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.

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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 back-drop 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

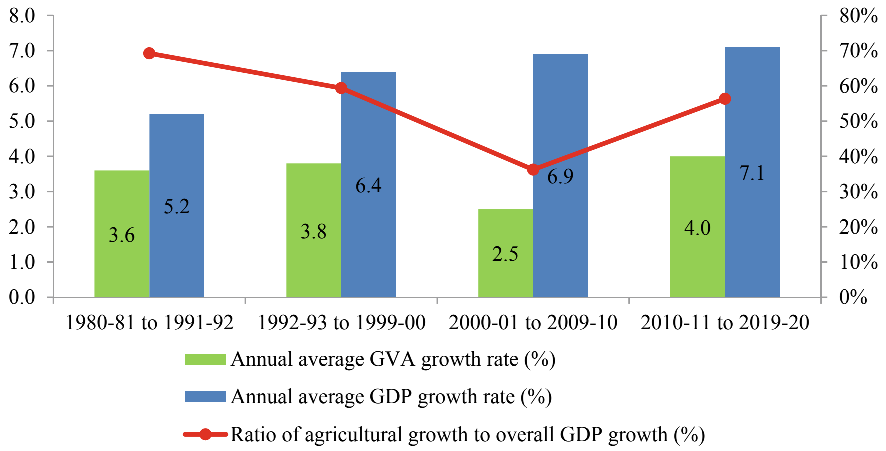

Fig. 1 Average annual growth rate in GDP and agricultural GVA. *Source* National Accounts Statistics, NSO (2019b)

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).

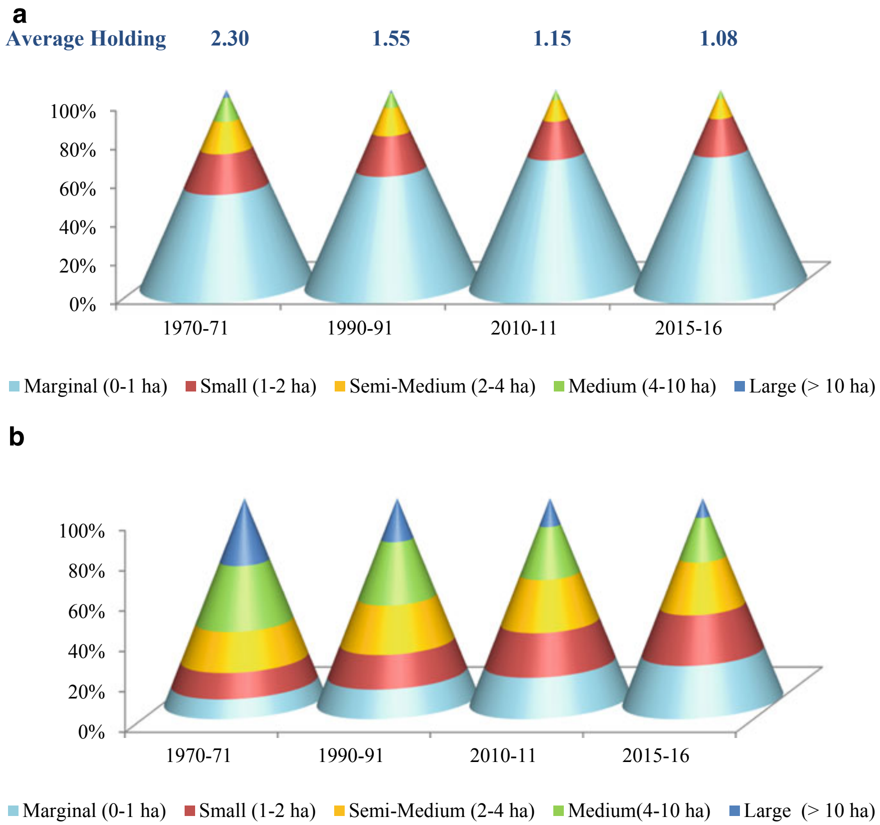

Fig. 2 **a** Percentage of operational holdings by size class. **b** Percentage of operated area by size class. *Source* Agriculture Census: 2015–16 (DoAC&FW, 2019)

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).

