged to use the e-NAM platform for more competition and better dissemination of commodity prices.

All these steps will enable the smallholders, having less than two hectares of land, be part of competitive agri-markets. The smallholders are unorganised and have to be securely linked with both back-end service providers and front-end agri-processors. Nearly 86% of the farmers are categorised as small and marginal. The share of tenant farmers, women farmers and women labourers in agriculture, horticulture, dairy and fisheries activities has been growing steadily. Male farmers own 86% of landholdings compared to women farmers who own just 14% holdings, mostly of less than two hectares area (FAO, 2016). Furthermore, women did not inherit agricultural land in several states. For example, the Uttar Pradesh Zamindari Abolition and Land Reforms Act, 1950 did not recognise daughters as primary heirs to agricultural land. It was only in 2006 that the provisions were modified to enable unmarried daughters also to inherit land as primary heirs, at par with sons. The Uttar Pradesh Revenue Code, 2006 which came into force in 2016 still places married daughters much lower in order of succession. They inherit agricultural land only if there are no widows, male lineal descendants, the mother and the father of the deceased or an unmarried daughter.[32]

Contrary to popular perception, studies indicate that the productivity of smallholding is not lower than that of the larger holdings, implying an inverse relationship between farm size and productivity.[33] As shown in Annex Table 6, on a per hectare basis, the marginal and small farmers earned slightly higher than the medium and large farmers but their major source of income was salary/wage (46.75% in the case of marginal farmers and 23.16% in the case of small farmers) and livestock activities. Similarly, women-headed farm households earned lesser net income as compared to the male-headed farm households, though their net income is almost the same on a per hectare basis (Annex Table 7). The problems small and marginal farmers, including women, conceal various challenges that they face in farming activities—the two most significant ones being accessing credit for production and marketing of their produce.

RBI (2019) noted that only 41% of small and marginal farmers are able to get credit from public and private sector banks (as per priority sector advances annual return of 2015–16). This despite the fact that, under priority sector lending norms, all the scheduled commercial banks have been given a target of 40% of their adjusted net bank credit (ANBC) or credit equivalent of off-balance sheet exposure, whichever is higher. Banks are also mandated to provide 8% of ANBC for small and marginal

[32] Source: https://www.indialegallive.com/cover-story-articles/il-feature-news/no-womens-land/

[33] Based on NSSO (2013) the per ha value of output is INR 14,754 for marginal farmers, INR 13,001 for small farmers, INR 10,655 for medium farmers and INR 8,783 for large farmers.

farmers. The RBI working group further noted that in 2015–16, only 40.9% of the 125.6 million small and marginal farmers, had accounts with scheduled commercial banks. Farmers having Kisan Credit Cards (KCC) get loans against negotiable warehouse receipts for the produce stored in warehouses registered with the WDRA. They also get the benefit of interest subvention of 2% for six months after harvest to prevent distress sales. These initiatives are not adequate as small farmers face several hurdles in accessing loans. Kumar et al. (2020) found that access to credit in eastern India benefitted farmers, and those who availed credit from formal sources are much better off than others who borrowed from informal channels. They suggested that the credit policy must offer a variety of loan products to cater to the requirements of different households.

Birthal et al. (2015) have maintained that smallholders prefer to produce high-value crops such as vegetables, fruits and milk. This is because they lack storage facilities for crops like sugarcane, wheat, paddy, pulses and cotton for which they can get a remunerative price through the government procurement system. However because of the relatively smaller quantity of produce, small farmers do not find it viable to hire transport to go to procurement centres and so their produce is sold to traders within the village. In such cases, even for wheat and paddy crops that are procured at MSP, they realise a lower value since they lack bargaining power.[34] Extending support to smallholders through contract farming under the new Act, supplemented with subsidised credit and insurance, can go a long way in improving their condition. According to Joshi (2015), small farmers and women should be organised across the entire value chain as technology, information, finance and markets are sometimes inaccessible to them due to low marketed surplus or other reasons.

India needs location-specific, differentiated programmes for smallholders and women farmers with clear responsibilities for the public and private sectors in order to make farming viable. Women farmers receive assistance and training under the *Mahila Kisan Sashaktikaran Pariyojana*[35] (MKSP) of the Ministry of Rural Development with a INR 656 million fund earmarked in 2018–19 and also under beneficiary-oriented schemes and programmes of the MoA&FW.[36] The Centre must give states flexibility in spending and in strategising plans that help small farmers and women farmers enter into contracts with private agencies.

[34] For instance, in May 2019, farmers in Gulabbagh in the State of Bihar sold maize at INR 1,100 to INR 1,200 per quintal even though the MSP announced was INR 1,765 per quintal. (10 quintal equals 1 tonne).

[35] Women Farmers Empowerment Scheme.

[36] It is reported that over nearly 13.9 million women have been trained in agriculture under various Central schemes during between 2016–17 and 2018–19. As per Census (2011), there were 36 million women cultivators (main and marginal) and 61.5 million women farm labourers (main and marginal) (Lok Sabha starred question number 155, 2 July 2019).

5 Conclusions and Way Forward

This chapter provided a historical perspective of the key reforms initiated in Indian agriculture and the structural changes that have taken place with the objective of highlighting some important governance issues for further action. The chapter began by delving into the relationship between the Centre and the states in the devolution of funds and their shared responsibilities towards agriculture development. Though under the Constitution of India, agriculture and irrigation fall within the jurisdiction of states, the Centre plays a crucial role in the formulation of policies which have deep impact on agriculture and allied sectors. Since the Centre has much more financial resources than most of the states, it plays a critical role in the release of funds/grants to states, extending price support and subsidies for agriculture inputs and output and pursuing the national development agendas of food and nutrition security, elimination of poverty and hunger. In policy formulation, especially in the enactment of laws by Parliament, good governance would mean wide consultation with state governments and other stakeholders. The state governments can, well within their powers, enact laws and regulations which bring more competition in the APMCs. Farmers already have the freedom to sell their produce outside the APMC. The purchasers have to pay applicable market fees and other charges. To bring more competition and efficiency in the APMCs, unified licenses for the entire state should be issued to the FPOs, corporates and large purchasers. However, a law for inter-state trade needs to be enacted by the Centre. Further, when it comes to implementation of policies, the Centre should give flexibility to states in strategising action plans that are suited to their particular requirements in order to encourage farmers and the private sector. There is a strong need for convergence of various schemes and, hence, effective coordination across Central ministries for which an empowered group of ministers should be formed. Within the states, cabinet sub-committees on agriculture and related departments (including of irrigation and power) should be constituted. The underlying intent should be to reinforce public administration as part of the governance reforms. The administrative reforms can reinforce state capacity and deliver growth with equity and inclusivity.

Almost every state in India is confronted with a fiscal crisis, and the brunt of the resource crunch has largely been borne by agriculture and irrigation, indicating a lower priority accorded to this sector in the expenditure policy. Public investment, which has always been skewed towards major and medium irrigation, has to be synchronised with the changing investment requirements of farmers, such as micro irrigation, storage, mitigating post-harvest losses, soil health and allied activities and digital farm services on weather advisories. This will intensify the 'crowding in' effect of public investment on private household investment. Government spending on input and output subsidies is much higher than that on investment, which has long term implications for growth. It is important to raise investments and target support towards the less developed states/regions and small and marginal farmers in order to achieve higher productivity as well as alleviating poverty.

Replacing the existing price support system with direct income support to farmers or encouraging them to use *neem*-coated urea and solar pumps has to be backed with a corresponding increase in public investments in the agriculture sector. Direct income support may assure efficiency in input use and financial autonomy to farmers, but the amount of cash transfers have to be estimated and aligned with the existing cropping pattern in each state as well as the usage of inputs and presence of tenants and share-croppers and women farmers. Having no titles to land, women farmers face credit bottlenecks, cannot avail crop insurance, have lower output (agriculture, poultry and livestock) and also find it difficult to become part of the value chain. Incentives should be given to enable them to form women farmer producer organisations (WFPOs), women SHGs federations, cooperatives and women-headed enterprises. Issuing of farmers' card to each cultivator, irrespective of gender and ownership of land, can go a long way in empowering women and allowing them to take advantage of various government schemes. Farmers should be shielded from price fluctuations through direct income support or price deficiency payment or other feasible systems.

Similarly, the new marketing reforms laws—FAPAFS Act, FPTC Act and the ECA—that are now repealed could have yielded the desired results only if adequate investments are made in rural and marketing infrastructure and adequate flow of credit and extension services to farmers is ensured. The process of agri-market reforms will continue across the states. The way forward for them is to take forward the reforms in agri-markets and create an enabling environment that incentivises the cooperatives, agri-businesses and private companies to enter the sector and also undertake investments in handling perishables. Institutional support can be taken from various industry forums, export houses, NAFED and the National Centre for Cold-chain Development. Subsequent to the enactment of the three laws, a few states initiated measures in their respective markets, whereas some like Punjab, Haryana, Uttar Pradesh, Rajasthan and Tamil Nadu opposed the laws mainly on grounds of loss of revenue and the apprehension that this would lead to Centre reducing grain procurement at MSP, leading to a fall in the market price of grains. States do have the autonomy to bring suitable changes in the laws but it is important that they frame rules for registration and code of conduct for trade as well as procedures for trading on newer, even online, platforms, which can also be linked to e-NAM.

