Chapter 3
Innovations in Production Technologies in India

3.1 Introduction

In agriculture, innovations in seed production could result in higher productivity, protect plants from pests and may even increase mineral, vitamin and protein content; innovation could also address how the application of water (irrigation), fertilisers, pesticides and other inputs can result in a higher value for a lower quantity/cost. There could be innovations in farming practices that not only increase productivity, but also save on costs or promote sustainable agriculture that can better withstand several abiotic and biotic stresses. In fact, innovations can make an impact beyond production technologies—in the field of institutions that ensure the effective implementation of policies; in storage, where effective logistics can avoid massive loss of food; and in better marketing of goods and services which bring higher value to its users. Thus, innovations can spread all along the agricultural value chain, from farm to fork, or, more aptly in a demand-driven system, from "plate to plough".

In this paper, we spell out the major innovations in production technology that have had a significant impact on overall productivity and production in India. We also touch upon innovations that are currently unfolding in inputs and production processes. More specifically, we will cover the following.

- Innovations in production technologies, ranging from seeds (high yielding and climate-resilient), farming practices, policies that led to the green revolution, white revolution, blue revolution, red (poultry) revolution, golden revolution and gene revolution
- The impact on agricultural total factor productivity (TFP)
- Innovations in water management—irrigation technologies, especially drip irrigation and sprinklers
- Innovations in farm mechanisation—Uberisation and custom hiring models, solar-based mobile irrigation pump sets based on a pay-per-use principle

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A. Gulati et al., *From Food Scarcity to Surplus*,
https://doi.org/10.1007/978-981-15-9484-7_3

- Innovations in fertiliser and soil management—soil health cards (SHCs) and *neem* coating of urea (NCU)
- Innovations in precision agriculture using smart technologies—artificial intelligence, drones, Internet of things (IoT), remote sensing, etc.
- Innovations in sustainable and protected agricultural practices—soilless farming systems (hydroponics, aeroponics and aquaponics) and poly-house farming systems under the Indo-Israeli Agriculture Project
- Role of research and development and education in agriculture.

3.2 Innovations and Revolutions in Indian Agriculture: A Chronological Account

3.2.1 The Green Revolution—Innovations in Seeds, Policies and Marketing Institutions (Wheat and Rice)

India gained independence in 1947 with a challenge to feed 330 million people. Inadequate domestic production, as well as negligible foreign exchange reserves to buy grains from global markets on commercial terms, posed serious food security concerns (Gulati 2009). In 1956, Jawaharlal Nehru, the first Prime Minister of independent India, launched a heavy industrialisation strategy embedded in the Second Five-Year Plan (1956–61). It became clear that the darling of development strategy was not agriculture but heavy industry, notwithstanding Nehru's famous quote "everything else can wait, but not agriculture".[1] The situation became grim when India was hit by back-to-back droughts during the mid-1960s. Grain production plummeted by 17 million metric tonnes (MMT), from 89.4 MMT in 1964–65 to 72.4 MMT in 1965–66 (Chopra 1981). India became heavily reliant on food aid enabled by the USA's Agriculture Trade Development and Assistance Act, also known as PL-480, and underwent a "ship-to-mouth" crisis. The then Prime Minister, Lal Bahadur Shastri, called on the nation to "miss a meal" every week to cope with the dire situation (Bandyopadhyay 2016).

Against this backdrop, it was imperative to achieve self-sufficiency in food grains in a sustainable way. The then Food Minister, Chidambaram Subramaniam, steered through political hurdles, bureaucratic wrangles and public debates to advocate the import of high-yielding variety (HYV) wheat seeds, developed by Norman E. Borlaug at the International Maize and Wheat Improvement Center (CIMMYT), Mexico. He even argued that if the new technology was not supported by appropriate policies on prices, fertilisers, land ownership, water and credit, it would not work (Maitra 1991). In January 1965, the Agricultural Prices Commission (APC) and the Food Corporation of India (FCI) were established to ensure "remunerative prices" to producers and to facilitate storage, marketing and distribution of grains (Gulati 2009). Finally, in 1966, 18,000 tonnes of HYV wheat seeds—Lerma Rojo 64 and Sonora 64—were

[1] Soon after independence, in 1948, Jawaharlal Nehru remarked that "everything else can wait, but not agriculture". He said this in the context of the Bengal Famine of 1942–43 and the acute food scarcity prevailing in the country in 1947 (Swaminathan 2007).

imported and distributed to the regions of Punjab, Haryana, and the western belt of Uttar Pradesh. This ushered in the Green Revolution in India. The adaptation of imported germplasm to improve indigenous varieties like Kalyan by D. S. Athwal and Sona by M. S. Swaminathan,[2] along with extensive irrigation and fertiliser usage, aided the spread of the revolution (Gulati 2014). Around the same time, the HYV miracle rice IR8, developed by Peter Jennings and Henry M. Beachell of the International Rice Research Institute (IRRI), were imported (Dalrymple 1985). An in-house breeding programme under the All-India Co-ordinated Rice Improvement Project (AICRIP), initiated by the Indian Council of Agricultural Research (ICAR), produced Padma and Jaya, the first indigenous HYV rice seeds that formed the backbone of India's revolution in rice. About a decade later, an improved variety, IR36, developed by Gurdev Khush at the International Rice Research Institute (IRRI), also made inroads into Indian fields and became the most widely planted food crop ever grown (The World Food Prize 1996a, 1996b).[3] The international exchange of wheat and rice germplasm through an alliance with the Consultative Group on International Agricultural Research (CGIAR) network, along with better pricing and marketing policies, played a catalytic role in driving the production breakthrough in wheat and rice.

While India's population has grown more than four times, from 330 million in 1947 to 1.38 billion in 2020, wheat production has increased over 16 times (from about 6.5 MMT in 1950–51 to 106.2 MMT in 2019–20) (DoAC&FW 2020) and productivity from less than 1 tonne per hectare (t/ha) to more than 3.5 t/ha during the same time period. It is worth noting that the very first wheat harvest after the release of HYV semi-dwarf seeds in 1967–68 recorded a jump of 45% from 10.4 MMT in 1966–67 to 16.5 MMT in 1967–68. Today, India is the second largest wheat producer in the world, contributing about 13% to total wheat production, next only to China with approximately a 17% share (USDA 2018a, b). Rice production has increased 5.7 times (from 20.6 MMT in 1950–51 to 117.5 MMT in 2019–20) with a 24% increase (from 30.4 MMT to 37.6 MMT) during 1966–67 and 1967–68. Moreover, rice productivity also increased from 0.6 t/ha in 1950–51 to 2.7 t/ha in 2018–19. Today, India is the second largest rice producer in the world, accounting for approximately a 23% share in total rice production, next to China with approximately a 29% share (USDA 2018a, b). Moreover, it is also the world's largest exporter of rice with about 12.7 MMT exports in 2017–18, valued at USD7.7 billion (APEDA 2018) (Figs. 3.1 and 3.2).

Punjab, the seat of the Green Revolution, was a front runner in agriculture during the late 1960s (Verma et al. 2017). Wheat and rice production literally doubled from 2.5 MMT to 5.6 MMT and from 0.3 MMT to 0.9 MMT, respectively, between 1966–67 and 1971–72 (Figs. 3.3 and 3.4).

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[2]In 1987, M. S. Swaminathan was honoured with the first World Food Prize for spearheading the introduction of high-yielding varieties to Indian farmers (The World Food Prize 1987).

[3]In 1996, Henry M. Beachell and Dr. Gurdev Singh Khush were honoured with the World Food Prize for ensuring sufficient food supplies for rapidly growing populations in Asia and around the world (The World Food Prize 1996a, b).

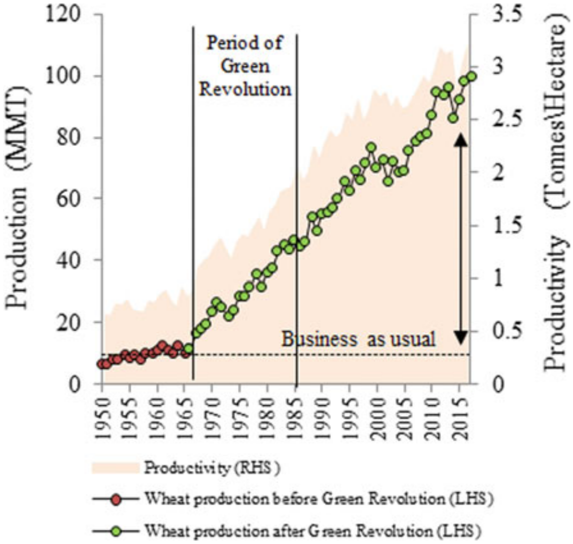

Fig. 3.1 All India wheat production and productivity. *Source* Agricultural Statistics at a Glance, Department of Agriculture, Co-operation and Farmers' Welfare (DoAC&FW), Government of India (GoI)

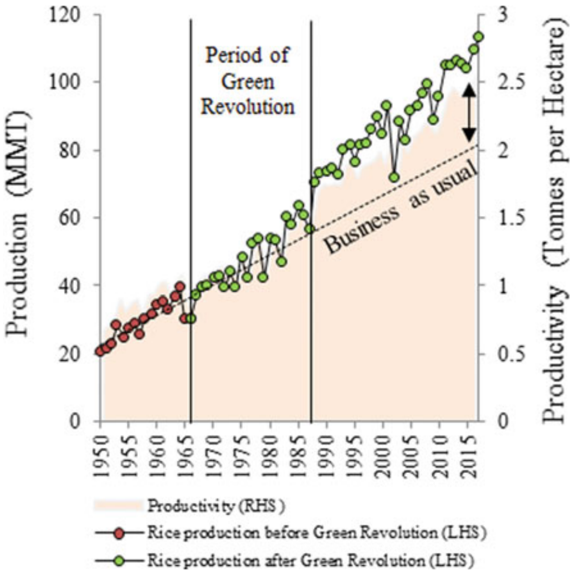

Fig. 3.2 All India rice production and productivity. *Source* Agricultural Statistics at a Glance, Department of Agriculture, Co-operation and Farmers' Welfare (DoAC&FW), Government of India (GoI)

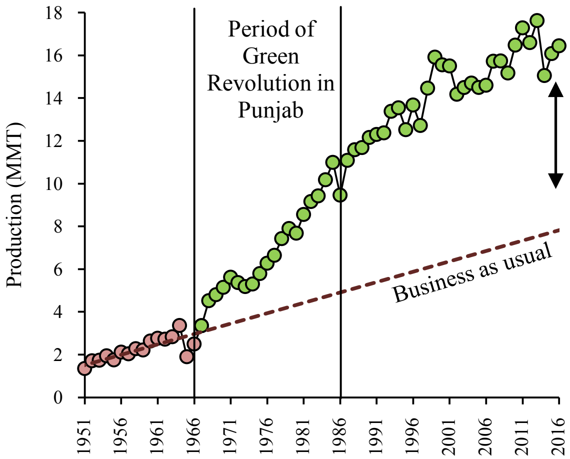

Fig. 3.3 Wheat production in Punjab, India. *Source* Bulletin on Food Statistics issued by the Economic and Statistical Adviser, Ministry of Agriculture, GoI (various issues)

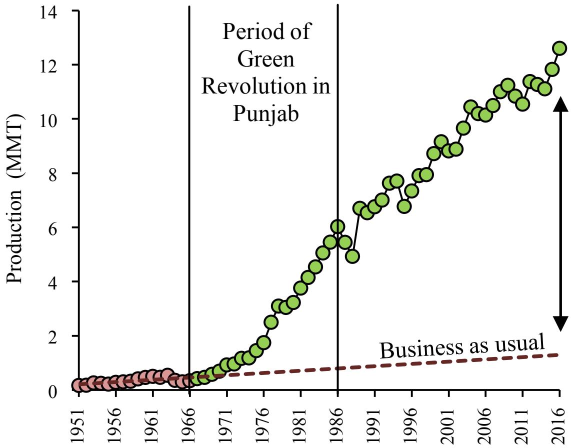

Fig. 3.4 Rice production in Punjab, India. *Source* Bulletin on Food Statistics issued by the Economic and Statistical Adviser, Ministry of Agriculture, GoI (various issues)

Basmati

Later on, between 2005 and 2013, a breakthrough in basmati rice came about through the landmark varieties—Pusa Basmati 1121[4] and Pusa Basmati 1509[5]—developed

[4]Pusa Basmati 1121 was developed by ICAR in 2003 and was first released as Pusa 1121 in 2005 vide Gazette Notification S. O. 1566(E) dated 5 November 2005. Then in 2008, it was substituted by Pusa Basmati 1121 vide Gazette Notification no. S.O. 2547(E) dated 29 October 2008.