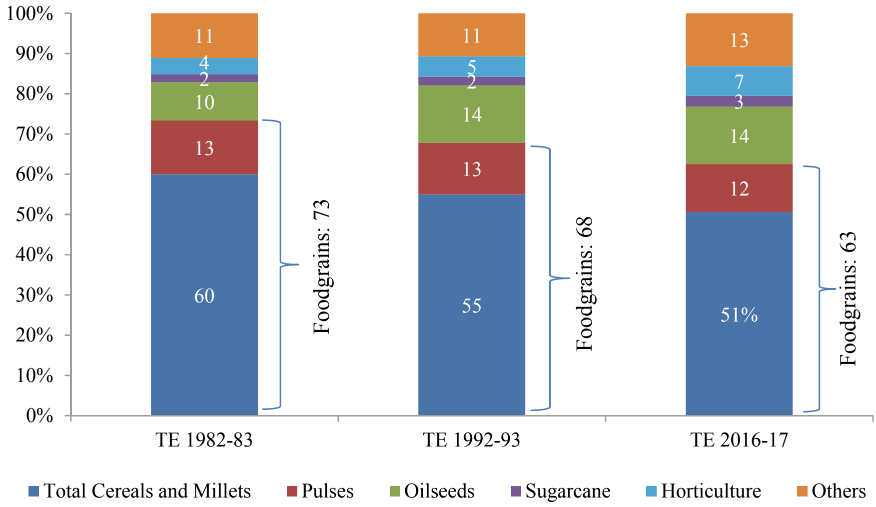

Fig. 3 Changing cropping patterns (percentage area under major crops). *Source* Land Use Statistics at a Glance (DES, 2017)

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

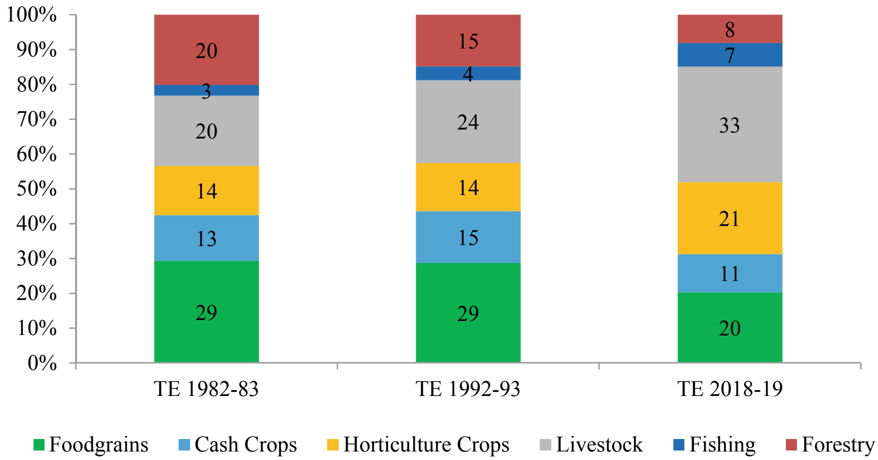

Fig. 4 Changing shares in value of output (percentage). *Note* Cash crops include oilseeds, sugar and fibres and horticulture crops include fruits and vegetables, floriculture and spices and condiments. *Source* National Accounts Statistics, NSO (2019b)

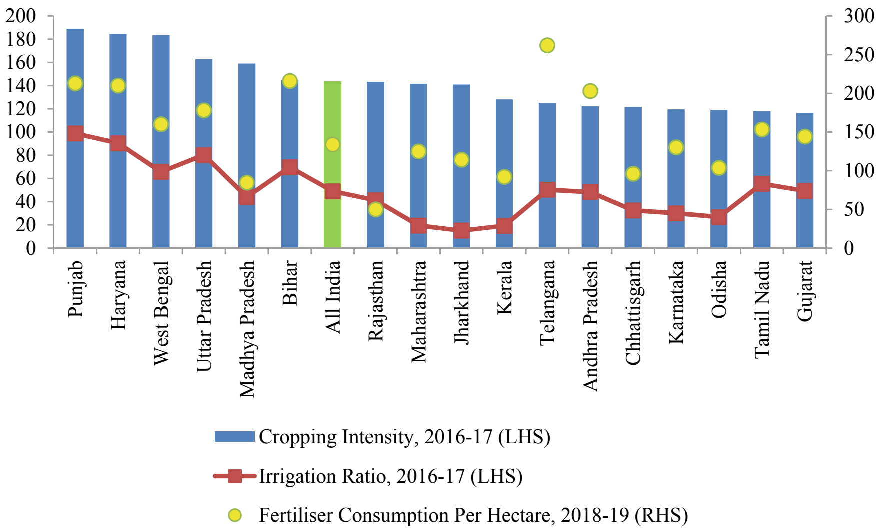

Fig. 5 State wise cropping intensity, irrigation ratio and per hectare fertiliser consumption.[5] *Source* Land Use Statistics at a Glance (DES, 2017) and Fertiliser Association of India, 2019

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.