In Punjab and Haryana, a major proportion of market arrivals of wheat and paddy (about 99% in the case of Punjab) are procured by government agencies. In Punjab, such transactions attracted market development fee (MDF) and rural development fee (RDF) of 3% each. In Haryana, the MDF and RDF fee was 2% each. In both the states, the *arhatiyas* were paid 2.5% of MSP as commission. The marketing boards of Punjab and Haryana earned about INR 35 billion and INR 16 billion respectively on this account. The Centre has since decided not to pay the MDF on paddy procured in the *kharif* marketing season 2020–21 (October to September). The difference in fees between APMC *mandis* and other markets has already prompted other state governments to reduce the fee within the former. Within days of the Centre notifying the FPTC Act, the Government of Punjab reduced the MDF and RDF on basmati paddy from 2 to 1% each.[37] Similarly, Haryana also reduced MDF and RDF on wheat and rice from 2% each to 0.5% each. Madhya Pradesh too reduced the *mandi* tax from 1.70% to 0.5%. On 6 November 2020, Uttar Pradesh reduced the *mandi* tax from 2 to 1%.

In order to ensure more competition and lower fee in the markets, the state marketing boards need to upgrade infrastructure in the existing regulated markets and make operations in these more efficient and transparent. Even though their income may decline due to the reduction of market fees and other charges, it is necessary that the state governments provide them required funds from the state budget.

APMCs own large tracts of land, mostly in towns and cities. So far there have been few cases of public–private partnership to create modern infrastructure for sorting, grading, drying and storage in these. It is possible that state governments will look for private collaborations to modernise the facilities within APMCs so that they remain competitive. In our opinion, private players may not venture into agri business/marketing in the short run. However, in the medium to long term, they can be expected to engage in agri-marketing, provided state governments facilitate such business practices and develop adequate infrastructure. We expect that by 2030, exporters and processors may set up their own purchase centres in the trade area which will provide facilities specific to a particular commodity or group of commodities. In all likelihood, both foodgrains and perishable horticulture produce will attract investment. This could be higher in the case of perishables, due to relatively less quantum of arrivals as well as the additional space required for their transactions. Even before the enactment of the FPTC Act, fruits and vegetables have largely been traded outside the APMCs. In the last few years, states like Delhi and Maharashtra had delisted them from the purview of the APMC Act. The emerging ecosystem of start-ups may see investment flowing into the establishment of value chains connecting producers with the processors and consumers.

The amendment in the ECA was seen as a step to reduce regulatory interference in business transactions. The latest example of such interference is the Centre using, in October 2020, the powers under the Act to impose stock holding limits on onions, stipulating that the wholesalers cannot store more than 25 tonnes while for retailers, the limit was fixed at only two tonnes. India's surpluses for most agricultural produce are marginal. India is a large importer of some commodities like edible oils and pulses and any natural calamity can cause damage to pulse crops, resulting in shortages. In the last three years, India had to allow import of maize (in 2019) as well as onion and potato (in 2020). From 2000 to 2015, the government has often resorted to restrictions on the movement, stocking and export of wheat, maize, chickpea, potato, onion, sugar, cotton and milk (OECD-ICRIER, 2018). Due to such adhocism, India may not be seen as a reliable exporter.

Even though the government has decided to repeal the amendment, there is a need to make the regulatory regime more predictable so that private investment can be attracted into the agri-supply chain. At present, the private sector is reluctant

[37] The MDF and RDF for basmati rice was 2% each while for common and grade A paddy it was 3%.

to make any investment as the government can suddenly impose stock limits or restrictions on the movement and export of agricultural produce. If India's crop productivity increases and the demand–supply situation improves, it is possible that the private sector may see opportunities to invest in the creation of infrastructure as well. A successful export-oriented supply chain of grapes and buffalo meat has already been created almost entirely by the private sector. By 2030, if there are surpluses in agricultural produce, such investment can be expected in other areas as well. The Agriculture Export Policy, 2018[38] already provides an assurance that organic produce and processed agricultural products will not be subject to any export restriction by way of minimum export price, export duty, ban on export, export quota, export capping, export permit, etc. However, the government has retained the powers to impose export restrictions on primary produce or non-organic produce. States must also devise some ways to record commodity stocks available with the private agencies, perhaps through registration with the WDRA.

The FAPAFS Act aimed to bring uniformity in contract farming. India already has a successful model in poultry and seed production. Under the contract system, aggregators provide extension services, including feed and medicines to small farmers who provide space and labour to grow one-day old chicks, also provided by the aggregators. The marketing risk is not borne by the farmers. It is estimated that about 66% of India's poultry production is under contract arrangements. Most of sugarcane production is also through a form of contract farming under which an area is reserved for supplying sugarcane to sugar mills. The farmers are assured of the FRP with the mills having to pay the SAP, which is higher than the FRP, in some states. This system of assured marketing has, however, provided a perverse incentive to farmers to grow sugarcane even in water-stressed regions. As a result, India produces more sugar than required for its domestic consumption. In the case of perishables, a few companies—Adani Agri Fresh Ltd., MAHAGRAPES, Mother Dairy-SAFAL, Haldiram Foods International Ltd., etc.—have entered into contracts with farmers in several commodities for both retail and value addition, but their penetration is still very low. This is despite the fact that the farmers in selected regions in Haryana and Himachal Pradesh got at least INR 100 to INR 150 per quintal[39] more for their produce from Mother Dairy-SAFAL compared to those selling to commission agents/traders (Bathla, 2016).

It is hoped that a legal framework for contract farming can provide the much-needed fillip and scaling up to these arrangements. In addition, it may encourage the production of better quality and high value produce. Going forward, one can expect that by 2030, Indian farmers will have sufficient incentive to enter into contracts for export-oriented agriculture and horticulture produce which will meet international standards of quality and food safety. Since contract farming has the potential to bring businesses and farmers together, it can enable the farmers to use better practices, including more appropriate use of fertilisers and pesticides. It can introduce

[38] https://commerce.gov.in/writereaddata/uploadedfile/MOC_636802088572767848_Agri_Export_Policy.pdf.

[39] 10 quintals equal 1 tonne.

appropriate technology in farming and in allied occupations like dairy, fisheries and beekeeping etc. It can also incentivise farmers to conserve water by adopting micro irrigation and fertigation practices. It is, therefore, imperative for states to strengthen institutional support, provision of credit and extension services that instil confidence among small holders and women farmers to engage in contract farming.

Acknowledgements The authors acknowledge the FAO and NITI Aayog for awarding this study and the support received throughout. We are grateful to Prof. Ramesh Chand, Dr. P.K. Joshi, the paper reviewers and the participants in the National Dialogue—Indian Agriculture towards 2030 (January 2021) for their valuable comments and suggestions.

Annex

See Tables 3, 4, 5, 6 and 7; Figs. 6 and 7.

Table 3 Agricultural orientation index (AOI) of public spending on agriculture and irrigation

States	TE 1983–84	TE 1993–94	TE 2003–04	TE 2012–13	TE 2015–16
Andhra Pradesh	0.46	0.51	0.49	0.90	0.85
Assam	0.55	0.40	0.26	0.37	0.38
Bihar	0.28	0.19	0.17	0.29	0.30
Gujarat	0.76	0.80	0.76	0.69	0.90
Haryana	0.51	0.44	0.34	0.52	0.34
Himachal Pradesh	0.57	0.54	0.41	0.54	0.57
Jammu & Kashmir	0.58	0.46	0.39	0.47	0.47
Karnataka	0.65	0.65	0.84	1.01	1.49
Kerala	0.44	0.45	0.35	0.52	0.63
Madhya Pradesh	0.75	0.54	0.48	0.56	0.44
Maharashtra	1.43	1.43	1.30	1.12	1.15
Odisha	0.54	0.50	0.41	0.79	0.73
Punjab	0.40	0.28	0.17	0.22	0.43
Rajasthan	0.52	0.46	0.36	0.30	0.25
Tamil Nadu	0.59	0.73	0.67	0.50	0.64
Uttar Pradesh	0.50	0.38	0.31	0.23	0.27
West Bengal	0.43	0.33	0.19	0.18	0.18
Chhattisgarh[a]	–	–	0.63	0.78	1.26
Jharkhand[a]	–	–	0.53	0.40	0.41
Uttarakhand[a]	–	–	0.58	0.86	0.95
Bihar-Jharkhand	0.28	0.19	0.25	0.32	0.33
Madhya Pradesh-Chhattisgarh	0.75	0.54	0.53	0.61	0.60
Uttar Pradesh -Uttarakhand	0.50	0.38	0.33	0.27	0.31
All 20 States	0.60	0.52	0.48	0.54	0.59

Source Bathla et al. (2021)
Note (1) TE—triennium ending. (2) AOI serves as an indicator of the degree to which the share of agriculture and irrigation in public expenditure is commensurate with the weight of the sector in GDP. Irrigation expenditure excludes flood control. Data is derived from Finance Accounts and GoI-NAS.
[a]Till 2000, these were part of Madhya Pradesh, Bihar and Uttar Pradesh respectively.