[5]Released commercially vide Gazette Notification no. S.O. 2817(E) dated 19 September 2013.

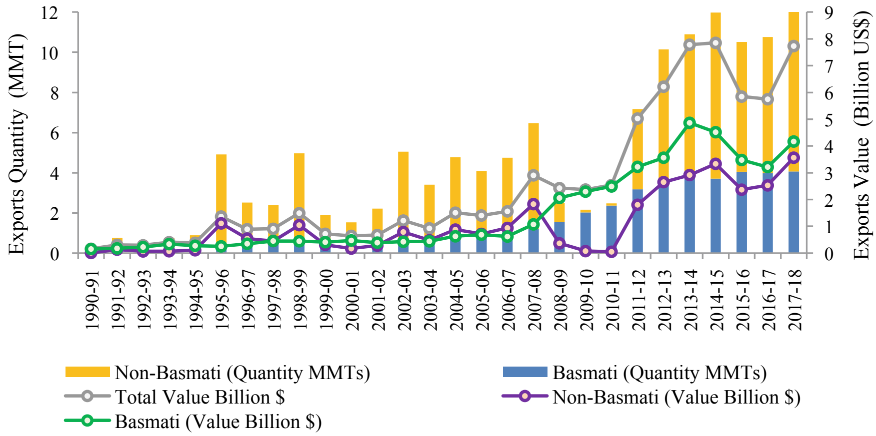

Fig. 3.5 Rice exports from India. *Source* Agricultural processing and export development authority (APEDA), GoI

by teams led by V. P. Singh, A. K. Singh and K. V. Prabhu at the Indian Agricultural Research Institute. This gave Indian rice more value with higher yields compared to traditional basmati (Fig. 3.5).

According to Singh et al. (2018), India is the largest cultivator and exporter of basmati rice in the world with 4 MMT in 2017–18 valued at USD4.17 billion, followed by Pakistan. Pusa Basmati 1121 is grown in approximately 70% of the total area under basmati cultivation in India. Moreover, the total value of exports of Pusa Basmati 1121 and domestic sales between 2008 and 2016 was estimated at USD20.8 billion, making it a highly profitable business (Singh et al. 2018).

Recent and Unfolding Innovations in Staples (Wheat and Rice) Some innovations in farming practices such as the system of rice intensification (SRI), direct seeding and zero tillage[6] hold great potential for higher yields and efficient resource management. SRI is a skill-intensive technology that saves the cost of inputs such as seeds and fertilisers and improves yields per hectare (NITI Aayog 2015). The economic impact evaluation study on SRI undertaken in Tamil Nadu and Andhra Pradesh reveals that the yield increase through SRI practices in comparison with non-SRI (conventional) was 37–39%. Further, the reduction in labour requirement per hectare was estimated to be 30–32% (Johnson et al. 2015). According to the paper based on Task Force on Agricultural Development constituted by the NITI Aayog, Government of India, "the area under SRI has increased progressively since 2000–01 and Tamil Nadu, Bihar and Tripura are the leading states that are practising the disruptive technology". Based on similar principles, the system of intensification has been extended to wheat (SWI).

[6]Zero tillage can allow farmers to sow wheat sooner after rice harvest, so that the wheat crop escapes terminal heat stress (ICAR-IARI 2018).

According to a report by ATMA (2008),[7] yields under SWI are 25–50% higher than that under conventional cultivation. It was also found that, based on SWI trials and farm-level data collected from Himachal Pradesh during 2008–09, the benefit-cost ratio under SWI was 1.81 compared to 1.16 under the conventional method (Chopra and Sen 2013). The paper brought out by the NITI Aayog titled *Raising Agricultural Productivity and Making Farming Remunerative for Farmers* stated that "the resource *(sic)* conservation technologies like zero tillage and residue management can reduce the cost of cultivation by 25–30% over conventional farming practices" (NITI Aayog 2015).

Climate change is one of the important areas of concern for our country. It is predicted that the temperature in India will rise in the range of 0.5–1.2 degree Celsius (°C) by 2020, 0.88–3.16 °C by 2050 and 1.56–5.44 °C by the year 2080. This will have a significant negative impact on crops, lowering yields by 4.5–9.0%, depending on the magnitude and distribution of warming (NICRA 2018). In order to cope with climate change, ICAR launched a flagship network project called the "National Innovations on Climate-Resilient Agriculture" (NICRA) in 2011. According to NICRA, about 60% of the net cultivated area in India is rain-fed and exposed to several abiotic and biotic stresses (ICAR-IARI 2018), due to which irrigated rice yields are projected to fall by about 4% in 2025 (2010–2039) and rain-fed rice yields by 6%. This poses a challenge of sustaining domestic food production for growing population. Therefore, developing crop varieties with higher yield potential and tolerance to climatic stresses (heat, drought, submergence, salinity) becomes imperative. Table 3.4 in the Annexure lists a few recently released climate-resilient wheat and rice varieties in India. NICRA has selected some villages based on climatic vulnerability to demonstrate climate-resilient practices and crops to enhance adaptive capacity to enable farmers to cope with climatic variability. Lessons learned from the demonstrations are then used to select the best planting lines and other management practices for further expansion.

The emergence of genomic sequencing and bioinformatics analysis further offer the potential to ramp up the process of developing crops with the desired agronomic traits, which can bring about a revolution in crop sciences, revealing avenues for economic benefits to farmers. The rice genome was decoded in 2002 and provided data to identify genetic markers for disease resistance, drought and flood tolerance and support plant-breeding strategies to develop superior varieties. Recently, in 2018, a group of scientists and breeders around the world under the International Wheat Genome Sequencing Consortium (IWGSC) have decoded the complex bread wheat genome, which is a major scientific breakthrough in the history of agriculture. It took more than a decade to decode the vast size of the genome (some five times larger than the human genome) with its highly repetitive nature (being a hybrid of three highly similar sub-genomes of earlier grasses, with more than 85% composed of repeated sequences) (IWGSC 2018). Wheat genome identification will contribute to global food security and potentially help develop highly productive, nutritious

[7]Report by Agriculture Technology Management Agency (ATMA), Nalanda with PRADAN—"Assessment, Refinement and Validation of technology through System of Wheat Intensification (SWI) in Nalanda".

and sustainable heat, water-logging and pest/disease-resistant and drought-tolerant grains. The best is yet to come!

Notwithstanding its food grain surplus, India faces a complex challenge of nutritional security. According to recent FAO estimates in *The State of Food Security and Nutrition in the World, 2018* report, 14.8% of India's total population is undernourished. Further, 38.4% of children aged below five years are stunted while 21% suffer from wasting and 51.5% of women in the reproductive age group (15–49) suffer from anaemia (FAO, IFAD, UNICEF, WFP and WHO 2018).

Several factors contribute to this, ranging from poor diets, unsafe drinking water, poor hygiene and sanitation, and low levels of immunisation and education, especially of women. However, the latest innovations in biotechnologies towards bio-fortification of major staples with micro-nutrients like vitamin A, zinc, iron, etc., can be game changers. Globally, the HarvestPlus programme of the CGIAR network is already doing a lot of work in that direction. In Uttar Pradesh, Bihar and Jharkhand, the release of high yielding zinc-rich wheat—BHU-3, BHU-6 (Chitra)—can potentially provide up to 50% of daily zinc needs, and short-duration, drought-tolerant iron pearl millet—ICTP 8203-Fe-10-2 (Dhanashakti), ICMH 1201 (Shakti-1201)—in Rajasthan and Maharashtra can potentially source 80% of daily iron needs (HarvestPlus 2017). The Indian Council of Agricultural Research (ICAR), through its independent research, has also released zinc- and iron-rich wheat (WB 02 and HPWB 01) with yields of more than five tonnes per hectare (t/ha), high protein and zinc-rich rice [CR Dhan 310 and DRR Dhan 45[8] (IET 23832)] and a fortified pearl millet hybrid with high iron and zinc (HHB 299 and AHB 1200) with yields averaging more than 3.2 t/ha. This could possibly lead to the next breakthrough in staples, making them more nutritious. Recently, a research team led by Dr Monika Garg at the National Agri-Food Biotechnology Institute (NABI), Mohali, has pushed frontiers and innovated bio-fortified coloured wheat[9] (black, blue, purple) through crosses between high yielding Indian cultivars (PBW550, PBW621, HD2967), blue wheat (TA3972) and purple wheat (TA3851) obtained from the Wheat Genetics Resource Center, Kansas State University, Kansas, USA, and black wheat obtained from Tottori University, Japan, which are exceptionally rich in anthocyanins[10] (40–140 ppm) (Sharma et al. 2018)[11] and zinc (35–38 mg per 100 g). According to nutrient requirements and the recommended dietary allowance (RDA), anthocyanins are antioxidants

[8]DRR Dhan 45 is India's first bio-fortified semi-dwarf zinc-rich and high-yielding variety, developed at ICAR-IIRR and released in India. It is developed from the cross IR 73707-45-3-2-3/ IR 77080-B-34-3; it is a medium duration culture (~130 days) with non-lodging plant type and long slender grain that is recommended for cultivation in an irrigated ecosystem yielding 5–6 t/ha with 22 ppm zinc.

[9]It is not genetically modified (non-GMO) and has been approved for human consumption by the Food Safety and Standards Authority of India (FSSAI) as F.No.04/Std/PA/FSSAI/2018 (inputs received from NABI).

[10]Anthocyanins are the naturally occurring antioxidants that give blueberries and *jamun* their colour and come under the list of healthy nutraceuticals under Schedule VI B of FSSAI's Nutraceutical Regulations.

[11]Plant material included one white wheat (cv, PBW621), three coloured donor wheat lines (purple, blue and black) and three high-yielding coloured advanced breeding lines (purple, blue and black)

Table 3.1 Comparative composition analysis of white and coloured wheat, India

Composition	In 100 g			
	White wheat	Purple wheat	Blue wheat	Black wheat
Anthocyanins in parts per million (ppm)	5	40	80	140
Energy in calories (kcal)	322	318	318	318
Carbohydrates in grams (g)	67.8	65.8	65.8	64.8
Protein (g)	10	11	11	12
Dietary fibre (g)	11	12	12	12
Fat (g)	1.2	1.2	1.2	1.2
Moisture in percentage	10	10	10	10
Potassium in milligrams (mg)	350	350	350	350
Sodium (mg)	2.5	2.5	2.5	2.5
Calcium (mg)	35	35	35	35
Iron (mg)	38	45	45	45
Zinc (mg)	28	36	38	35

Source NABI (2018)

that prevent oxidative damage and help in delaying ageing and reducing cancer, and help prevent cardiovascular diseases, diabetes and other disorders (NABI 2018).

Table 3.1 gives a comparative composition analysis of coloured and white wheat. In June 2018, the varieties were approved for human consumption by the Food Safety and Standards Authority of India (FSSAI). More recently, under the contract farming model with private companies,[12] the purple and black varieties have been harvested in over 700 acres across India—from Patiala and Jalandhar in Punjab to Vidisha in Madhya Pradesh (Sharma 2019).