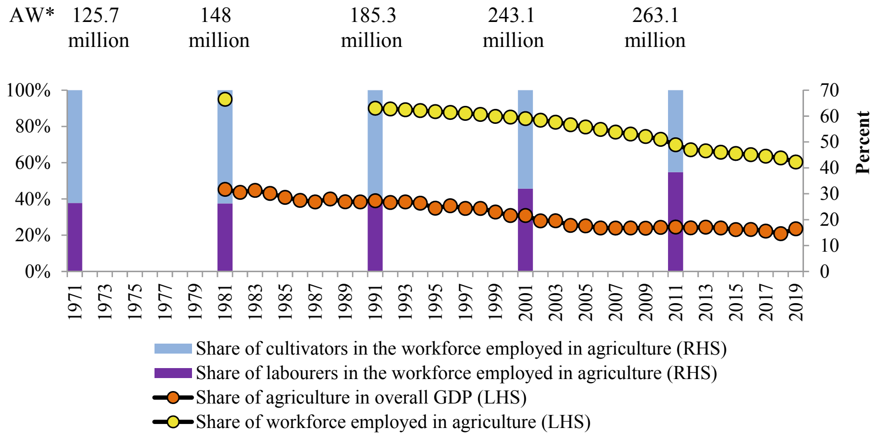

Fig. 6 Share of agriculture in total GDP, share of workforce employed in agriculture and composition of agriculture workforce. *AW = Agriculture workforce. *Source* World Bank (2019), NSO (2019b) and Census of India (various issues)

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

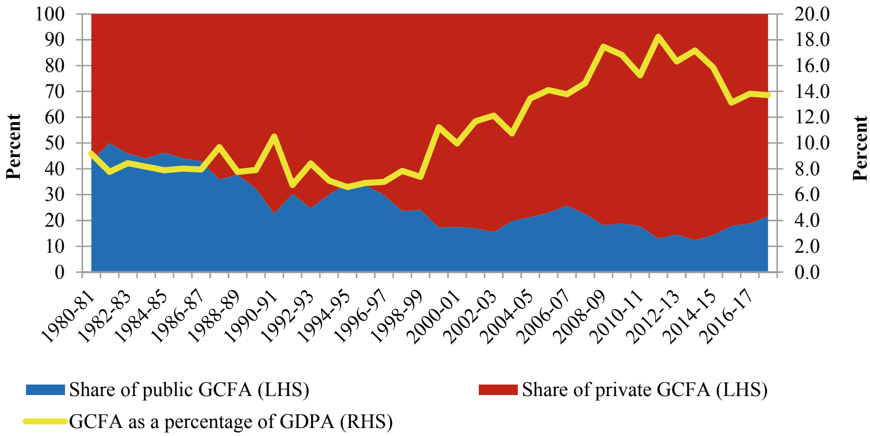

Fig. 7 Gross capital formation in agriculture as a percentage of agriculture GDP. *Source* National Accounts Statistics, NSO (2019b)

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.

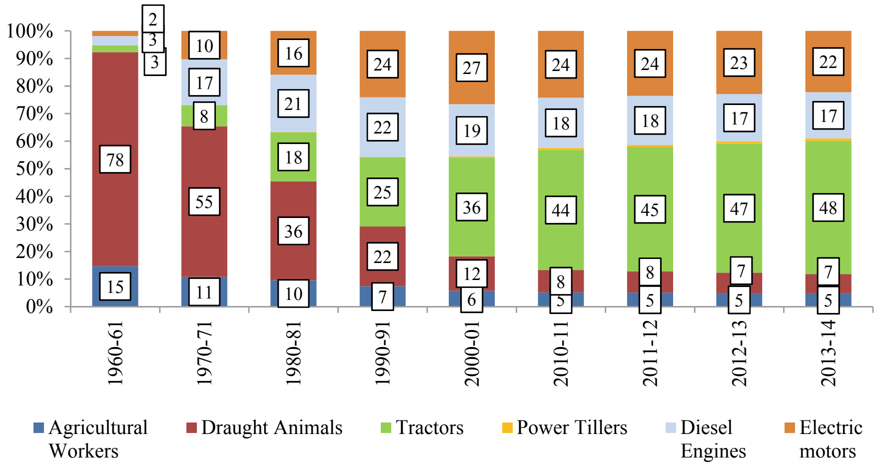

Fig. 8 Percentage availability of farm power from different farm power sources. *Note* For converting various sources of farm power into a comparable yardstick, it is assumed that one human power is equated to 0.05 kilowatt (kW); one draught animal power equals 0.38 kW; one tractor equals 26.1 kW; one 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).