Table 4 Composition of revenue and capital expenditure on irrigation, agriculture & allied activities (2011–12 prices)

Expenditure Heads	Revenue Expenditure (percentage share)	Capital Expenditure (percentage share)	Revenue Expenditure (INR billion)	Capital Expenditure (INR billion)
	TE 2015–16	TE 2015–16	TE 2015–16	TE 2015–16
Irrigation and Flood Control	**100**	**100**	**248.96**	**488.59**
Major & Medium Irrigation	70.28	72.44	175.39	354.29
Minor Irrigation	21.40	18.45	52.98	89.73
Command Area Development	3.29	1.01	8.08	4.92
Flood Control and Drainage	5.03	8.10	12.51	39.65
Agriculture and Allied Activities	100	100	790.21	75.92
Crop Husbandry	39.21	12.53	312.76	9.30
Soil and Water Conservation	2.42	16.50	19.04	12.47
Animal Husbandry	9.50	6.16	74.54	4.49
Dairy Development	2.38	0.45	18.59	0.37
Fisheries	1.96	6.35	15.43	4.69
Forestry and Wildlife	13.76	23.11	107.95	16.49
Plantations	0.01	0.01	0.082	0.006
Food Storage and Warehousing	12.68	19.65	99.37	15.79
Agricultural Research and Education	6.65	1.59	52.17	1.15
Agricultural Financial Institutions	–	–	–	0.003
Cooperation	8.23	11.77	63.45	9.66

(continued)

Table 4 (continued)

Expenditure Heads	Revenue Expenditure (percentage share)	Capital Expenditure (percentage share)	Revenue Expenditure (INR billion)	Capital Expenditure (INR billion)
	TE 2015–16	TE 2015–16	TE 2015–16	TE 2015–16
Other Agricultural Programmes	3.21	1.89	26.82	1.49

Source Based on Finance Accounts, GoI. The expenditure is taken for 20 major states
TE—triennium ending

Table 5 Percentage share of sources of credit in private investment in agriculture, 2012–13

Land Class	Distribution of farm expenditure as per source (per cent)			Percentage share of investment from	
	Own source (non-borrower)	Borrowing from formal sources	Borrowing from informal sources	Formal (institutional sources)	Informal (non-institutional) sources
Landless	18.6	48.4	33.0	59.4	40.6
Marginal	17.4	39.6	43.0	47.9	52.1
Small	13.9	59.6	26.5	69.2	30.8
Medium	10.9	60.6	28.6	67.9	32.1
Large	7.4	73.2	19.4	79.1	20.9
All Classes	13.8	53.8	32.5	63.4	36.6

Source NSSO AIDIS, 2013. Schedule 18.2

Table 6 Net income of agricultural households, INR/ha, 2012–13

	Marginal (< = 1 ha)	Small (1–2 ha)	Medium (2–4 ha)	Large (>4 ha)	All
Agriculture	39,656	36,480	33,699	31,156	35,345
Livestock	19,035	7364	5524	2913	9057
Non-farm business	13,467	5227	2607	1760	6031
Salaried/wages	63,359	14,789	7696	3252	23,776
Total	135,516	63,860	49,526	39,080	74,210
Percentage share of income					
Agriculture	29.26	57.13	68.04	79.72	47.63
Livestock	14.05	11.53	11.15	7.45	12.20
Non-farm business	9.94	8.18	5.26	4.50	8.13
Salaried/wages	46.75	23.16	15.54	8.32	32.04
Total	100	100	100	100	100

Source NSSO AIDIS, 2013. Schedule 33

Table 7 Agriculture economy of agricultural households as per gender (2012–13)

	(INR/hh)		(INR/ha)		(INR/hh)	(INR/ha)
Particular	Male	Female	Male	Female	Ratio Female to Male	Ratio Female to Male
Value of product	58,646	39,949	55,051	55,905	0.68	1.02
Value of by-product	3688	2681	3462	3752	0.73	1.08
Value of output	62,334	42,630	58,513	59,656	0.68	1.02
Seed	2846	1720	2671	2407	0.60	0.90
Fertiliser	5320	3676	4994	5145	0.69	1.03
Manure	596	487	560	682	0.82	1.22
Plant protection chemical	1874	1013	1759	1417	0.54	0.81
Diesel	1233	532	1158	745	0.43	0.64
Electricity	466	300	437	420	0.64	0.96
Labour (human)	5200	3703	4881	5182	0.71	1.06
Labour (animal)	359	304	337	425	0.85	1.26
Irrigation	785	665	737	931	0.85	1.26
Minor repair & maintenance of machinery and equipment	502	235	471	329	0.47	0.70
Interest	363	202	341	282	0.56	0.83
Cost of hiring of machinery	2660	1778	2497	2489	0.67	1.00
Lease rent for land	1850	499	1737	698	0.27	0.40
Other expenses	803	654	754	916	0.81	1.21
Value of input	24,856	15,768	23,333	22,066	0.63	0.95
Net income from agriculture	37,477	26,861	35,180	37,590	0.72	1.07

Source NSSO AIDIS, 2013. Schedule 33

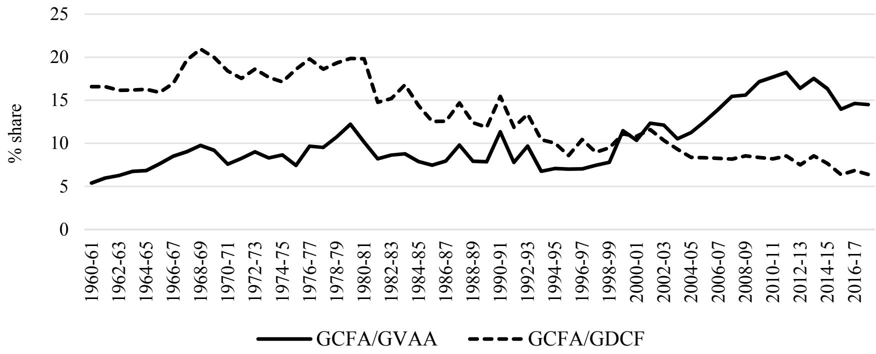


Fig. 6 Percentage share of GCFA in GDCF and GCFA in GVAA. *Source* National Accounts Statistics, MoSPI

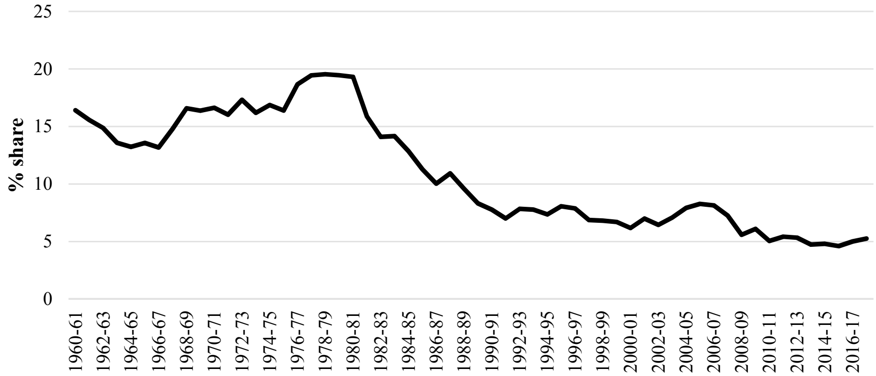


Fig. 7 Percentage share of public GCFA in public GDCF. *Source* National Accounts Statistics, MoSPI

References

NITI Aayog. (2016). *Evaluation study on efficacy of minimum support prices (MSP) on farmers.* Report No. 231. New Delhi, NITI Aayog Development Monitoring and Evaluation Office.

Acharya, S. S. (2017). Effective implementation of agricultural price and marketing policy for doubling farmers' incomes: doable priority actions. *Agricultural Economics Research Review, 30*(Conference number), 1–12.

Bathla, S. (2014). Public and private capital formation and agricultural growth: State-wise analysis of inter-linkages during pre- and post-reform periods. *Agricultural Economics Research Review, 27*(1), 19–36.

Bathla, S. (2016). Organised fresh food retail chains vs. traditional wholesale markets: marketing efficiency and farmers' participation. In C. Rao, R. Radhakrishna, R. K. Mishra & K. Venkata Reddy (eds), *India Studies in Business and Economics*. Singapore, Springer Nature.

Bathla, S., & Kannan, E. (2020). *Irrigation investments, governance and agricultural outcomes: A state level analysis.* Report (unpublished) submitted to the ICAR-NIAP, New Delhi.

Bathla, S., & Kumari, Y. (2017). Investment behaviour of farmers across Indian States: determinants and impact on agriculture income. In S. Bathla, & A. Dubey (Eds.), *Changing contours of Indian agriculture: Investment, income and non-farm employment.* Singapore, Springer Nature.

Bathla, S., Joshi, P. K., & Kumar, A. (2020). *Agricultural growth and rural poverty reduction in India: Targeting investments and input subsidies.* Springer Nature.