Bio-fortified crops have huge market potential. This seems to be only the beginning of a new journey, from food security to nutritional security in India. But these innovations in bio-fortified foods can help alleviate malnutrition only when they are scaled up with supporting policies, including augmented expenditure on agricultural R&D, with due accountability to deliver. If we trust science with a human face, the best is yet to come.

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selected from back-crossed filial generations (BC1F8) of cross between white and donor coloured wheat lines. They were grown and advanced in the farms of the National Agri-Food Biotechnology Institute, Mohali, Punjab, India (30°44’10” N latitude at an elevation of 351 m above sea level) in 2015–2016 (Sharma et al. 2018).

[12]Farm Grocer, Ambala; Borlaug Farm Association for South Asia, Ludhiana, Golden Agrigenetic India Ltd., Lucknow; Premier (India) Seed Company, Vidisha; Habitat Genome Improvement Primary Producer Company, Hisar; Bishwanath Agrawal (BNA), Purnea; Puddings and Pie, Mohali; Urban Platter, iStore Direct Trading LLP, Mumbai; Dayspring Foods, Porbandar; Antho Grains Pvt. Ltd., Mohali.

However, research in plant-breeding technique has broken records with the significant innovation of **golden rice**,[13] a genetically engineered and bio-fortified crop with high levels of beta carotene, the precursor to vitamin A. It is recognised by the World Health Organization that vitamin A deficiency (VAD) is a public health problem affecting about 44% children aged 6–59 months in South Asian countries where two-thirds or more of the daily calorie intake is obtained from rice; golden rice thus provides a sustainable solution for VAD at the same cost to farmers as other rice varieties (UNICEF 2019; IRRI 2018). Golden rice has been accepted as safe for human consumption by the governments of Australia, Canada, New Zealand and USA, and registrations have been applied for in the Philippines and Bangladesh (Dubock 2000). However, due to opposition by activists and non-governmental organisations (NGOs) to genetically modified crops, golden rice has not been approved in India.

3.2.2 White Revolution—Innovations in Policies, Value Chain Development and Institutional Engineering (Milk)

Another big transformational change in Indian agriculture came through the innovation "Operation Flood (OF)" that ushered in the white revolution during the 1970s through the mid-1990s. Hit by a severe milk crisis during 1945–1946, farmers in Kaira district suffered from controlled procurement and low prices due to the presence of middlemen. To end their exploitation, Sardar Vallabhbhai Patel stepped in to solve the problem of low milk prices. He gave India its first and largest milk co-operative (Anand Milk Union Limited or AMUL) and, in the process, emerged as a leader of farmers. Steered by Morarji Desai and Tribhuvandas Patel, and spearheaded by Verghese Kurien, Operation Flood transformed India's dairy industry from a drop to a flood of milk; the programme even today remains one of the largest dairy development programmes ever executed in the world (Kurien 2005). The programme was driven by three crucial principles—one, introducing co-operatives into the milk value chain; two, setting up the first processing plant at Anand to convert excess buffalo milk into milk powder, cheese, baby food and other milk products; and three, innovations in logistics such as automatic milk collection units, bulk milk coolers, rail- and road-insulated stainless steel milk tankers travelling around 2000 km from Kaira to Kolkata, bulk vending and so on—that completely revolutionised the process of milk collection, preservation and distribution.

The operation was executed by the National Dairy Development Board (NDDB) on the recommendation of Lal Bahadur Shastri in three phases during the period

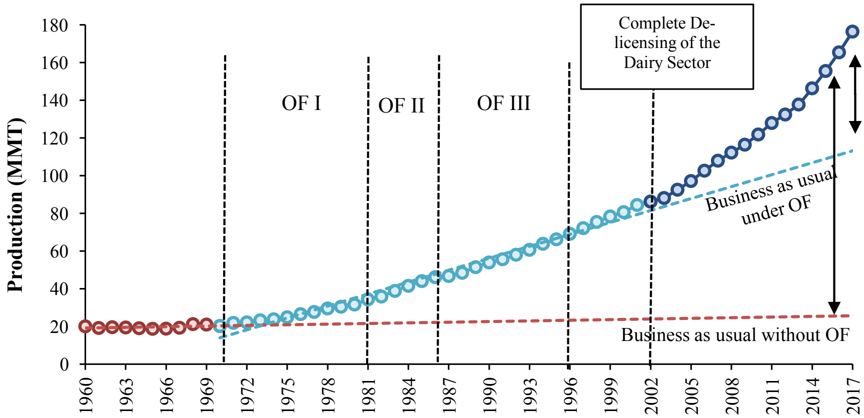
[13]The golden rice prototype was first developed in the 1990s by European scientists Ingo Potrykus and Peter Beyer independently. In early 2001, they sold the licence to the International Rice Research Institute (IRRI) in the Philippines for further development. Later, the scientists sold commercial rights to the core technology to Syngenta. Scientists made further improvements to the golden rice variety, primarily with much higher levels of beta carotene, in 2005 (Dubock 2000).

1970–1996. In phase I (1970–1980), the focus at the village level was on organising dairy co-operatives and at the union level on creating the physical and institutional infrastructure for milk procurement, processing and marketing. It started with linking 18 milk sheds to major collection centres in four metropolitan cities, namely Mumbai, Delhi, Kolkata and Chennai (NDDB 2017). During phase II (1981–85), 136 milk sheds were linked to over 290 urban markets. The sales proceeds of the grants provided by the European Commission (through the World Food Programme in the form of skimmed milk powder and butter oil), World Bank loans and internal resources of the NDDB (Gulati 2009) created a self-sustaining system of 43,000 village co-operatives covering 4.25 million milk producers by 1985 (Kurien 2004). In phase III (1985–96), around 30,000 new dairy co-operatives were added and focus was placed on augmenting the productivity of dairy animals by providing services such as artificial insemination, veterinary first-aid health care and nutritious feed to the co-operative members (NDDB 2017). By the end of the period, in 1995–96, there were 72,744 dairy collection centres in 170 milk sheds in the country with a membership of 9.3 million milk farmers (Gulati 2009).

As a result, India's milk production increased year after year and set new records. During the three phases of Operation Flood, production shot up from 20 MMT in 1970–71 to 31.6 MMT in 1980–81, then 44 MMT in 1985–86 to 69.1 MMT in 1995–96: a jump of 50 MMT in 25 years (DoAHD&F 2017a). Due to this institutional engineering, India emerged as the world's largest milk producer, surpassing the USA after 1996–97. Subsequent to the amendment of the Milk and Milk Product Order (MMPO) in 2002[14] and the entry of private entities in the dairy sector, milk production further shot up from 88.1 MMT in 2002–03 and reached a mark of 176.4 MMT in 2017–18, a massive jump of 88 MMT in just 15 years (Fig. 3.6), which is much higher than milk production in the USA (97 MMT) and mainland China (41 MMT) (FAOSTAT 2017). As a result of rapidly increasing milk production, per capita milk availability also shot up to 355 g per day in 2016–17 from less than 110 g per day in 1970–71 (DoAHD&F 2017b). Not only this, the new co-operative institutions created a much broader social and economic impact by bringing together dairy farmers from different castes and religions. It also promoted dairy co-operatives of women in a major way, by training women in modern animal husbandry practices under the Women Dairy Co-operative Leadership (WDCL) programme launched by NDDB. At present, some 2476 all-woman dairy co-operative societies (DCSs) are functioning in the country in selected states. Out of a total membership of 9.2 million in the DCS, 1.63 million are women (18%) (Dairy India 2017).

According to data from FAOSTAT, buffalo milk yields showed a significant increase from fewer than 1000 kg/animal/year in the 1960s to about 2000 kg/animal/year in 2017, whereas yields of cow increased from fewer than 500

[14]The Milk and Milk Product Order (MMPO) was first introduced in 1992 under Sect. 3 of the Essential Commodities Act, following the economic liberalisation policy of the government of India. It was last amended in 2002 when the concept of cowsheds was removed (Dairy India 2017). The MMPO helped improve the supply of quality milk and increase the share of organised players in the dairy sector (Gulat et al. 2008).



Note: OF – Operation Flood

Fig. 3.6 All-India milk production. *Source* DoAHD&F (2017b)

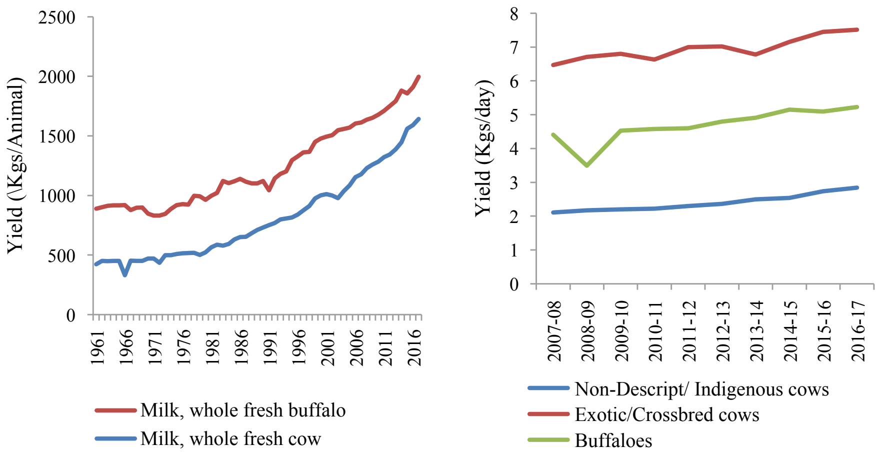


Fig. 3.7 Milk yields in India. *Source* FAOSTAT 2018 and BAHS 2017

kg/animal/year to more than 1500 kg/animal/year, mainly on account of increasing number of exotic/cross-bred cows in the period (Fig. 3.7 LHS). Basic Animal Husbandry Statistics gives milk yields in kg/day for different species. As depicted in Fig. 3.7 (RHS), exotic/cross-bred cows yield the highest milk on an average per day (more than 7.5 kg/day) followed by buffaloes (slightly more than 5 kg/day) and indigenous cows (less than 3 kg/day) DoAHD&F (2017b).

Unfolding Innovations in the Dairy Sector: India faces a challenge of a burgeoning bovine population with limited investments in productivity augmentation. According to the 19th Livestock Census, the proportion of cattle and buffalo in the total bovine population is about 64% and 36%, respectively, while the share of adult females in the total cattle and buffalo population is only 40% and 52%, respectively (DoAHD&F 2017a). Consequent to the ban on cattle slaughter, unproductive male and female cattle cannot be culled. Moreover, they consume feed and fodder that could be given to productive cattle. Therefore, ensured development of the dairy sector depends on measures such as sex-selection semen technology to increase the proportion of female cattle in the total bovine population as well as measures such as cross-breeding to improve productivity.

Selective Sex Semen Technology is about predetermining the sex of offspring by sorting X and Y chromosomes from natural sperm mix. In countries like India with less than 50% of productive cows, sexed semen innovation is of great relevance. This will reduce the dairy animal population and save rearing costs by eliminating the birth of male calves on the one hand and facilitating the production of genetically improved high-milk-producing females at a faster rate on the other (BAIF 2015). Under this strategy, the probability that the female cattle will conceive is around 45%, but if it does, then the probability of producing female progeny is more than 90%, instead of 50% as would be in the case of unsorted semen (Mohteshamuddin 2017). This sexed semen technology uses the principle of DNA concentration of X and Y chromosomes. Sperms with an X chromosome (which results in females) contain 3.8% more deoxyribonucleic acid (DNA) than Y-chromosome-bearing sperms (which result in males) (BAIF 2015). The sperms are then treated with a fluorescent dye that allows for differentiation in the amount of DNA in the sperm. Then, they are diluted and placed in droplets. During the sorting process, the droplets pass through a flow cytometer machine where a laser is used to energise the dye; X-chromosome-bearing sperms are more fluorescent. A computer quantifies the fluorescence of the sperm and assigns the sperm droplet as either X or Y, or uncertain. The sperm sequentially passes through an electromagnetic field where they are tagged by a charge (positive charge to the sperm containing an X chromosome). These charged sperms then get deflected towards the collection vessel. Sexed semen technology was originally patented by the USA-based XY Inc., which was later acquired by Sexing Technologies™ headquartered in Navasota, Texas. The commercially available sexed (sorted semen) straws are supplied by major genetic companies such as Select Sires, Genex, Accelerated Genetics, CRV, ABS Global WWS and Prime Genetics, produced using Sexing Technologies' proprietary sperm-sorting technology (Damodaran 2017).