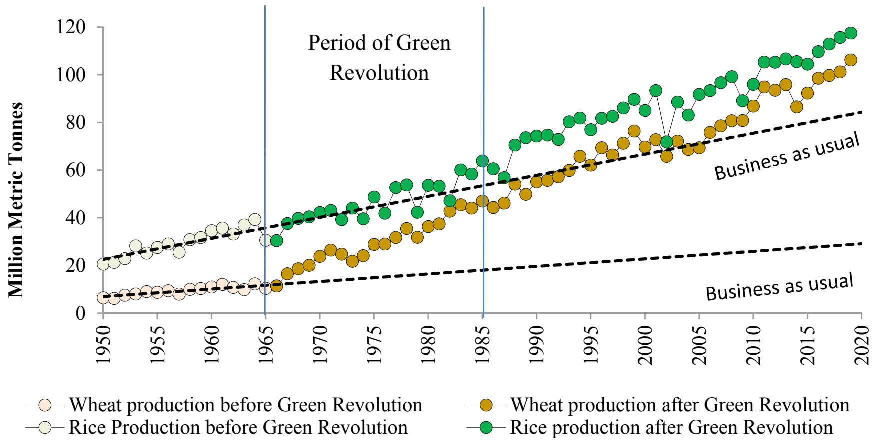

Fig. 9 Production of wheat and rice in India. *Source* Agricultural Statistics at a Glance, various issues, Directorate of Economics and Statistics, MoA&FW

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

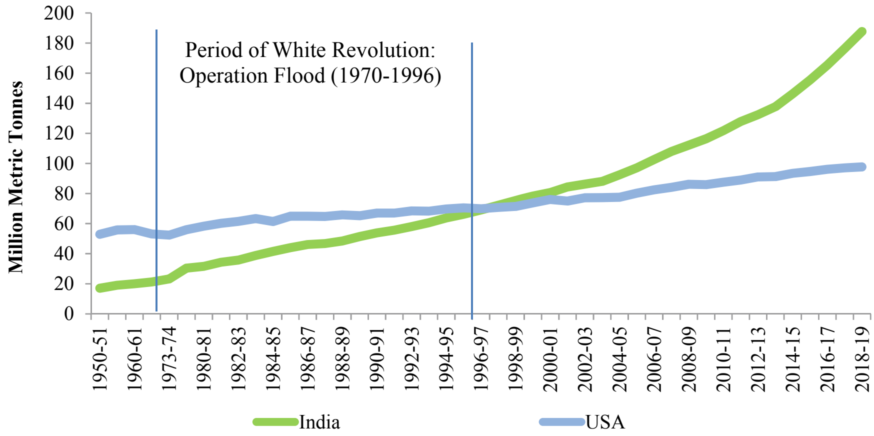

Fig. 10 Production of milk in India and United States of America. *Source* DoAHD&F (2017)

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.

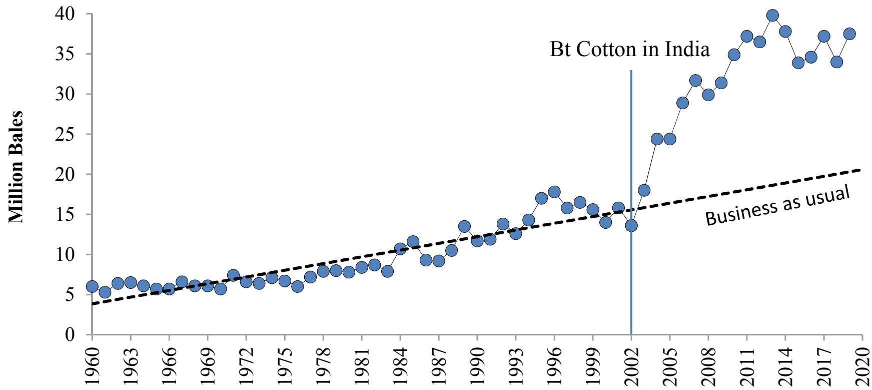

Fig. 11 Cotton production in India. *Source* USDA (2019–20)