Bathla, S., Kannan, E., Das, G. K., & Aggarwal, R. (2021). Estimating efficiency of public investments in irrigation across the Indian states. In A. K. Biswas, Cecilia Tortajada & G. Chadha (Eds.), *Water governance & management in India: Issues & perspectives, Vol. 2*, Singapore, Springer Nature.

Binswanger-Mkhize, H. P., & D'Souza, A. (2012). India 1961–2010: structural transformation of the Indian economy and of its agriculture. In K. Fuglie, S. L. Wang & E. Ball (Eds.), *Agricultural Productivity: An International Perspective.* USDA Economic Research Service. Wallingford, United Kingdom, Centre for Agriculture and Bioscience International (CABI).

Birthal, P. S., Roy, D., Khan, M. T., & Negi, D. S. (2015). Farmers' preference for farming: Evidence from a nationally representative farm survey in India. *The Developing Economies, 53*(2): 122–34.

CGWB. *Groundwater Year Book of States.* Central Ground Water Board. Department of Water Resources, River Development and Ganga Rejuvenation. New Delhi, Ministry of Jal Shakti, Government of India.

Chand, R. (2019). Innovative policy interventions for transformation of farm sector presidential address. *Agricultural Economics Research Review., 32*(1), 1–10. https://doi.org/10.5958/0974-0279.2019.00001.6

Chand, R., & Parappurathu, S. (2012). Temporal and spatial variations in agricultural growth and its determinants. *Economic and Political Weekly, 47*(26–27), 55–64.

Chand, R. (2020). *New Acts: Understanding the implications.* Working Paper Series 1. New Delhi, NITI Aayog, Government of India.

Chand, R., Kumar, P. (2004). Determinants of capital formation and agricultural growth: Some new explorations. *Economic and Political Weekly, 39*(52), 5611–16 43

Chand, R., & Pandey, L. M. (2008). *Fertilizer growth, imbalances, and subsidies: trends and implications.* Policy paper. National Centre for Agricultural Economics and Policy Research.

Chand R., & Pavithra, S. (2015). Fertiliser use and imbalance in India: analysis of states. *Economic and Political Weekly, 50*(44).

Chandrasekhar, C. P., & Ghosh, J. (2002). *The market that failed: A decade of neoliberal economic reforms in India.* Leftword Books.

Debroy, B., & Bhandari, L. (Eds.). (2012). *The state of economic freedom in India.* Academic Foundation.

Department of Commerce. (2018). Agriculture export policy. New Delhi, Ministry of Commerce and Industry, Government of India. https://commerce.gov.in/writereaddata/uploadedfile/MOC_636802088572767848_Agri_Export_Policy.pdf

Fan, S., & Hazell, P. (2000). Should developing countries invest more in less favoured areas? An empirical analysis of rural India. *Economic and Political Weekly., 35*(17), 1455–1464.

FAO. (2016). Promoting gender equality and women's empowerment in fisheries and aquaculture. Food and Agriculture Organization, Rome, Italy.

FCI. (2015). Report of the high level committee on reorienting the role and restructuring of food corporation of India (FCI). New Delhi, Food Corporation of India. Unpublished.

Gautam, M. (2015). Agricultural subsidies: Resurging interest in a perennial debate. *Indian Journal of Agriculture Economics, 70*(1), 83–105.

Gulati, A., & Banerjee, P. (2017). Emerging water crisis in India. In U. Kapila (Ed.), *India's Economy: Pre-liberalisation to GST.* (p. 571–604). New Delhi, Academic Foundation.

Gulati, A., & Chopra, Kanchan. (1999). *Reform of the subsidy regime: implications for the agricultural sector*. A consolidated report of IEG, ISEC & IIM, Ahmedabad. September (unpublished).

Gulati, A., & Terway, P. (2018). Impact of investments and subsidies on agricultural growth and poverty reduction in India. In A. Gulati, M. Ferroni & Y. Zhou (Eds.), *Supporting Indian Farms*

the Smart Way (pp. 343–367). New Delhi: Academic Foundation and Indian Council for Research on International Economic Relations.
Gulati, A., & Bathla, S. (2001). Capital formation in Indian agriculture: Revisiting the debate. *Economic and Political Weekly, 36*(20), 1697–1708.
Gulati, A., & Narayanan, S. (2003). *Subsidy Syndrome in Indian Agriculture.* Oxford University Press.
Gulati, A., Chatterjee, P. & Hussain, S. (2018). *Supporting Indian Farmers: Price Support or Direct Income/Investment Support?* Working Paper No. 357. New Delhi, ICRIER.
Gulati, A., Roya, & R., Saini, S. (2021). *Revitalizing Indian agriculture and boosting farmer incomes.* Springer Nature.
Hoda A., Rajkhowa, P., & Gulati A. (2017). *Unleashing Bihar's agriculture potential: sources and drivers of agriculture growth.* Working Paper 336. New Delhi, Indian Council for Research on International Economic Relations (ICRIER).
Joshi, P. K. (2015). Has Indian agriculture become crowded and risky? Status, implications and the way forward. Presidential address. *Indian Journal of Agricultural Economics, 70*(1), 1–41.
Joshi, P. K., & Kumar, A. (2016). Transforming agriculture in eastern India: challenges and opportunities. In C. Ramasamy & K. Ashok (Eds.), *Vicissitudes of Agriculture in the Fast-Growing Indian Economy—Challenges, Strategies and the Way Forward* (pp. 125–150). New Delhi, Academic Foundation.
Kannan, E. (2012). *Rationalisation of agricultural subsidies: study of electricity and fertiliser subsidies in Karnataka and Tamil Nadu.* Unpublished report, Institute for Social and Economic Change, Bengaluru.
Kannan, E., Bathla, S., & Das, G. K. (2019). Irrigation governance and the performance of the public irrigation system across states in India. *Agricultural Economics Research Review. 32*(Conference Number), 27–41.
Kant, A. (2020). It's now or never: states are driving bold reforms. We will never get this opportunity again, seize it, *The Times of India* May 12.
Kaufmann, D., Kraay, A., & Zoido-Lobaton, P. (1999). Governance matters. Policy Research Working Paper 2196, World Bank, Washington, D.C.
Kaufmann, D., Kraay, A., & Mastruzzi, M. (2009). Governance matters VIII: Aggregate and individual governance indicators, 1996–2008. Working Paper No. 4978, World Bank, Washington, D.C.
Keuleers, P. (2004). Governance in the least developed countries in Asia and Pacific: an assessment of the current situation. United Nations Development Programme (UNDP).
Kumar, A., Mishra, A., Saroj, S., & Joshi, P. K. (2017). Institutional versus non-institutional credit to agricultural households in India: Evidence on impact from a national farmers' survey. *Economic Systems, 41*(3), 420–432.
Kumar, A., Sonkar, V. K., & Saroj, S. (2020). Access to credit in eastern India: Implications for the economic well-being of agricultural households. *Economic and Political Weekly., 4*(21), 46–54.
MoA&FW. (2015). All India Report on *Agriculture Census 2010–11.* New Delhi, Ministry of Agriculture and Farmers Welfare, Government of India
MoA&FW. (2018). *Doubling Farmers' Income.* Report of the Committee constituted under Dr. Ashok Dalwai. New Delhi, Ministry of Agriculture and Farmers' Welfare, Government of India. http://agricoop.nic.in/doubling-farmers.
MoA&FW. (2019). All India Report on *Agriculture Census 2015–16 (Phase 1).* New Delhi, Ministry of Agriculture and Farmers Welfare, Government of India. http://agcensus.nic.in/document/agcen1516/T1_ac_2015_16.pdf
NSSO. (2013). *All India Debt and Investment Survey.* National Sample Survey 70th Round. National Sample Survey Organisation. New Delhi, Ministry of Statistics and Programme Implementation, Government of India.
OECD. (2015). China in *agricultural policy monitoring and evaluation 2015.* Paris, OECD Publishing.https://doi.org/10.1787/agr_pol-2015-10-en

OECD-ICRIER. (2018). *Agriculture Policies in India.* OECD Food and Agricultural Reviews. Paris, OECD Publishing.

Patnaik, P. (2018). Trends of centre–state relations in India under the neo-liberal regime. *Studies in People's History., 5*(1), 83–91. https://doi.org/10.1177/2348448918759872

RBI. (2019). Report of the internal working group to review agricultural credit, Reserve Bank of India, 13 September 2019. https://rbidocs.rbi.org.in/rdocs//PublicationReport/Pdfs/WGREPORT101A17FBDC144237BD114BF2D01FF9C9.PDF

Sahoo, N. (2015). *Centre-State Relations in India.* ORF Occasional Paper 62, March. New Delhi, Observer Research Foundation.

Satyasai, K. J. S., & Singh, A. (2021). Food processing industry in India: regional spread, linkages and space for FPOs. In S. Bathla & E. Kannan (Eds.), (2021), *Agro and Food Processing Industry in India—Inter-sectoral Linkages, Employment, Productivity and Competitiveness.* Singapore, Springer Nature.

Saxena, R., Chand, R., & Rana, S. (2015). Estimates and analysis of farm income in India, 1983-84 to 2011–12. *Economic and Political Weekly, 50*(22).