On 15 August 2009, *Paschim Banga Go Sampad Bikash Sanstha* (PBGSBS), run by the Government of West Bengal, established the Becton Dickinson (BD) Influx cell sorter laboratory under the *Rashtriya Krishi Vikas Yojana* (RKVY) (Mumtaz et al. 2017). This was the beginning of semen sorting using a flow cytometer or high-speed semen sorter in India at the Frozen Semen Bull Station, Haringhata. The organisation reported the birth of the first male calf, "Shreyas", using sexed semen in 2011. Subsequently, some female calves were born using the technology with a conception rate of between 20 and 35% (Mumtaz et al. 2017). Under a pilot project jointly taken by the Kerala Livestock Development Board (KLDB) and the Department of Animal Husbandry, two sexed semen calves were born to Jersey crossbred heifers and Holstein Friesian (HF) cross-bred cows, respectively, at Vakkavu in Nenmara, Palakkad, using imported frozen semen straws. Prime Bovine Genetics, in collaboration with Sexing Technologies, provides sexed semen of Holstein Friesian, Jersey, Brown Swiss and Gir cross-breeds in India. In September 2017, ABS India launched "sexed dairy genetics" in Chandigarh to provide sexed semen for indigenous cattle breeds like Sahiwal, Gir, Red Sindhi cows and Murrah buffaloes. However, the adoption of the technology in the country is not yet as robust and the biggest hindrance to its widespread adoption by farmers is the high cost involved in importing semen straws from foreign countries. Some NGOs, along with private companies including BAIF, JK TRUST and other big institutions like NDDB and AMUL, have pitched in to establish sexed semen stations in India, which could potentially bring down the cost of the semen straws. The technologies exist; the need is to ramp up R&D, extension and delivery stations to transform the dairy sector into a vibrant, competitive and more remunerative sector for farmers.

3.2.3 Blue Revolution—Fisheries

The Indian fisheries and aquaculture sector constitute an important source of nutritional security, livelihood and inclusive economic development. From a meagre 0.75 MMT in 1950–51, fish production has increased more than 15 times to 11.41 MMT in 2016–17 (MoA&FW 2017).[15] The sector at present contributes the second largest share of about 6% to global fish production, next to the largest producer China, which accounts for about 40% (FAO 2018). The sector also contributes about 1.1% to the country's gross domestic product (GDP) and around 5.3% to its agricultural GDP (Ayyappan et al. 2016). India has a long coastline that stretches over 8129 kilometres (km), encompassing an exclusive economic zone of 2.02 million sq km and varied fishery resources comprising rivers and canals (191,024 km), reservoirs (3.15 million hectare (Mha)), ponds and tanks (2.35 Mha) (NFBD 2016).[3] The country's total fish production comes from two sectors—inland and marine. The share of the inland fishery sector in total fish production has gone up from 29% (0.2 MMT) in 1950–51 to 80% (8.6 MMT) in 2016–17, while the share of marine fisheries has gone down from 71% (0.5 MMT) to 20% (2.1 MMT) during the same period[16] (Fig. 3.8). According to the National Fisheries Development Board (NFDB), the Freshwater Fish Farmers' Development Agency (FFDA) reports that freshwater productivity is 3000 kg/ha/year and the Brackish Water Fish Farmers' Development Agency (BFDA) reports that the productivity in brackish water is 1500 kg/ha/year.

In terms of exports, marine products account for the second highest share in the total value of exports from India. During 2018–19, they reached an all-time high at USD6.7 billion, as against USD4.69 billion in 2015–16 (MoA&FW 2017). The

[15]Press Information Bureau, Government of India, issued by Ministry of Agriculture & Farmers' Welfare dated 21 November 2017 (http://pib.nic.in/newsite/PrintRelease.aspx?relid=173699), accessed on 25 March 2018.

[16]Calculated using data from Handbook on Fisheries Statistics, Department of Animal Husbandry, Dairying and Fisheries; Agricultural Statistics at Glance 2016 and Indiastat, accessed on 26 March 2018.

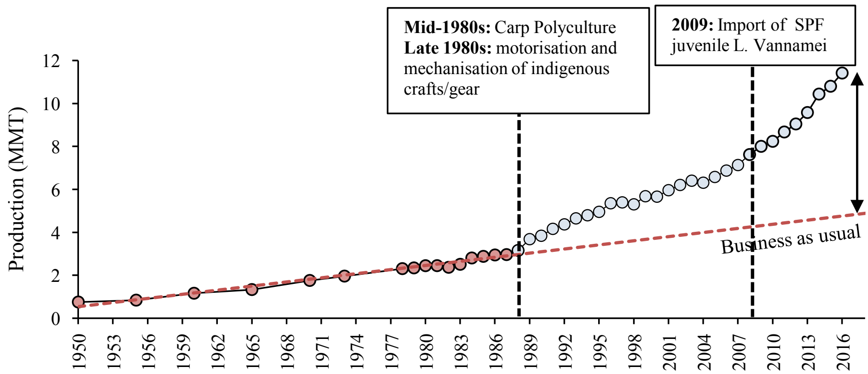


Fig. 3.8 All India Fish production. *Source* Handbook on Fisheries Statistics, DoAHD&F, Government of India; Indiastat

USA, South East Asia, the European Union and Japan are India's top export markets. Later sections give an account of innovations in breeding technologies, products and practices that revolutionised the traditional fish sector over time, turning it from being primarily capture-based into today's commercial and capital-intensive industry (Ayyappan et al. 2016).

Innovations in Farming Practice, Breeding and Diversification: The blue revolution began with a breakthrough in seed production technology through induced breeding by Hiralal Chaudhuri and K.H. Alikunhiat at the "Pond Culture Division" of the CIFRI substation (Cuttack, Odisha) in 1957. The technique of "hypophysation" and spawning of major Indian carp varieties—catla, rohu and mrigal—with induced breeding by pituitary extract was widely adopted and became an integral part of the fish culture programme (Katiha and Pillai 2004). In addition to the Indian carp, the Bangkok strain of the common carp (*Cyprinus carpio*) and other exotic species—silver carp (*Hypophthalmichthys molitrix*) and grass carp (*Ctenopharyngodon idella*)—were introduced in 1957 and 1959, respectively. The innovative composite fish culture added a new dimension to aquaculture during the late seventies and became a popular technology among farmers (Katiha and Pillai 2004). Under this technique, compatible and non-competing species (rohu, catla, mrigal, silver carp, grass carp and common carp) were cultured simultaneously using different feeding zones in a pond, to increase the total production from a unit area of water (Lekshmi et al. 2014). This was followed by the development of a carp polyculture during the mid-1980s, which contributed greatly to the transformation of inland capture fisheries to commercial aquaculture enterprise.[17] With widespread adoption in terms of area coverage and intensity of operation, production levels went up from 3–5 tonnes/ha/year to 10–15 tonnes/ha/year (Ayyappan 2005). At present, freshwater aquaculture and, more specifically, carp fish contribute about 80% of the total inland fish production (Laxmappa 2015). The Indian government has provided substantial

[17]Private hatcheries supply over 60% of the carp fingerlings for polyculture (Nair and Salin 2007).

support through a network of fish farmers' development agencies, brackish water fish farmers' development agencies and the research and development programmes at the Indian Council of Agricultural Research (ICAR). Additional support was extended by organisations and agencies like the Marine Products Export Development Authority and financial institutions (FAO 2014). As a result, total production increased by more than 50% in the five years between 1987–88 (2.9 MMT) and 1991–92 (4.37 MMT) and inland production exceeded marine production from 1988 onwards.

Notwithstanding stagnancy in the growth rate of marine fish production since the late 1980s, innovations in motorisation and mechanisation of indigenous crafts and gear, including motorised ring seine units,[18] contributed to increase fish production to the tune of 2 MMT in 1989–90 (Ayyappan et al. 2016). These motorised ring seine units are particularly efficient in catching shoaling pelagic resources such as the Indian oil sardine and the Indian mackerel. Consequently, there was an increase in production of Indian oil sardine of 113%—from 0.13 million tonnes in 1988 to 0.28 million tonnes in 1989—and an increase of 180% in the production of Indian mackerel from 0.1 million tonnes in 1988 to 0.29 million tonnes in 1989. In 1989, these two species formed nearly 26% of the total marine production of the country.[19] The Central Institute of Fisheries Technology (CIFT) further provided foundation for research to design specific fishing vessels and equipment, and emphasised "Gear Designing" so as to enhance production from mechanised vessels and diversify fishing activities. This gave birth to different harvesting equipments such as stern trawling, outrigger trawling, mid-water trawling and long lining, which increased catching efficiency[20] by 30% (Ayyappan 2005). Subsequently, several designs of small-, medium- and larger-sized mechanised boats were also introduced (Punjabi and Mukherjee 2015).

Unfolding Innovations in Fish Production: Commercial farming of shrimp picked up during the early nineties with the entry of the private sector and the opening up of trade. However, the breakthrough came in 2009, when the Coastal Aquaculture Authority granted permission to import juveniles (up to 10 g) of specific pathogen-free (SPF) Pacific white shrimp (*Litopenaeus vannamei*) from selected suppliers abroad to hatcheries in India for rearing to adult broodstock and seed multiplication and shrimp farming in India (DoAHD&F 2017).[21] *L. vannamei* is, today, the largest cultured shrimp in terms of production and productivity, farmed mainly in states like Andhra Pradesh, Gujarat, Tamil Nadu and Odisha. Because of its fast growth, low incidence of native diseases, availability of domesticated strains and high international market demand, *L. vannamei* is an attractive alternative to other prawn production (Singh and Lakra 2011). From 2009 to 2016, production levels of

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[18]Ring seine units showed an increase of 152% in terms of fishing units and 163% in terms of fishing hours from 1988 to 1989.

[19]Inputs received from A. Gopalakrishnan, Director, CMFRI, on 25 March 2018.

[20]Catch per unit effort of a specific gear and craft.

[21]*L. vannamei* is backed under two relevant acts—Livestock Importation Act, 1898 (Amended 2001), which regulates import and quarantine and the Coastal Aquaculture Authority Act, 2005, which regulates breeding and farming.

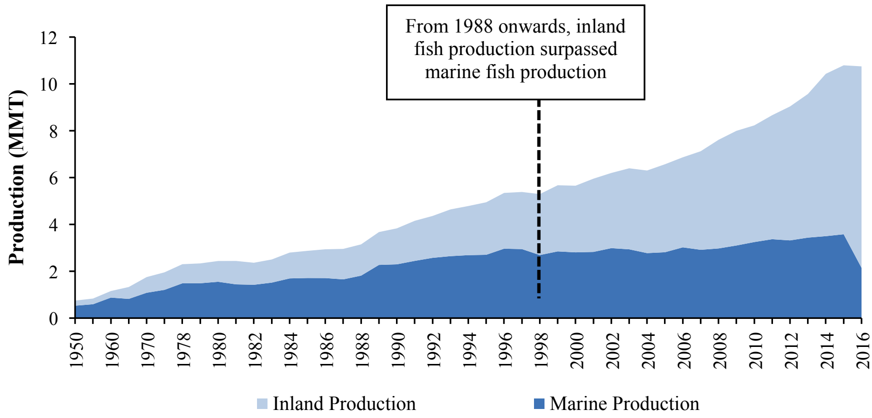

Fig. 3.9 All India inland and marine production. *Source* Handbook on Fisheries Statistics (2018), DoAHD&F, Government of India and Indiastat (2018)

SPF *L. vannamei* increased considerably, ranging between 8 and 10 tonnes/ha/year (DoAHD&F 2017). Shrimp cultivation reached 0.6 million tonnes during 2016–17, up from 28,000 tonnes during 1988–89 (Katiha and Pillai 2004). *L. vannamei* contributed a 90% share in volume and 70% share (in terms of value) to total shrimp exports (USD4.8 billion) (Kumar 2018), mainly to the USA, South East Asia, the European Union, Japan, etc. In a comprehensive study on the technical efficiency[22] of *L. vannamei* farming in India, it was found that *L. vannamei* farms achieved 90% of the maximum possible output from a given set of inputs, where stocking density, feed quantity, adoption of zero water exchange and cropping intensity were the major determinants of technical efficiency (Kumaran et al. 2017). The Government of India recently took another step towards sustainable cultivation of *L. vannamei* by permitting the culture of this species in freshwater/inland farms. Guidelines for this have already been notified under the CAA Act, 2005.