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

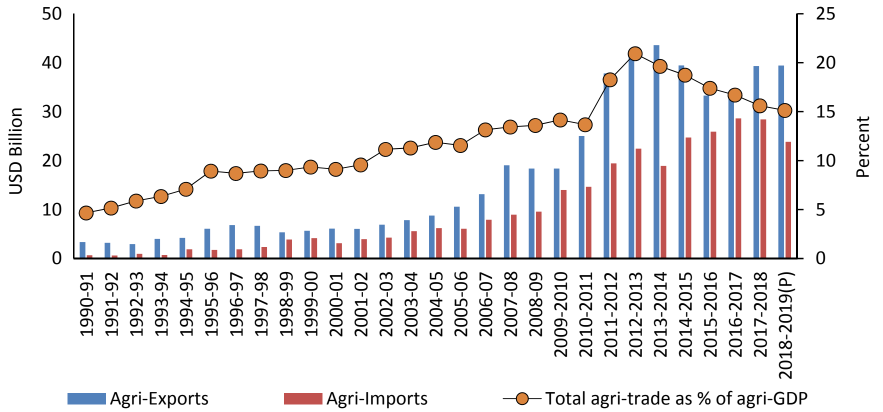

Fig. 12 Agricultural exports and imports and share of agricultural trade in agricultural GDP. *Source* World Bank (2019)

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.

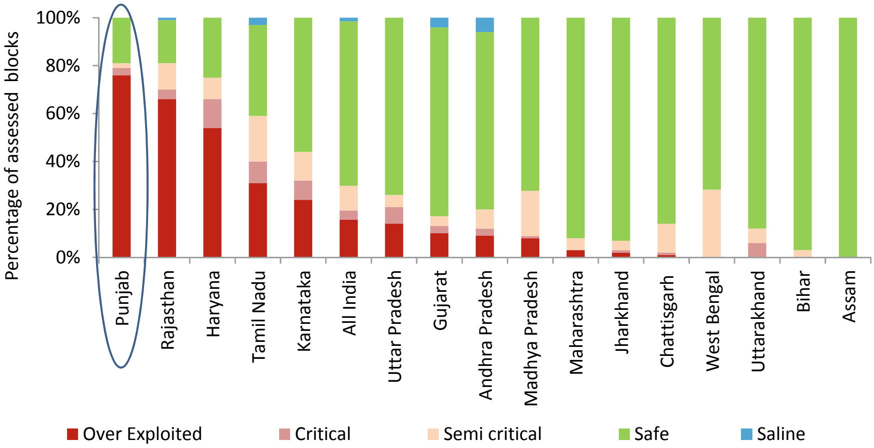

Fig. 13 Status of groundwater level in India, 2017. *Source* CGWB (2017)

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.

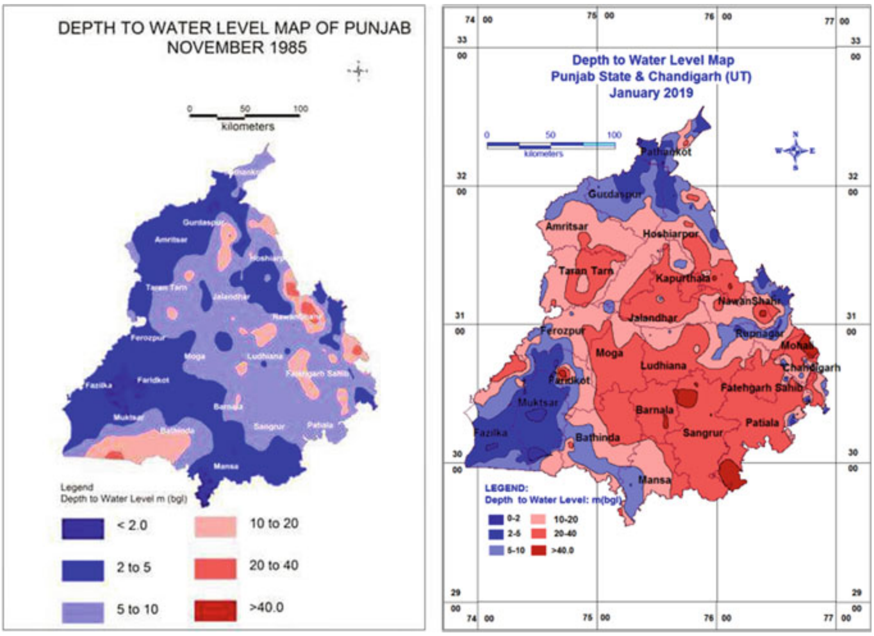

Fig. 14 Depth to water level status of Punjab. *Source* CGWB (2019)

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.

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