Sen, T. K. (2016). Public finances and development: the case of Punjab. In L. Singh & N. Singh (Eds.), *Economic Transformation of a Developing Economy—The Experience of Punjab, India.* Singapore, Springer Nature.

Sharma, V. P. (2013). *The role of fertilizer in transforming agriculture in Asia: a case study of the Indian fertilizer sector*. Centre for Management in Agriculture, Indian Institute of Management, Ahmedabad.

Sharma, B. R., Gulati, A., Mohan, G., Manchanda, S., Ray, I., & Amarasinghe, U. (2018). *Water Productivity Mapping of Major Indian Crops.* NABARD and ICRIER, New Delhi.

Singh, P. (2008). *Federalism, nationalism and development: India and the Punjab economy.* Routledge.

Singh, P. (2016). How centre-state relations have shaped Punjab's development pattern. In L. Singh & N. Singh (Eds.), *Economic transformation of a developing economy—the experience of Punjab, India.* Singapore, Springer Nature.

Singh, R.B. (2019). *Agricultural Transformation—A Roadmap to New India.* National Academy of Agricultural Sciences.

Singh, L., & Singh, N. (2016). Economic transformation and development experience of Indian Punjab—An introduction. In L. Singh & N. Singh (Eds.), *Economic Transformation of a Developing Economy—The Experience of Punjab, India.* Singapore, Springer Nature.

Terway, P. (2021). *Production and distribution aspects of input subsidies in Indian agriculture: A case study of Jharkhand*. Thesis submitted to Jawaharlal Nehru University.

Tiwari, S., & Surya, S. (2019). *State of State Finances.* New Delhi, PRS Legislative Research.

Tortajada, C. (2010). Water governance: some critical issues. *International Journal of Water Resources Development, 26*(2), 297–307.

United Nation Development Programme. (2014). Governance for sustainable development: integrating governance in the post-2015 development framework, Discussion Paper, United Nations Development Programme (UNDP).

Other References

Agricultural Statistics at a Glance (1980 to 2017). New Delhi, Ministry of Agriculture and Farmers' Welfare.

National Accounts Statistics, (1980 to 2017). New Delhi, Ministry of Statistics and Programme Implementation. 46

Annual Reports of State Electricity Boards. (1980 to 2016). Planning Commission, Government of India.

Remandating Indian Agriculture: Pathways for Transformation

Pramod Joshi and Shyam Khadka

This book began with a short description of the challenges facing global and Indian agriculture, and highlighted India's commitments to the Sustainable Development Goals (SDGs) and climate change. Underlining the changes that the agriculture sector in India has gone through and that more can be expected, the first chapter emphasised the need for a transformative vision that should prepare the sector for the next decade. The chapters that followed detailed the contours of this transformative vision, focusing on the following themes: structural reforms and governance issues; sustainable use of water; science and technology; dietary diversification; nutrition and food safety; pests, pandemics and preparedness; and managing climate risks. This chapter will now present the pathways for transforming the Indian agri-food system. Before doing so, it will briefly dwell upon the demand and supply responses of the Indian agri-food system, with a focus on how the consumption patterns and production portfolio of major food commodities are changing and what the key enablers and hurdles in the transformation of the agri-food system are.

1 Demand and Supply Aspects of the Indian Agri-Food System

The Indian agri-food system is going through a lot of changes, with both the demand and supply side responding to demographic changes, economic growth, government policies and institutions.

P. Joshi (✉)
Formerly with International Food Policy Research Institute, New Delhi, India

S. Khadka
Formerly with Food and Agriculture Organization, New Delhi, India

R. Chand et al. (eds.), *Indian Agriculture Towards 2030*,
India Studies in Business and Economics,
https://doi.org/10.1007/978-981-19-0763-0_10

1.1 Historical Trends in Consumption Patterns

Three broad trends can be seen in India's food consumption patterns: (a) share of food in total expenditure is declining, (b) consumption of food items is diversifying in rural and urban areas and (c) calorie consumption is rising while that of protein is declining.

The share of food in consumption expenditure has fallen from 62.7% in 1983 to 46% in 2011 (Joshi et al., 2016). The food consumption diversity index increased from 0.43 in 1983 to 0.55 in 2011, with the diet diversity being more among urban consumers than rural consumers (Joshi et al., 2016). Food consumption trends show that the demand for cereals-based commodities is declining, while those of high-value commodities (such as fruits, vegetables, dairy, meat and fish) is rising. At the all India level, the per capita annual consumption of cereals declined from 168 kg in 1983 to 133 kg in 2011 and the share of cereals in food expenditure fell from 42.7 to 23.5% over the same period. In contrast, the per capita annual consumption of fruits and vegetables increased from 49 kg in 1983 to 68 kg in 2011 and that of milk rose from 45 to 64.9 kg over the same period. Within food grains, there is a steep fall in the consumption of coarse cereals (−82.5%), followed by pulses (−15.65%) during the same period (Joshi et al., 2016).

This changing dietary pattern is leading to imbalance in nutrient intake, with the consumption of fat rising while those of calories, protein and iron is falling. This is leading to undernourishment as well as obesity.

1.2 Drivers of Changes in Consumption Pattern

The change in consumption patterns has several drivers: consumer's income, prices of commodities, urbanisation, globalisation, changing tastes and preferences and social safety net programmes.

Joshi et al. (2016) observe that income of consumers is one of the key factors influencing consumption patterns, with high income consumers consuming more food and also having a more diverse diet than low income consumers. There is also a rural–urban divide. Barring staples, the urban consumer consumes higher quantities of food than rural consumers. The annual per capita rice consumption is higher in rural areas (85.45 kg) than in urban areas (71.50 kg), though the difference in wheat consumption is a negligible 1.78 kg. However, in the case of vegetables, the annual per capita consumption in urban areas is 57.86 kg against 55.75 kg in rural areas. Urban consumers consume 71 kg of milk and milk products per capita per year while rural consumers consume 61 kg.

Kumar and Joshi (2016) find that (a) low income consumers are more responsive to prices than high income consumers, and (b) both groups are more responsive to high-value commodities than staple food commodities. The price elasticity of rice and wheat for poor consumers is −0.469 and −0.508, respectively, while that for rich consumers it is −0.200 and −0.303. The corresponding elasticities for vegetables are −0.729 and −0.397, and for fruits these are −0.801 and −0.562 for poor and rich, respectively.

Globalisation is integrating food markets and influencing consumption of different food items. Food habits are changing due to imports, migration and easy access of information about different cuisines. Supermarkets are bringing food from other parts of the world to Indian homes. Pingali and Khwaja (2004) report that the Asian countries, including India, are gradually transforming their dietary pattern from cereals to high-value and processed commodities.

1.3 Projected Demand and Supply of Food by 2030

Future demand for different food commodities depends on a range of factors: population, income, price elasticities, the indirect demand for feed, industrial uses and seed as well as expected wastages. Kumar and Joshi (2016) take all these factors into consideration and project the demand for different food commodities for 2030 under three different scenarios of gross domestic product (GDP) growth: (i) business as usual (BAU), (ii) pessimistic scenario: 25% lower than BAU and (iii) optimistic scenario: 25% higher than BAU. The projections of food grains requirement under the different scenarios range from 303.9 million tonnes to 318.4 million tonnes in 2030.

On the other hand, the requirement for high value commodities is expected to grow much faster in the future than was the case in the past. The projected demand for fruits and vegetables is expected to be in the range of 295.04 million tonnes to 315.83 million tonnes in 2030 and that of milk between 184.91 million tonnes and 201.30 million tonnes.

However, land, water and other resources needed to produce sufficient quantities to meet this future requirement are limited, and efforts need to be made to produce more from less. The role of improved technology will be a key factor in this.

The authors also projected the supply of food commodities by 2030 under (a) BAU; (b) 50% acceleration in total factor productivity (TFP) growth over the baseline; (c) 50% deceleration in TFP growth over the baseline. India will be surplus in rice, wheat and coarse cereals by 2030 but deficit in pulses and edible oils. It is expected to be surplus in high-value commodities if appropriate measures are taken to minimise losses in perishable commodities.

1.4 Supply Side Transformation of Agriculture

Indian agriculture has gone through a significant trajectory of transformation over the last six decades—from a food deficit country to one that is self-reliant and, now, one with surpluses seeking to increase exports. The marketable surplus of a majority of non-perishable crops is now 80–90%. In short, Indian agriculture has gradually commercialised, mechanised, diversified and globalised.

Food grain production nearly quadrupled between 1970–71 and 2018–19, the most notable gains being made in rice and wheat, while yield levels almost trebled. Though the performance of nutri-cereals and pulses is not as impressive, the yield gain is about three times.

Among commercial crops, there has been an impressive increase in the production of sugarcane and cotton. Production of sugarcane trebled between 1970–71 and 2018–19 and that of cotton saw a six-time increase over the same period. The story is similar in the case of horticulture (production of fruits and vegetables nearly trebled between 1991–92 and 2017–18), milk (India is the world's largest producer of milk) and poultry. These impressive gains notwithstanding, food safety and quality standards are still an area of weakness.