Another major activity in the aquaculture sector is the cage/pen culture in open waters, which has become very popular in recent years. It offers vast potential for inland aquaculture in the country. The production potential from sustainable cage culture for table fish production is about 50 kg/m^3 with enormous possibility for further expansion and intensification (DoAHD&F 2017a, b). Yet, there is still huge potential for large-scale cultivation of valuable fish, such as shrimp, pearl spot and sea bass since out of 1.24 million hectares of brackish water, only 15% of the area is developed for commercial cultivation (DoAHD&F 2017a, b) (Fig. 3.9).

[22]Technical efficiency measures the ability of a farmer to get maximum output from a given set of inputs.

3.2.4 Red Revolution—Poultry Meat and Egg

The poultry sector in India underwent a significant shift in structure and operation during the late 1990s—from mere backyard farming to an organised commercial industry. At present, it is one of the fastest growing sectors of Indian agriculture with the country's egg production jumping from 1.83 billion in 1950–51 to 88.1 billion in 2016–17 and poultry meat production from 0.06 MMT in 1961–62 to 3.46 MMT in 2016–17 (Fig. 3.10). India has emerged as the third largest egg producer after China and the USA and the fifth largest poultry meat producer after the USA, Brazil, China and the European Union. In India, the organised commercial poultry sector accounts for an 80% share of the total output and the unorganised backyard sector accounts for the remaining 20% (DoAHD&F 2017c). During 2016–17, India exported small quantities of poultry products (such as table eggs, hatching eggs, egg powder, live birds, frozen whole chicken and cuts) amounting to 0.5 MMT (worth USD79.51 million), mainly to the Middle East and Asia, and recently to Japan and South East Asia (DoAHD&F 2017c). Egg powder is also sent to the European Union (EU), Japan and some African countries (DoAHD&F 2017c). Innovations like the entry of private companies, import liberalisation of grandparent poultry breeding stock, and the spread of vertically integrated poultry practices, along with the contract farming model, played a catalytic role in bringing about the poultry revolution in India, as discussed in detail in later sections. Growth in the poultry sector has been engineered and dominated by the large-scale commercial private sector, which controls roughly 80% of total Indian poultry production and is concentrated in the southern states of Andhra Pradesh and Karnataka.

Innovations in Policies, Institutions and Breeding Stock: With the entry of private enterprises like Venkateshwara Hatcheries Private Limited (VH Group), Suguna Group, Rani Shaver Poultry Breeding Farms Private Limited, Kegg Farms

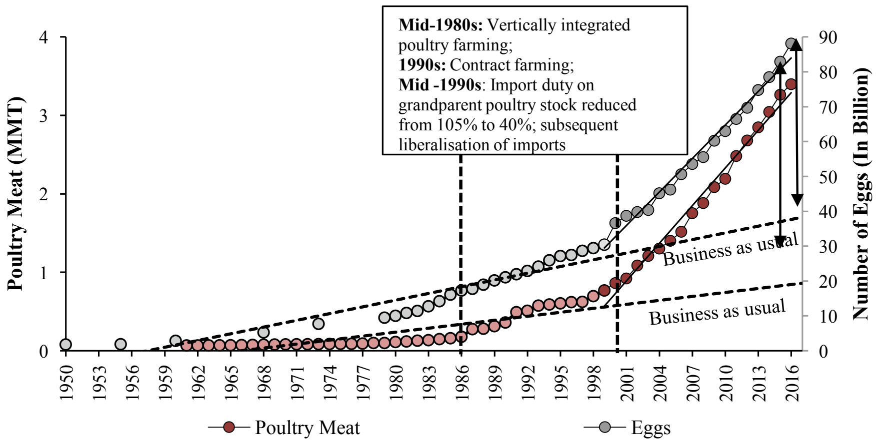

Fig. 3.10 All India poultry meat and egg production. *Source* DoAHD&F (2017b) and Food and Agriculture Organization of the United Nations (FAOSTAT)

Private Limited, Skylark Hatcheries and others, the concept of integrated poultry operations became well known in India (Manjula and Saravanan 2015).[23] These companies, through international collaborations, pooled investments and initiated the import of genetically improved breeding stock for commercial use. For instance, a joint venture between VH Group and the USA-based Cobb Vantress in 1974 initiated imports of grandparent stock of foreign breeds (Cobb strains) that kick-started the development of indigenous pure-line breeding in India (IFPRI 2003).[24] In order to achieve self-sufficiency in genetically improved germplasm, the Government of India, during the mid-1980s, took a major decision to disallow imports of grandparent stock along with other products. This split the industry into lobbies of grandparent importers and indigenous pure-line breeders (Tiwari 1990).[25] Realising that the industry was in its infancy in terms of research and development (R&D) and needed overseas support in breeding, the government revoked the decision and lifted the ban in April 1993. To encourage modernisation and diversification in agriculture, the government, in its 1993–94 budget, reduced the import duty on different agricultural items, including import duty on grandparent poultry stock, from 105 to 40% (Murty 1996).[26] Subsequently, in the budget speech of Manmohan Singh, the then Finance Minister, on 15 March 1995, it was proposed to reduce the import duty on grandparent poultry stock to 20%.[27] In 2001, all quantitative restrictions on India's imports of poultry items were dismantled and grandparent breeding stock was imported without any barriers (Mehta et al. 2008).[28] The policy resulted in a massive increase in private investment in breeding operations with the use of imported grandparent stock. It also led to the production of day-old chicks under strict bio-secure conditions leading to performance improvement in the pure-line stock of improved parent lines (Emsley 2006).

During the mid-1980s, Venkateshwara Hatcheries, which is, at present, Asia's largest fully integrated poultry group, became the first company to initiate vertically integrated poultry operations in South India, wherein they integrated different aspects of the poultry value chain from raising grandparent and parent flocks, rearing day-old chicks, compounding feed, providing veterinary services and marketing. The model gained popularity during the mid-1990s across the country and acted as a catalyst in facilitating commercial poultry growth (DoAHD&F 2017c). Currently, there are

[23]Article titled Poultry Industry In India under a Globalized Environment—Opportunities and Challenges in International Journal of Scientific Research (https://www.researchgate.net/publication/280609553_Poultry_Industry_In_India_Under_Globalised_Environment_-_Opportunities_and_Challenges).

[24]http://www.fao.org/WAIRDOCS/LEAD/x6170e/x6170e09.htm#bm09.

[25]https://www.indiatoday.in/magazine/economy/story/19901130-poultry-industry-grows-despite-import-policy-problems-turbulent-political-situation-813333-1990-11-30.

[26]https://books.google.co.in/books?id=YY0XLt6d0BgC&printsec=frontcover#v=onepage&q&f=false, accessed on 25 March 2018.

[27]Budget (1995–96), Speech by Shri Manmohan Singh, Minister of Finance on 15 March 1995. https://www.indiabudget.gov.in/bspeech/bs199596.pdf, accessed on 15 April 2018.

[28]http://www.fao.org/tempref/AG/Reserved/PPLPF/Docs/Reports%20&%20Papers/PAP_MT_SA_UP_03_India%20Poultry%20&%20WTO_Mehta.pdf, accessed on 1 August 2018.

about 60 thousand plus poultry farms in India that function under a modern integrated management system (Hellin et al. 2015; DoAHD&F 2017c). The founder of Venkateshwara Hatcheries, Dr Banda Vasudev Rao,[29] played a pivotal role as the architect of the Indian poultry industry's growth and modernisation. To ensure that producers get remunerative prices and are free from exploitative trade practices, he brought them together under the umbrella organisation of the National Egg Coordination Committee (NECC) in 1981 and made the clarion call "my egg, my price, my life" (Frontline 2003). In the broiler segment, Rao gave birth to BROMARK in 1994 (Broiler Marketing Cooperative Society): the All India Broiler Farmers' Body registered under the Multi-State Co-operative Societies Act to promote chicken meat consumption by advertising its nutritive value and reducing the gap between producer's and consumer's price (Bhardwaj 2014).

In the 1990s, Suguna Foods Private Limited (Coimbatore, Tamil Nadu) emerged as a leading enterprise with a unique model of contract farming[30] in the south. The model emerged as a success with commitment on the part of farmers to provide reared birds in a specified quantity and of specific quality, as well as a commitment on the part of the integrator to support the farmer's production and to buy back the fully grown birds[31] (Zakir 2008). The twin institutional innovations of a vertically integrated system along with contract poultry farming contributed substantially in stimulating the commercial growth of the poultry sector. As a result, there has been an increasing trend for expansion in farm size, from less than 500 birds to an average of 7000–8000 birds, which in turn provides scope for the mechanisation of feed production, feeding and egg handling.

Recent and Unfolding Innovations in the Poultry Sector: These private enterprises have proactively taken up R&D of parent stock (both indigenous and international breeds), meat broilers and egg layers and have developed international breeds that suit Indian environmental conditions. A number of bird hybrids are reared for rapid growth, feed efficiency and higher profits. Kegg Farms has developed a hybrid, high-yielding variety bird called the Kuroiler. Another popular broiler variety—Cobb 100—more commonly known as Vencobb and owned by VH Group accounts for 65–70% of total broiler production (DoAHD&F 2017). Cobb 100 is actually an old breeding stock imported from the USA that has been acclimatised to the Indian climate and disease conditions (Landes et al. 2004). Other popular broiler breeds include Ross, Marshall, Hubbard, Hybro Avian and Anak. In the layer sector,

[29] Also known as the "Father of Modern Poultry in India".

[30] Contact farming in poultry is broadly defined as an agreement between an integrator and farmers to produce/raise poultry birds at predetermined prices.

[31] Under the arrangement, the integrators (hatcheries) provide quality inputs, technical guidance, management skills, credit as well as knowledge of new improved technology, through intermittent supervision. Farmers, on behalf of the integrators, look after the chicks and rear them in their poultry sheds to slaughter weight while maintaining strict bio-security level. The farmers found the guaranteed returns of contract farming preferable to the vagaries of market returns as they got a fixed income, assured market, credit support, reduced risk and uncertainty. The live birds are then purchased either by the integrators for slaughter and further processing or by a wholesaler who distributes them via live markets (DoAHD&F 2017).

Babcock is the most preferred breed in India and constitutes 65% of the market share (Shukla and Nayak 2016). The strain was imported from the Netherlands-based Hendrix Genetics, while other varieties like Lohman, Bovans and Hyline are also commonly produced (DoAHD&F 2017c).

Several innovations have helped the sector to develop different varieties of eggs with specific nutritional value. Suguna Foods has developed four value-added speciality egg varieties, namely Active, Pro, Shakthi and Heart, which are enriched with special nutrients such as omega 3 fatty acids, selenium, vitamins and minerals. Kishore Farm Equipment and Dhumal Industries are leading firms that have developed auto-feeding systems, watering systems, climate control, flooring and brooding systems designed for Indian markets to ensure efficient poultry management (iBAN 2017). These innovations have led to branded shelf products, retailed at supermarkets. As a result, the feed conversion ratio for broilers has improved considerably from the ratio 2.2 in the 1990s to 1.65 in 2016–17 and the laying capacity of birds has increased from 260 to 320 plus eggs per annum (Kotaiah 2016). Moreover, according to APEDA market news (2016), per capita egg consumption has gone up from 30 to 68 and chicken from 400 g to 2.5 kg over the last five years.

However, nutritionists' recommend the consumption of 180 eggs and 10 kg chicken per year (APEDA 2016); so, there is still ample scope for production enhancement as well as increasing consumption of poultry products. India also has great potential to play a major role in the international market. India currently accounts for less than 0.5% of the global trade in poultry. Some major integrated poultry groups like Venky's (India) Ltd., Suguna Foods, Shanthi Poultry Farm (P) Ltd., etc., are selling processed branded frozen chicken that conform to stringent international quality norms to international markets including the Middle East, Europe and America, and to Indian outlets of large multinational food chains such as McDonalds, KFC, Pizza Hut and Domino's (Hellin et al. 2015). Sustained improvement in nutrition, high-quality feed, efficient utilisation of inputs and high hygiene standards are critical to remain competitive in the global market and to continue to grow to meet increasing consumer demand for eggs and meat (Hellin et al. 2015).

3.2.5 Golden Revolution—Fruits and Vegetables

After the Green Revolution in the mid-1960s and the White Revolution in the 1970s, the horticulture sector, comprising fruits and vegetables, spices and floriculture, has contributed significantly to agricultural growth in the country. In terms of production, over the last few years, there has been a voluminous increase in horticultural production overtaking food grains output in volume terms since 2012–13 (Fig. 3.11). The area under horticulture has increased by 3% per annum, and production has increased by an average of 5% per annum during the last decade. In 2016–17, production crossed the record mark of 300 MMT and is expected to reach 306.81

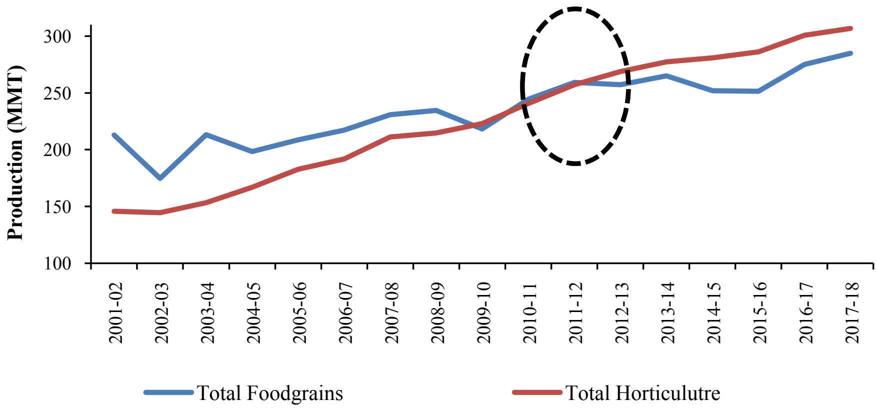

Fig. 3.11 Production of Horticulture vis-à-vis Food Grains, India. *Source* Horticultural Statistics at a Glance (2017), DoAC&FW, MoA&FW, GoI

MMT from an area of 25.6 Mha in 2017–18[32] (NHB 2018). Fruits and vegetables (F&V) account for nearly 90% share in terms of volume and about 77% in terms of value in total horticulture output. The area under F&V since the year 2001–02 has increased by 63.4% (from 10.1 to 16.6 Mha), and production has increased by 109% from 131.6 to 276 MMT (NHB 2017, 2018) during the same period. Consequently, India is now the second largest producer of F&V (with 9.3% share) in the world only next to China (with 35.4% share). The vast production base offers India good opportunities for exports, provided it is globally competitive. During 2016–17, India exported F&V worth USD1552.26 million, which comprised fruits worth USD667.51 million and vegetables worth USD884.75 million (APEDA 2017). Mangoes, walnuts, grapes, bananas and pomegranates among fruits and onions, okra, potatoes and mushrooms among vegetables constitute major portion of exports to countries like UAE, Bangladesh, Malaysia, Netherland, Sri Lanka, Nepal, UK, Saudi Arabia, Pakistan and Qatar" (APEDA 2017).[33]

The establishment of the Indian Institute of Horticultural Research (IIHR) at Bangalore and eight All-India Co-ordinated Crop Improvement Projects kick-started research and development (R&D) in several horticulture crops across the country during the Fourth and Fifth Five-Year Plans. A tremendous increase in expenditure for central sector schemes of the Department of Agriculture & Co-operation for horticulture from Rs. 250 million during the Seventh Five-Year Plan (1985–90) to Rs. 10,000 million during the Eighth Five-Year Plan (1992–97) established the road map for the golden revolution. However, the real boost came during 2005–06, when the Ministry of Agriculture and Farmers' Welfare launched the "National Horticulture Mission (NHM) to develop horticulture to its maximum potential and provide holistic growth of the sector through area-based regionally differentiated strategies, modern infrastructure for better storage management and lower post-harvest losses". Since the

[32]Third advance estimates 2017–18.

[33]According to APEDA, Ministry of Commerce and Industry, Government of India.

implementation of NHM, horticulture production has increased at a higher rate. The government also launched the Mission for Integrated Development of Horticulture (MIDH), a centrally sponsored scheme, during the Twelfth Five-Year Plan beginning in 2014–15, which subsumed earlier missions like the National Horticulture Mission (NHM), the Horticulture Mission for North East & Himalayan States (HMNEH), the National Bamboo Mission (NBM), the National Horticulture Board (NHB), the Coconut Development Board (CDB) and the Central Institute for Horticulture (CIH), Nagaland, to increase production and improve productivity of horticulture crops through various interventions.

Unfolding Innovations in Seeds and Cultivation Practices: A number of innovations implemented recently on a large scale have contributed to the production breakthrough and exports of these F&V[34] such as the adoption of crop-specific innovative planting technologies that promote crop diversification in the country, and the introduction of several high-yielding hybrid crop varieties (for instance, hybrid varieties developed using exotic mango cultivars from Florida (USA), Brazil and Peru) and the innovative farming technique of ultra-high-density plantation (UHDP)[35] contributed to the mango production breakthrough). In the case of banana, propagation of quality planting material such as "micro-propagation—tissue culture" led the boost in the country's banana production—as a result of this technique, 98% of plants bear bunches, field management is easy, and there is also uniformity in flowering and a reduction in crop duration (Chadha 2016).

In the case of potato, identification of suitable parental lines for production of true potato seed (TPS) or botanical seeds[36] by the Central Potato Research Institute (CPRI) in collaboration with the International Potato Center (CIP), Peru, and promotion of hi-tech aeroponic technology[37] for commercial adoption by CPRI has increased the rate of seed multiplication four times compared with those conventionally grown through mini-tubers (Chadha 2016). Moreover, the introduction of the short-duration, high-yielding variety "Kufri Pukhraj" in 1998 by ICAR-CPRI, which came into commercial adoption in 2005–06, had a positive impact on potato production as well as on the yield 20–40 t/ha if the crop is harvested within 60 and

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[34]Covering innovations in mango and banana production among fruits and in onion and potato production among vegetables, because mango and banana account for a 53% share in the total fruit production and onion and potato account for a 40% share in the total vegetable production.

[35]Based on closer planting of mango grafts, dwarf rootstocks and canopy architect management are key disruptions that have led to optimised use of land, nutrients and other resources. Generally, the recommended space between trees is 10 m * 10 m, but in UHDP, experts recommend only 4.5 m * 4.5 m to control growth of trees within two metres and height within six feet (Innovative Farming Solutions 2014).

[36]Under this technology, seeds are produced by transplanting seedlings raised in nursery beds or by planting seedling tubers produced in the previous season. ICAR-CPRI supplies these seeds to various state government organisations for further multiplication in three more cycles, such as Foundation Seed 1 (FS-1), Foundation Seed 2 (FS-2) and Certified Seed (CS) under strict health standards (Mustaquim 2017).

[37]Under the technology, plants are grown in an air or mist environment without the use of soil or an aggregate media. This is an alternative method of soilless culture in nutrient solutions under controlled environments (Mustaquim 2017).

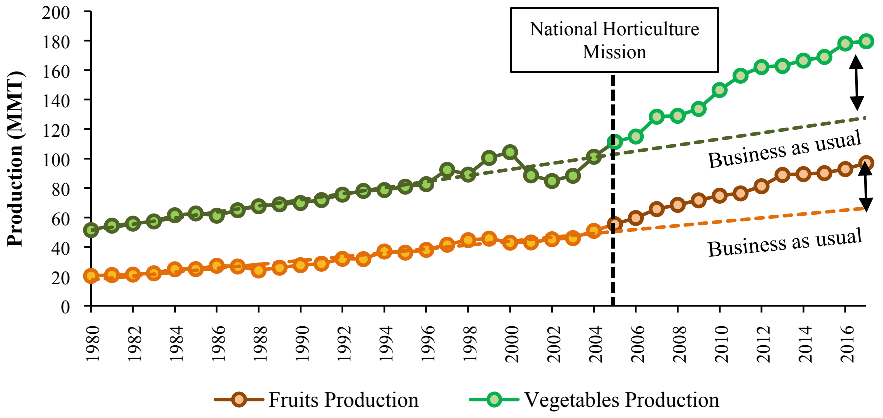

Fig. 3.12 All India fruit and vegetable production. *Source* FAOSTAT and NHB

75 days of planting, respectively.[38] At present, 33% of total potato area is under the Kufri Pukhraj variety.[39]

At the same time, in the case of onion, production was earlier confined to the *rabi* season due to low productivity during the *kharif* season. In 2001–02, the ICAR-Directorate of Onion and Garlic Research (DOGR) developed improved *kharif* production technology of raised beds with micro-irrigation, which doubled productivity during *kharif* and increased the area under onion production during the *kharif* season not only in Maharashtra but also in other states, i.e. Karnataka, Gujarat and Madhya Pradesh. Further, decanalisation of onion exports[40]in 1999 and the global demand for dehydrated onions[41] from India boosted its production.

As a result of the innovations in planting material and cultivation practices, India experienced a structural breakthrough in total fruits and vegetable production in 2005–06 compared to a "business-as-usual" scenario. Production of fruits increased from 20.4 MMT in 1980–81 to 97 MMT in 2017–18, while that of vegetables increased from 58.5 to 179.7 MMT during the same period (Fig. 3.12) (NHB 2018). However, this breakthrough is not as sharply evident as in the case of wheat during the Green Revolution and milk during the white revolution.

[38]Inputs from Dr. S. K. Chakrabarti, Director, ICAR-Central Potato Research Institute, Shimla.

[39]This variety has replaced the Kufri Jyoti as the number 1 variety and covers nearly 33% of the area under potato today.

[40]Onion exports were canalised by the National Agricultural Co-operative Marketing Federation (NAFED) until 1998 to protect domestic consumers and producers from unduly high prices and gluts. In January 1999, GoI introduced a new export–import policy and certain changes were made in the system of onion trade by including 13 state trading enterprises as canalising agencies for onion trade, namely the Maharashtra Agricultural Marketing Board, Gujarat Agro Industries Corporation, Karnataka State Co-operative Marketing Federation, Andhra Pradesh Marketing Federation, etc., so that no agency acquires a monopoly position.

[41]According to Punjabi and Mukherjee (2015), there are 100 onion dehydration units in India, of which 85 are located in Gujarat, and the remaining in Maharashtra and Madhya Pradesh. In 2016–17, India produced 50,000 tonnes of dehydrated onions and contributed approximately 40% to the

Moreover, there has been a significant increase in productivity over the decade, from 10.7 t/ha in 2001–02 to 14.3 t/ha in 2016–17 in the case of fruits, and from 14.4 to 17 t/ha in the case of vegetables (Fig. 3.13).