Use of animal and human power in agriculture and related activities has reduced significantly, from about 66% in 1971 to about 12% in 2013–14 (Chapter "Transforming Indian Agriculture"), while the use of mechanical and electrical sources has increased from about 34% to about 88% over the same period. Tractors account for about 48% of total farm power in 2013–14 and a large acreage of rice and wheat is harvested using harvesters and combines.

In line with the dietary diversification noted earlier, agricultural production has also diversified and is becoming more commercial. Gulati and Juneja (2020) note that the share of food grain crops in total cultivated area is declining (from 73% in the triennium ending (TE) 1982–83 to 62% in TE 2016–17) and those of commercial crops (or cash crops) is rising. Earlier, Joshi et al. (2006) estimated that agricultural diversification was the main source of agricultural growth during the 1990s, followed by agricultural prices; it used to be yield during the 1980s.

Indian agriculture is now in the early stages of integration with the global market, with both exports and imports of agricultural commodities showing exponential growth. Export growth has been faster—from INR 586 billion in 2006–07 to INR 2835 billion in 2018–19, while imports grew from are INR 296 billion to INR 1619 billion. The trade surplus from agriculture increased from INR 290 billion to INR 1216 crore over the same period.

2 Pathways for Transformation of the Agri-Food System

The seeds of the Green Revolution were sown in India against the backdrop of a drastic fall in agricultural production,[1] forcing India to rely on imported wheat from the United States of America, under the PL-480 programme, to meet its food requirement. The Green Revolution, which relied on high yielding varieties of wheat

[1] It fell by 17 million metric tonnes (MMT) from 89.4 MMT in 1964–1965.

and rice, complemented by a host of other support services, led to Indian agriculture growing rapidly and enabled India to become a global player.[2]

A serious imbalance, however, has emerged between output and employment, requiring urgent attention to be paid to the need to create jobs in manufacturing, services and construction. For example, over time, while the headcount of the poor has gone down, more than 189.2 million remain undernourished in 2017–19.[3] Similarly, growing population, increasing urbanisation and climate change are putting pressure on agricultural land for cultivation and adversely affecting soil and water quality. There is, therefore, a need to remandate Indian agriculture building upon the success it achieved in past five decades while aiming at making it more productive, efficient, resilient, resource-conserving, nutrition-centred and globally-focused. This section focuses on the pathways that will help achieving these outcomes.

2.1 Increased Investment in Agriculture

The growth rate of investment and capital formation in agriculture, which is essential for its progress, has seen an unhealthy trend in recent years, falling from close to 10% per year during the 2002–03 to 2011–12 period to 2% between 2010 and 2020. The private corporate sector accounts for less than 2% of the total investment in agriculture and less than 0.5% of the total annual investments of the corporate sector in the Indian economy. There is a pressing need to revive investments in agriculture in order to modernise the sector. Such investments should mainly focus on increasing productivity and making Indian agriculture more efficient. The key areas that would require substantial boost in investments are briefly described below.

In most of crops, increase in productivity has been accompanied by an increase in the average cost of production, which necessitates an increase in output prices to keep incremental production profitable. There is a need for shift in strategy from 'growth' to 'efficient growth', such that any increase in productivity is associated with a reduction in the average cost of production. This requires upgradation of agricultural technology, application of modern skills in farm practices, new innovations in farming and lowering wastages in the use of fertiliser, water and other inputs (Chand, 2019).

The adoption of improved technologies by Indian agriculture is still far below the potential. This can be gauged by the fact that the seed replacement rate and use of certified quality seed distributed by various agencies is quite low. Fertiliser use in most states is also sub optimal (Pavitra & Chand, 2015). Less than 50% of the area under cultivation has more than one crop grown on it. The fact that more than 30% area under cereals is still under traditional varieties shows that improved technology has not yet reached a large number of farmers. The main reasons for this

---

[2] With wheat production of 106.2 MMT and rice production of 117.5 MMT in 2019–20, India is the second largest producer of both these commodities. It also has become the largest exporter of rice (12.7 MMT, USD 7.7 billion in 2017–18).

[3] FAO et al. (2020).

are poor extension, missing links with the supply chain of quality seed and quality plant propagation material and low availability of institutional credit in many states.

Efficiency is driven by strong and vibrant research and development (R&D), whether by the public sector or private sector. Public sector R&D is showing fatigue and suffers from resource constraints, disciplinary fragmentations and lack of drive and inspiration. Private sector investment in agri R&D is also low due to the prevailing intellectual property regime. Consequently, the gap between domestic and global agricultural innovations is increasing and many interesting developments in global agriculture have bypassed India. There is a need to facilitate farmers' access to global technology, seeds, germplasm and other knowledge products.

Reorientation of agricultural science, technology and innovation focusing on greater use of new scientific developments and scaling of innovations is needed to accelerate agricultural GDP growth, as Chapter "Science, Technology and Innovation", has described. These may include:

1. genetic resource management and crop improvement through germplasm enhancement/pre-breeding using wide gene pools and molecular breeding techniques;
2. adopting genomics and gene editing as preferred technologies for precision breeding;
3. using genome editing in livestock to achieve enhanced prolificacy and reproductive performance, improved milk production and increased disease resistance;
4. increased application of genetically modified (GM) technology without compromising biosecurity; and
5. adopting protected cultivation to increase productivity and income.

Similarly, application of digital solutions and Artificial Intelligence can help ushering in an Evergreen Revolution, using big data for creating support systems. Precision agriculture holds out even more promise. Indeed, there are several innovative technologies ready to be scaled up and scaled out. India is making rapid advances in the use of non-fossil fuels and these can easily account for 20% or more of its total fuel use. While the use of solar power in Indian agriculture is still limited, it can account for a significant share of renewable energy.

Concern has been raised about inadequate investment in agriculture extension and the consequent decline in all aspects of extension. This is also evident from the gap between the existence and adoption of improved technologies, and between attainable and actual farm yields. Use of information communication technology and digital technology will go a long way in filling the gaps in extension and knowledge dissemination.

The diversified Indian agroecosystems and sectors are plagued by pests and pandemics, which affect the edifice of India's biosecurity, threatening food, nutrition, health, livelihood, biodiversity and ecosystem services. Rapid, large-scale movement of people and material in a globalised world, climate change and inadequate surveillance will exacerbate pandemics in the future. Research-cum-developmental organisations and industries dealing with the health systems of human, livestock, poultry and fish have the paraphernalia needed for effective preparedness and management of pests and pandemics. However, their operational success is hampered by lack of coordination and collaborations.

Slight adjustments and reorientation in the functioning of different programmes interlinked through a common hub under the One Health concept would raise the standards of diagnostics, preparedness and pest management. For India to be a part of this preparedness, transformational changes in transboundary pest surveillance, strict quarantine, rapid molecular diagnosis, anticipatory research and training are essential. Transparency, political commitment, investment in research and development, analysis and interpretation of big data, meta-analysis, multilateral institutional/international cooperation is the way forward for preparedness and biosecurity. It is also important to note that pandemics need a united regional and global approach rather than mere national focus.

Indian agriculture has also witnessed greater levels of mechanisation. However, since the average farm size is low at 1.08 ha (hectares) (only 0.57% farms have holding size above 10 ha), farmers often end up adopting technologies which are not scale-neutral. One obvious solution to this challenge is to enable consolidation of small farms into larger tracts by enabling land leasing—though this comes with its own set of challenges relating to land titles. As farm mechanisation and precision farming could benefit small farmers, custom hiring centres can be promoted extensively. Similarly, aggregation of transactions through the use of computing/mobile devices or affordable rental of farm equipment is a promising option.

2.2 Making Indian Agriculture Globally-Focused

Though Indian agriculture has shifted from being a subsistence-oriented one to a market-oriented one, it is yet to be viewed as an enterprise and treated holistically as being part of a larger value chain. India currently processes less than 10% of its agri output. The share of high value and value-added agriculture produce in India's agri-export basket is less than 15%, against 25% in the case of the United States of America and 49% in the case of China. Given the globalisation of value chains, it is imperative that the country make concerted efforts to boost exports of high margin, value-added and branded processed products. The food processing sector has been exhibiting robust growth and constitutes as much as 8.83% of gross value added in manufacturing and 10.66% of gross value added in agriculture sector (CII, 2019). Changing consumption patterns due to urbanisation, changes in the gender composition of the work force and growing consumption have all contributed to the increase in the size of the domestic processed food market. Backed by progressive policies, fiscal incentives and an enabling regulatory environment, the Indian market size for food is expected to reach USD 544 billion by 2020–21 (CII, 2019). This will be amply complemented by a very high export growth target set by the new Agriculture Export Policy (AEP), 2018.