In the case of mango, India emerged as the largest producer with 21.2 MMT in 2017–18, up from 8.4 MMT in 1980–81, contributing about 40% (20 MMT) of total world mango production (46.2 MMT) followed by China (10%), Thailand (7.38%), Mexico (4.72%) and Indonesia (4.7%); it is also a prominent exporter. In terms of yields, India cultivated 9.2 t/ha in 2017–18, up from 5.5 t/ha in 2008–09 (Fig. 3.14). During 2016–17, India exported 52.76 thousand tonnes of mangoes, worth USD67 million, to countries such as the UAE (54%), the UK (5.7%) and Saudi Arabia (4.5%)

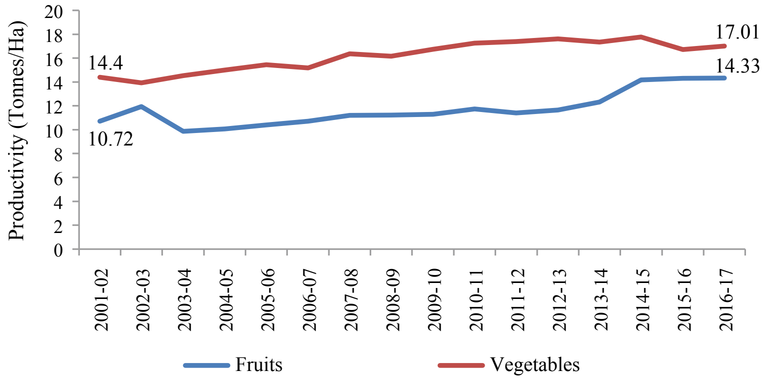

Fig. 3.13 Fruit and vegetable productivity in India. *Source* NHB (2017)

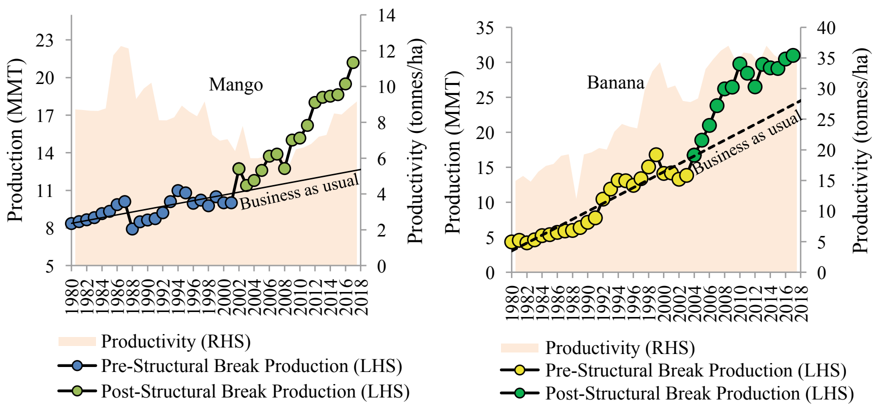

Fig. 3.14 All India mango (left) and banana (right) production and productivity. *Source* FAOSTAT and NHB

total global export of dehydrated onions, next only to the USA, which exported approximately 50%; the remainder is exported by Egypt and China. India exports to Europe, Russia, France, etc.

(APEDA 2017). In the case of bananas, production touched 31 MMT in 2017–18 from less than 5 MMT in 1980–81, contributing the largest share of 26% to total world production (FAOSTAT 2017). In terms of yields, while the world produces 20.6 t/ha on an average, India produces an average of 35.2 t/ha (FAOSTAT 2017). Additionally, in major banana-growing states like Madhya Pradesh, Gujarat, Bihar, Tamil Nadu and Maharashtra, yields are well above the country's average at 66 t/ha, 64.1 t/ha, 51.5 t/ha, 46.1 t/ha and 44 t/ha, respectively (NHB 2017). Some of the popular commercial varieties grown in India are Grand Naine (from France), Robusta, Dwarf Cavendish, Red Banana and Nendran, among others. The Grand Naine variety is extremely popular due to its tolerance to biotic stress and good-quality bunches; it is cultivated in sizable quantities in Maharashtra (Jalgaon) and Gujarat. According to a World Bank case study on Indian bananas (2011), "Unlike the rest of the world's major banana growing areas, which are dominated by large-scale commercial farms, the Indian banana industry is based on large numbers of small, independent farmers, typically cultivating less than 3 acres" (World Bank 2011).

Among vegetables, the structural break in the case of onion production is dramatic: from 2.6 MMT in 1980–81 to 22 MMT in 2017–18, with the yield increasing from 9.9 to 17 t/ha during the same period (Fig. 3.15). India is the second largest onion-growing country (contributing a 21% share) in the world next only to China (contributing a 26% share). Indian onions are famous for their pungency and are available all year round. In 2016–17, India exported 1.4 MMT of fresh onion to the world (worth USD389.36 million), including countries such as Bangladesh, Malaysia, Sri Lanka, the UAE and Nepal (APEDA 2017). In the case of potato, production increased from less than 10 MMT in 1980–81 to 48.5 MMT in 2017–18, and the yield rose to 22.7 t/ha from 12.1 t/ha during the same period. Globally, India is the second largest producer of potatoes, contributing an 11.6% share or 48.2 MMT after China (with a 26.3% share or 99.12 MMT) during 2016–17.

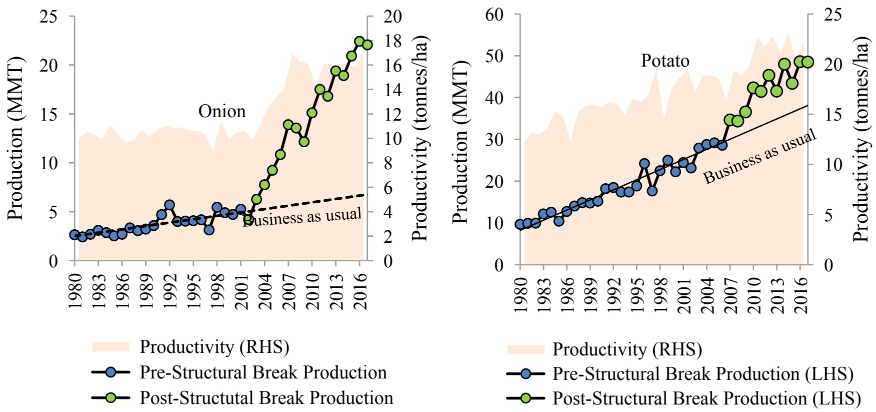

Fig. 3.15 All India onion (left) and potato (right) production and productivity. *Source* FAOSTAT and NHB

3.2.6 Gene Revolution—Cotton

Cotton (Gossypium), the "king" of fibres, is an important commercial crop of global significance. Across the world, India, China, the USA, Pakistan, Brazil and Australia are leading cotton producers, contributing about 80% of global cotton (lint[42]) production.[43] India is the only country in the world that produces all four species of cultivated cotton, i.e. *Gossypium arboreum* and *G. herbaceum* (Asiatic cotton), *G. barbadense* (Egyptian cotton) and *G. hirsutum* (American upland cotton) besides hybrid varieties.[44] Riding on the success of the Gene Revolution, India today is the largest producer of cotton with 37.2 million bales[45] in 2017–18, cultivated on 12.24 Mha (ISAAA 2017a, b, c).

Innovations in Seed Technologies and Policies: During the decade 1990–91 to 2000–01, the cotton sector was characterised by stagnation in production, heavy use of pesticides[46] and fertilisers, bollworm infestation, a decelerating trend in yield and over-reliance on imports. Repetitive use of fertiliser and insecticide gradually developed resistance in bollworm, which resulted in its consequent resurgence and massive outbreaks, which resulted in adverse ecological as well as human health effects (Gutierrez et al. 2015).[47] In 1996, the St. Louis, USA-based company, Monsanto Holdings Pvt. Ltd. introduced *Bacillus thuringiensis* (Bt) cotton seeds to grow bollworm-resistant cotton. It has since been approved for use around the world.

In India, between 1998 and 2001, Monsanto and Maharashtra Hybrid Seeds Company Pvt. Ltd. (Mahyco) conducted field trials of genetically modified seeds featuring the cry1Ac gene. However, use of GM seeds invited severe opposition from several NGOs and civil society groups due to its harmful impact on human health and environment. After long debates and consideration regarding the adoption of Bt cotton, finally on 26 March 2002, the then Prime Minister Atal Bihari Vajpayee took the bold decision to commercially introduce Bt cotton through the Genetic Engineering Approval Committee (GEAC), set up by the Ministry of Environment and Forests. Initially, three hybrids—MECH 12, MECH 162 and MECH 184 of Mahyco Monsanto—were recommended for cultivation in the central and southern cotton-growing zones (DCD 2009). With this, India became the 16th nation to commercialise

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[42] Lint is cotton fibre that is removed from the seed during the cotton ginning process. From here on, cotton lint is referred to as cotton.

[43] Issued by Ministry of Textiles, Government of India, through the Press Information Bureau on 9 March 2017.

[44] Report on "Revolution in Indian Cotton" published by Directorate of Cotton Development, Department of Agriculture & Co-operation, Ministry of Agriculture, Government of India, in 2009.

[45] Million bales of 170 kg each.

[46] About 40–50% of total crop pesticide used in the country was applied just on cotton (DoAC&FW 2016).

[47] Research study on "Deconstructing Indian cotton: weather, yields, and suicides" by Andrew Paul Gutierrez, Luigi Ponti, Hans R Herren, Johann Baumgärtner and Peter E Kenmore published in Springer Open Journal (https://link.springer.com/content/pdf/10.1186/s12302-015-0043-8.pdf).

transgenic cotton seed. Atal Bihari Vajpayee, in an inaugural speech at IIT Kanpur, on 1 October 2003 said, “The next big revolution that is unfolding in the world is the biotechnology revolution. This too is going to touch the lives of ordinary people in ways that we cannot even fully imagine today. We must not lag behind others in this revolution. Indeed, India should aspire to be one of the leaders of this revolution. We must plant its healthy saplings in different parts of the country so that we can reap their fruits soon” (GOI 2003). Subsequently, the government approved six biotech events expressing versions of Cry genes, including Bollgard I or MON531 (cry1Ac gene) of Mahyco Monsanto; Bollgard II or MONN15985 (cry1Ac and cry2Ab genes) of Mahyco Monsanto; Event 1 of IIT Kharagpur and JK Agri Genetics Seeds Ltd; and GFM event (cry 1 Ab + cry Ac gene) by Nath Seeds sourced from China and BNBt LA-01 of the Indian Council of Agricultural Research and MLS9124 of the National Research Centre on Plant Biotechnology (Udikeri S. S., Kranthi, K. R., Patil S. B. and Khadi B. M.).[48]

As a result, there was a breakthrough in cotton production in 2003–04. India more than doubled cotton production from 13.6 million bales in 2002–03 to 37.2 million bales in 2017–18, surpassing China in 2014–15 to become the number one cotton-producing country in the world (DCD 2017). According to the ISAAA Report on the Global Status of Commercialized Biotech/GM Crops in 2017, 11.4 Mha is under Bt cotton cultivation, with an average rate of adoption of 93%. In addition, there are more than 2000 Bt hybrids, developed by more than 30 seed companies (mostly private), which have been approved by the GEAC for commercial cultivation (ISAAA 2017a).[49] It was the innovation and adoption of Bt cotton technology—the only commercialised GM crop in the country—and the decisions made by policymakers coupled with infrastructure (irrigation, power, roads), access to foreign markets and untiring efforts by the private sector to supply improved seed qualities which led to a major breakthrough in the sector and ushered in the Gene Revolution in India. Cotton yield also increased from 125 kg per hectare in 1960–61 to 302 kg per hectare in 2002–03 to 566 kg per hectare in 2013–14, a more than 85% increase in 10 years (Fig. 3.16) (CCI 2016–17). During this period, the area under cotton cultivation also increased by 56%, indicating production gains emanating largely from a breakthrough in productivity (CCI 2016–17).