India is the eighth largest exporter of agricultural produce, with export earnings of USD 38.5 billion in 2018–19.[4] There is immense potential to increase agricultural exports, given the immense diversity and quantum of agricultural production, the fact that India's share in global agricultural export is only 1.8%,[5] European Union exports are as high as USD 181 billion and United States of America exports are USD 172 billion. A 2010 report by the World Trade Organization (WTO) states that India might become the world's fifth-largest exporter of agricultural commodities, surpassing Thailand and Indonesia.[6] Given the untapped potential and against the backdrop of the government's commitment to double farmers' income, the AEP aims to double agricultural exports to about USD 60 billion by 2022 and USD 100 billion in the next few years thereafter.[7]

In order to achieve these targets, it is important that India:

1. gears its agricultural development objective from heavy emphasis on self-sufficiency to providing quality products for export markets;
2. re-orient the role 715 *Krishi Vigyan Kendras* (agricultural science centres) towards enhancing the growth of crops that are in demand in global markets;
3. educate farmers on the prudential use of pesticides and other chemicals to eliminate the chances of rejection of Indian consignments; and
4. lay more emphasis on developing horticulture crops.[8]

[4] Agricultural exports accounted for 12.6% to total merchandise export (USD 303.7 billion) in 2018–19. Indian agricultural commodities and processed foods are exported to more than 200 countries. The top ten destinations for exports are Vietnam, Iran (Islamic Republic of), Saudi Arabia, the United Arab Emirates, the United States of America, Indonesia, Nepal, Bangladesh, Malaysia and Iraq. Commodities with export value of above USD 1 billion include: basmati rice (USD 4.71 billion), buffalo meat (USD 3.59 billion), spices (USD 3.31 billion), non-basmati rice (USD 3 billion), cotton (USD 2.1 billion), oil meals (USD 1.5 billion), marine products (USD 1.5 billion) and sugar (USD 1.3 billion). See, Hitul Awasthi, *India Agricultural Exports and Market Analyses*, Krishi Jagran, 17 June 2020. https://krishijagran.com/agripedia/indian-agricultural-exports-and-market-analysis/.

[5] Despite being the largest producer of papayas, lemons and limes, India meets only 3.2% of the world papaya demand, 0.5% for lemons and limes. However, the country has outperformed in exports of capsicum chilly, castor oil, tobacco extracts and sweet biscuits. It also has well established in the export market of basmati rice, meat and marine products. See Gurmeet Kaur, India Can Become Top Five Agriculture Goods Exporters in the World: WTO Report, Grain Mart. https://www.grainmart.in/news/india-can-become-top-five-agriculture-goods-exporters-in-the-world-wto-report/.

[6] https://www.grainmart.in/news/india-can-become-top-five-agriculture-goods-exporters-in-the-world-wto-report/.

[7] These targets are to be achieved by maintaining a stable trade policy regime accompanied by: (i) diversification of the export basket; (ii) promoting novel, indigenous, organic, ethnic, traditional and non-traditional agricultural products; (iii) providing an institutional mechanism for pursuing market access, tackling barriers and deal with sanitary and phytosanitary issues; and (iv) enabling farmers to get the benefit of export opportunities in the overseas market.

[8] Emphasis on horticultural crops is important also because the current level of minimum support prices make some crops like wheat uncompetitive in global markets.

2.3 Increasing the Efficiency of Water and Other Resources

India has made phenomenal progress in the development of irrigation and this played a key role in transforming Indian agriculture and making the country self-sufficient in food. Water also made agriculture more resilient to drought and climate variability over the years. Irrigated area increased from 20.9 million ha in 1950–51 to 67.30 million ha in 2015–16. The gross irrigated area went up from 22.6 million ha in 1950–51 to 96.62 million ha in 2015–16—almost half of the land under food grains is irrigated. Around 40% of total agricultural land in India is reliably irrigated and the remaining 60% is still rainfed and dependent on the monsoon. Groundwater is the source of almost 65% of the irrigated area. Over the years, area irrigated by groundwater increased much faster than the area irrigated by surface water.

The excessive use of groundwater, however, has led to steady decline in the water table and water quality. At least 60% of India's districts are either facing a problem of over-exploitation or severe contamination of groundwater (Vijayshankar et al., 2011). The Central Ground Water Board revealed that many parts of India are witnessing a steep fall in the groundwater table in many parts of India. It is estimated that the groundwater table in as many as 30% of total blocks in the country is either over-exploited or in a critical and semi-critical stage. The over-exploitation is more pronounced in north-western India, western India and southern peninsular India. There is also evidence of fluoride, arsenic, mercury and even uranium and manganese contamination in groundwater in some areas. The over-exploitation of groundwater is largely attributed to power being supplied free or at low tariff rates. Improved water management practices and micro-irrigation (drip and sprinkler) are available and can be used for improving water use efficiency and enhancing agricultural production.

It is in the above context that Chapter "Symbiosis of Water and Agricultural Transformation in India", argues for a paradigm shift in Indian agriculture. The way forward it suggests involves adopting an agroecological approach, changing the cropping pattern, applying improved technology in conserving water, reversing the neglect of the rainfed areas and introducing radical changes in the way in which water is managed, including the adoption of participatory management in both surface and groundwater systems.

2.4 Making Agriculture Climate Resilient

Climate change has become a major challenge to agricultural production. There are several projections about the varying impact of climate change on the agriculture sector in different regions. According to the Indian Network for Climate Change Assessment (INCCA) Report (INCCA, 2010), the rice crop (which is the major food grain crop), would suffer yield loss of 4–20% under irrigated conditions and 35–50% under rainfed conditions as early as 2030. Pal et al. (2019) reported that these projections are much more alarming than earlier ones, and tally with Cline's estimates of 30–40% yield loss (Cline, 2007). More worrying is the revelation that what was expected to happen in 2080 may happen in 2030 itself. The negative impact of climate change on milk production has been estimated at about 1.6 million tonnes in 2020 and more than 15 million tonnes in 2050 (Upadhyay et al., 2009). An IPCC (2014) report indicates that climate change is occurring faster than earlier predicted. Small farm holdings, which are the main source of food, nutrition and livelihood security in India, are more prone to climate change impacts (Joshi & Tyagi, 2019). Small farm holders, who have the least capacity to overcome the consequences, as they have fewer resources to adapt socially, technologically and financially, are likely to be the worst affected.

Besides climate change, climate variability—including extreme events such as tropical storms, sudden rise and fall in temperature—is also expected to affect production of all food commodities. Kumar et al. (2014) point out that an increase in drought intensity will lead to fall in production, thereby pushing up the prices of food commodities. The authors estimated that a 10% increase in drought during the monsoon period will lead to the price of rice surging by 23%, maize by 16%, sorghum and millets by 13% and *tur* by 10%. The higher prices of food commodities will lead to fall in demand for them—approximately 5.5% in the case of rice and 2–4% in other commodities.

Agriculture is both part of the problem and part of the solution to climate change and sustainability. It is necessary to seize every opportunity available to move away from inefficient farm practices and towards long-term sustainability, efficiency and resilience. Of all sectors of the economy, agriculture offers the best hope for environmentally sustainable green growth. It is in this context that Chapter "Managing Climatic Risks in Agriculture" mentions several technological and institutional options that are now available to build resilience in Indian agriculture to current as well as future climate change. Most of these are no-regret options with mitigation co-benefits linked to SDGs. However, more targeted and detailed research is necessary to identify exact strategies.

The intelligent use of climate information services and big data analytics can facilitate the efficient use and targeting of increased public and private investment in natural capital through the management of water, energy, soil quality and natural resources and climate change literacy. A bottom-up farmer level consultation is equally, if not more, important, if only to indicate an equitable path, going forward. More research is also needed to understand risk profiles, the implications of various agricultural service delivery models for various social groups to strengthen resilience and finally to reduce loss and damage by investing in climate proof agricultural system. There are immense opportunities in targeting climatic services, advisories, insurance and precision agronomy, but there is a need for sound business models in order to take these to scale. There is a growing need for right partnerships, science-based actions, policies, market/non-market incentives, investments and institutional changes. Investments in natural resources, infrastructure, knowledge and human resource and social and institutional capital, and valuing their impact for creating green jobs in these sectors and impact on various dimensions of human wellbeing are becoming imperatives in policy planning.

2.5 Tackling Dietary Diversity, Nutrition and Food Safety

India is faced with a triple burden of malnutrition, namely, under-nutrition, micronutrient deficiency and over-nutrition. In 2017, about 68.2% of the deaths of children under five years of age in India was due to malnutrition (Chapter "Dietary Diversity for Nutritive and Safe Food"). The prevalence of stunting among children under five years of age was high, at 34.7% during the 2016–2018 period (CNNS, 2019). The body mass index of 23% of women in the 14–49 age group was below normal in 2015–16 (NFHS, 2017). Moreover, two-thirds of India's population is estimated to be deficient in micronutrients (Rao et al., 2018). The deficiency of micronutrients exists despite good economic growth (6% in 2018–19), a high level of food grain production, an increase in the per capita net availability of food grains (MoA&FW, 2020) and a significant decline in the percentage of population below the poverty line. Along with undernutrition, overweight and obesity have emerged as severe public health challenges, leading to an increase in non-communicable diseases (NCD). In 2017, about 63% of all deaths in India were attributable to NCDs (WHO, 2018).

It is vital to address the issue of malnutrition, especially in children and women, in order to ensure proper cognitive growth, overall health and productivity. Inadequate access to food, inadequate care for children and women, inadequate education, insufficient health services and unhealthy environment are the underlying factors behind this dismal situation.

The pathways for safe and healthy diets for nutritional security in India consist of the following:

1. improving dietary diversity,
2. reducing post-harvest losses,
3. bio-fortification of staples,
4. empowerment of women,
5. enforcing standards of food safety, packaging and labelling,
6. improving the Water, Sanitation and Hygiene (WASH) environment and
7. food safety awareness and nutrition education.

The need of the hour is expedited implementation of food safety and nutrition programmes, adopting a multi-pronged strategy with increased coverage, better targeting, change in the design, higher allocations of funds and coordination between different policies and programmes to achieve SDG2 targets. This should be accompanied by an effective use of digital technology. Additionally, food and nutrition security initiatives will need to be harmonised with changing demographics, livelihood patterns, environmental sustainability, health-specific needs and overall development activities.

2.6 Strengthening Institutions

India is dominated by small holdings and the future of agriculture depends upon them. The smallholders suffer from scale disadvantage, resource constraints and, typically, have small marketable surplus. However, various studies show that small farmers, especially in Asia, are more productive than large farmers (Chand et al., 2011). They have a significant labour advantage which can be tapped into for producing skill-based labour intensive products with institutional support like farmer producers' organisations (FPO) or cooperatives. Contract farming has also been very successful in addressing the resource constraints and market challenges that small farmers face and enabling them to diversify towards high value crops. Impressed by the success of such initiatives, the Government of India has implemented important policy reforms and launched an initiative to promote 10,000 FPOs.

A sharper focus on the role of three I's—Innovations, Incentives and Institutions—could help produce more, diversified and nutritious food economically, and in an environmentally and financially sustainable manner (Chapter "Transforming Indian Agriculture"). The major innovations in production technologies that can significantly impact overall productivity and production in India include climate resilient seeds and protected and sustainable agriculture. An incentive structure needs to be put in place for farmers to encourage them to adopt new technology and augment production. Possible interventions include direct income/cash transfer and incentives for water and energy conservation. In the case of the land institution, there is an urgent need to reform land laws, free up the lease market and revoke all restrictions, like ceilings on land holdings. In order to regulate the unsustainable extraction of water for irrigation, the government needs to create an institution that regulates spacing of tube wells, identification of aquifers, size of pumps and the overall rate of exploitation. This should be accompanied by institutional arrangements governing rights over water, land tenure, users' relationships and financial incentives.

2.7 Adopting Appropriate Policies and Improving Governance

An increase in agricultural production is essential, but is not sufficient to yield a substantial increase in farmers' income. Farmers need help to get higher prices and some of them need to be moved to non-farm occupations. Prices at the farm level can be raised in two ways—by ensuring farmers get minimum support prices (MSP) and by creating competitive markets. In many states, farmers get prices that are 10–20% lower than MSP. This is true even for paddy and wheat, where a large part of the marketed surplus is procured by the government. Ensuring MSP in such cases will raise farmers' income by 13–26%. It needs to be noted that the Green Revolution happened in only those states where farmers got remunerative prices. Recently, this has also been noted in in central and eastern India. At the same time, it is important to emphasise that procurement at MSPs that are higher than open market prices causes many distortions. There is a need to think of alternative mechanisms, like deficiency price payment, which are less costly, more equitable and non distortionary (Chand, 2018).

Reforms in the system of marketing is a more effective means of ensuring better prices to farmers, without putting pressure on consumer prices. The current markets system and its infrastructure are outdated and exploitative. Rather than evolving, agricultural markets have decayed and serve the interest of intermediaries rather than of farmers and consumers. Competitive and modern markets and other reforms in the agriculture sector can make the sector vibrant, self-reliant and economically attractive.

The key areas for policy reform (Chapter "Structural Reforms and Governance Issues in Indian Agriculture") include:

1. accelerating rural infrastructure in a manner that targets specific regions as well as small and marginal farmers (including women farmers), and creating a competitive environment that stimulates investment, productivity and marketing efficiency;
2. giving state governments more autonomy and flexibility to draw up 'fit for purpose' action plans relating to production and marketing so as to encourage both the farmers and the agripreneurs;
3. enabling women farmers to form farmer producer organisations, women self-help groups and women-headed enterprises with the objective of easing the hurdles they face in getting loans from the banking system, mainly because of lack of land titles in their names;
4. ensuring adequate investments in rural and marketing infrastructure, credit flow and extension services while formulating and implementing innovative and inclusive market reforms; and
5. expansion of contract farming in a way that encourages the production of better quality and high value produce and provides farmers sufficient incentive to enter into contracts for export-oriented agricultural and horticultural products which meets international standards of quality and food safety.

References

Chand, R. (2018). Innovative policy interventions for transformation of farm sector. *Agricultural Economics Research Review, 32*, 1.

Chand, R. (2019). Transforming agriculture for the challenges of 21st century. *Think India Journal, 22*(26). Presidential Address to 102nd Annual Conference of Indian Economic Association, AERO University, Surat.

Chand, R., Prasanna, L., & Singh, A. (2011). Farm size and productivity: Understanding the strengths of smallholders and improving their livelihoods. *Economic and Political Weekly, Review of Agriculture, 46*(26 & 27), 5–11.

CII. (2019). *Indian food processing sector—Trends and opportunities.* Confederation of Indian Industry, Foodpro, and FACE.

Cline, W. R. (2007). *Global warming and agriculture: Impact estimates by country*. Centre for Global Development and Peterson Institute for International Economics.
CNNS. (2019). *Comprehensive National Nutrition Survey national report.* Ministry of Health and Family Welfare, Government of India, UNICEF and Population Council.
FAO, IFAD, UNICEF, WFP, & WHO. (2020). *The state of food security and nutrition in the world, 2020.*
Gulati, A., & Juneja, R. (2020). *Farm mechanization in Indian agriculture with focus on tractors.* ZEF-Discussion Papers on Development Policy No. 297, University of Bonn, Center for Development Research (ZEF), Bonn, available at: https://hdl.handle.net/20.500.11811/9508.
INCCA. (2010). *Climate change and India: A 4 x 4 assessment—A sectoral and regional analysis for 2030s.* Indian Network for Climate Change Assessment (INCCA), Report 2. Ministry of Environment and Forest, Government of India.
IPCC. (2014). *Climate change 2014: Synthesis report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change.
Joshi, P. K., Birthal, P. S., & Minot, N. (2006). *Sources of agricultural growth in India: Role of diversification towards high-value crops.* MTID Discussion Paper 98. International Food Policy Research Institute.
Joshi, P. K., Shinoj, P., & Kumar, P. (2016). Dynamics of food consumption and nutrient insecurity in India. *Proceedings of the Indian National Science Academy, 82*(5), 1587–1599.
Joshi, P. K., & Tyagi, N. K. (2019). Small farm holders and climate change: Overcoming the impacts in India. In B. Deb Pal, A. Kishore, P. Joshi, & N. Tyagi (Eds.), *Climate smart agriculture role of technologies, policies and institutions*. Springer.
Kumar, P., & Joshi, P. K. (2016). Food consumption pattern and nutritional security among rural households in India: Impact of cross-cutting rural employment policies. In F. Brouwer & P. K. Joshi (Eds.), *International trade and food security: The future of Indian agriculture* (pp. 19–28). CABI.
Kumar, P., Joshi, P. K., & Aggarwal, P. (2014). Projected effect of droughts on supply, demand, and prices of crops in India. *Economic and Political Weekly, 49*(52), 54–63.
MoA&FW. (2020). *Agricultural statistics at glance 2019* (p. 165). Directorate of Economics and Statistics, Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India.
NFHS. (2017). *National family health survey 2015–16.* International Institute for Population Sciences.
Pal, B. D., Joshi, P. K., & Tyagi, N. K. (2019). Two-way association between agriculture and climate change. In B. D. Pal, A. Kishore, P. K. Joshi, & N. K. Tyagi (Eds.), *Climate smart agriculture in South Asia* (pp. 1–6). Springer.
Pavitra, S., & Chand, R. (2015). Fertilizer use imbalance in India: Analysis of states. *Economic and Political Weekly, 50*(44).
Pingali, P., & Khwaja, Y. (2004). *Globalization of Indian diets and the transformation of the supply side system.* Agricultural and Development Economics Division, FAO of United Nations.
Rao, N. D., Min, J., DeFries, R., Ghosh-Jerath, S., Valin, H., & Fanzo, J. (2018). Healthy, affordable and climate-friendly diets in India. *Global Environmental Change, 49*, 154–165.
Upadhyay, R. C., Sirohi, S., Singh, S. V., Kumar, A., & Gupta, S. K. (2009). Impact of climate change on milk production of dairy animals in India. In P. K. Aggarwal (Ed.), *Global climate change and Indian agriculture, case studies from ICAR network project* (pp. 104–106). Indian Council of Agricultural Research.
Vijayshankar, P. S., Kulkarni, H., & Krishnan, S. (2011). India's groundwater challenge and the way forward. *Economic and Political Weekly, 46*(2).
WHO. (2018). *Noncommunicable diseases (NCD) country profile.* World Health Organization. Available at https://www.who.int/nmh/countries/ind_en.pdf?ua=1. Accessed on 5 August 2020.