As a result, India became a net exporter, with raw cotton export increasing from a meagre 0.09 million bales in 2002–03 to, at its the highest, 12.9 million bales in 2011–12 and 11.7 million bales in 2013–14, a 130 times increase in just 12 years (CCI 2016–17). A forthcoming study of ICRIER by Gulati and Juneja estimates the cumulative gain from import saving, extra raw cotton export and extra yarn export—compared to the business-as-usual scenario—between 2003–04 and 2019–20 at USD84.7 billion at the all-India level.

[48]ICAC Report on “Emerging Pests of Bt Cotton and Dynamics of Insect Pests in Different Events of Bt Cotton” by Udiker S. S., Kranth K. R, Pati S. B. Khad B. M. (https://www.icac.org/tis/regional_networks/asian_network/meeting_5/documents/papers/PapUdikeriS.pdf).

[49]https://www.isaaa.org/resources/publications/biotech_country_facts_and_trends/download/Facts%20and%20Trends%20-%20India.pdf.

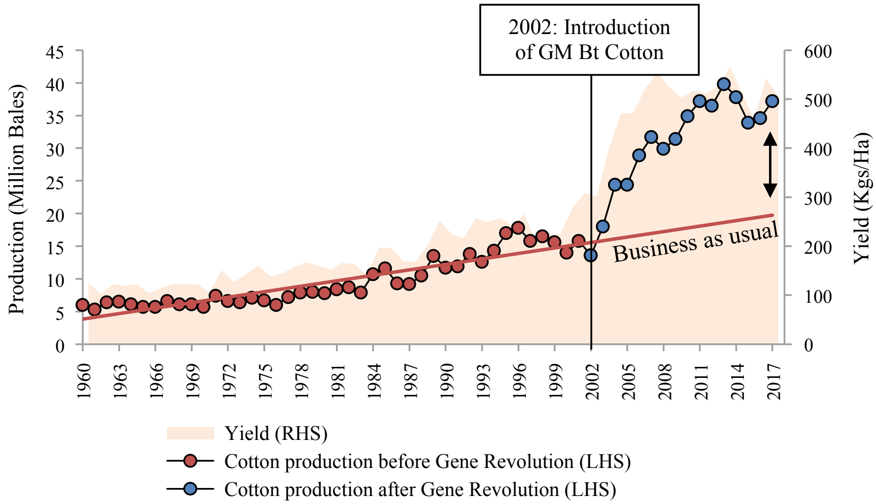

Fig. 3.16 All-India cotton production and yields.
Source United States Department of Agriculture USDA (2018a, b) and CCI (2016–17)

Unfolding Innovations and the IPR Question: Following GEAC approval for commercial cultivation of GM Bt cotton in India, Mahyco Monsanto Biotech (India) Limited (MMB) introduced Bollgard I (containing cry1Ac) in 2002 and Bollgard II (containing cry1Ac and cry2Ab genes) in 2006. Further, release of Bollgard II (with Roundup Ready Flex (RRF)) and Bollgard III with additional pest-resistant proteins (cry1Ac, cry2Ab and Vip3A), along with herbicide-tolerant (HT) RRF traits for enhanced pest resistance, was released in other countries—Australia, Brazil and the USA. Notwithstanding wide adoption of Bt cotton or Bollgard I—more than 90% in India—and ongoing field trials of improved seeds, Bollgard II RRF and Bollgard III have not yet been released, owing to widespread criticism by NGOs, political ideologues and some domestic seed companies.[50] However, in the recent report submitted by the Field Inspection and Scientific Evaluation Committee (FISEC), set up at the insistence of the Prime Minister's Office (PMO), it is reported that there was illegal cultivation of (HT) Bt cotton in states such as Andhra Pradesh, Gujarat, Maharashtra, Telangana and Punjab, to the extent of 15% during the 2017 *kharif* season.

More recently, seeing better yields and a better future with herbicide-tolerant Bt (HtBt) cotton, farmers' groups have come forward and are openly supporting cultivation of HtBt cotton in several states. They even criticise the government for

[50]The government has even stepped into private contracts and imposed price regulations as observed in March 2016, when the price of Bollgard II seed prices was controlled at Rs. 800 per 450-g pack (these had been previously selling at Rs. 830–1000 in different states) and the royalty fee or trait value paid by domestic seed firms to technology developer MMB was slashed by 70 from Rs. 183.26 earlier to Rs. 49 per packet by the government (Seetharaman 2018). Further, for the 2018 *kharif* season, GoI fixed the maximum sale price of Bt cotton seeds at Rs. 740 per packet of 450 g and reduced the royalty fee to Rs. 39 per packet (Press Trust of India 2018).

not giving commercial clearance to Bt brinjal and mustard, which had already been approved by the GEAC in 2010 and 2017, respectively. The late Sharad Joshi's outfit "Shetkari Sanghatana" was the first farmers' organisation to launch a civil disobedience movement for "Freedom of Technology", fighting for the cause of farmers' freedom to choose the best farm technologies (Gulati 2019a, b).

The government needs to provide farmers with access to the latest technologies and the freedom to exercise their prudence to be able to accept or reject a technology based on its merits. So, a careful re-examination of policies in the best interests of Indian farmers is required at this moment in order to address their concerns rather than to penalise them for being pro-technology.

3.3 Total Factor Productivity (TFP) in Agriculture

TFP in agriculture is a holistic measure of a sector's growth, defined as the share of output increase with the same amount of inputs such as fertilisers, land, labour, capital or material resources employed in production. TFP captures the effects of technological change, skills or infrastructure, as well as the increase in efficiency with which inputs are utilised in production (USDA 2018a, b; OECD/ICRIER 2018). It is calculated as the ratio of total agricultural output to total production inputs. A higher ratio implies that resources are being used efficiently (IFPRI 2018).

India's TFP growth since 2001 has been robust, reversing the slowdown of the early 1990s. Technological progress has been the main and consistent driver of TFP growth over the past two decades. The main components of technological progress in India included the use of improved seeds, as well as better infrastructure coverage and quality (irrigation, road density, electricity supply). In another study by Rada (2013), results suggested renewal of farm TFP growth in India following the economic reforms of the 1990s. The study further mentions that the transition to a more diversified production composition resulted in the renewal of TFP growth in Indian agriculture. That is, it was led primarily by horticultural and livestock products and by the southern and western regions as they benefited from higher returns from high-value commodity production following diversification (Rada 2013; OECD/ICRIER 2018) (Table 3.2).

Table 3.2 Average annual Total Factor Productivity (TFP) growth in Indian agriculture

Period	Fuglie (2018)	Rada (2013)
1961–70	0.5%	
1971–80	0.7%	
1981–90	1.3%	3.6%
1991–00	1.1%	1.32%
2001–14	2.32%	3.08% (2000–08)

Source Rada (2013), Fuglie (2018) and Lele et al. (2018)

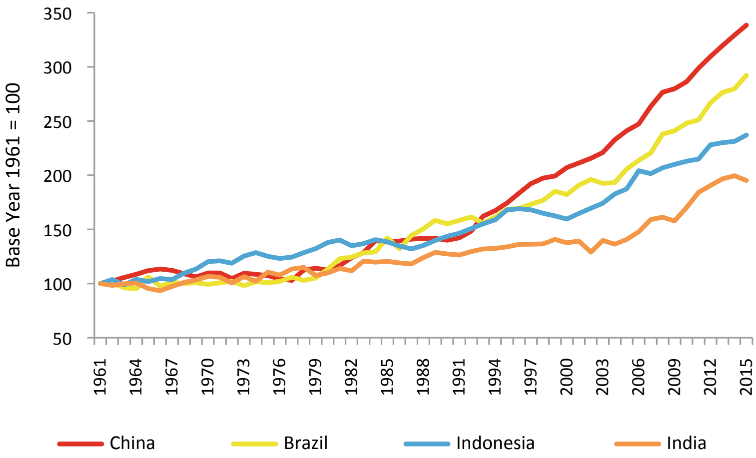

Fig. 3.17 Growth in total factor productivity in selected Asian countries, 1961–2015. *Source* Fuglie (2018). *Note* TFP growth rate is calculated as the difference between output and input growth rates

Besides this, Chand et al. (2012) also assessed the contribution of different productivity-enhancing factors to TFP growth for a variety of Indian crops and found that public investment in agricultural research constituted a significant source of TFP growth in 11 out of 15 crops. When compared to other countries such as China, Brazil and Indonesia, as per Fuglie's estimates, India's TFP growth is rising; however, since 1982, there has been an increasing gap vis-à-vis TFP growth in China, Brazil and Indonesia (Fig. 3.17). Before that, India's TFP growth was slightly better than China's (i.e. during the period of the Green Revolution); thereafter, China took off significantly by investing heavily in productivity growth, surging ahead of other countries (Lele et al. , 2018). Similarly, Brazil's TFP growth was slower than India's until it surpassed India's in the 1980s (Lele et al. 2018).

Besides, recent USDA Estimates indicate that agricultural TFP in India increased at an average annual growth of 2% during 2000–16, which is lower compared to the growth in China (3.4% per annum) and Israel (2.4% per annum) during the same period (USDA 2018a).

Thus, experts suggest that investments in infrastructure, R&D and extension services are needed to ensure sustainable agricultural productivity growth in order to keep pace with rapidly increasing consumer demand for food, feed and fibre (Global Harvest Initiative 2014).

3.4 Innovations in Irrigation Technologies

Almost 54% of agricultural area in India faces high to extreme water stress, i.e. more than 40% withdrawal of available water supply.[51] Of this, agriculture consumes more than 78% of water in India, which is well above the global average of 70%. According to the Ministry of Agriculture and Farmers' Welfare (MoA&FW), Government of India, surface water irrigation through canals accounts for 24% of the net irrigated area in the country while groundwater irrigation accounts for 63%, and tanks and other sources irrigate 13% of the net irrigated area. However, efficient water use, under surface irrigation and groundwater irrigation through conventional application practices like flood irrigation, is as low as 40%–49%. It is in this context that innovative irrigation technologies such as sprinkler and drip irrigation (micro-irrigation) improve application efficiency to about 85%–90%.

Sprinkler and Drip Irrigation: Sprinkler irrigation and drip irrigation are the two main types of micro-irrigation technologies. Up to March 2018, the area brought under micro-irrigation was about 10 Mha (15% of the net irrigated area) in India, with the area under sprinkler irrigation (SMI) spread over 5.44 Mha (53%) and drip irrigation (DMI) over 4.77 Mha (47%). Micro-irrigation has seen a steady growth rate in India over the years, increasing at the rate of 9.07% annually from 2005–06 to 2017–18[52] (Fig. 3.18).

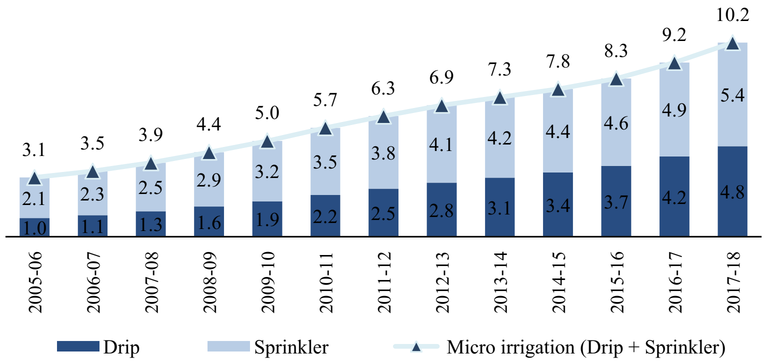

Fig. 3.18 Area under micro-irrigation (drip and sprinkler) in Mha, India. *Source* PMKSY (http://pmksy.gov.in/microirrigation/Physical_Report.aspx)

[51] http://www.wri.org/sites/default/files/india_water_tool.pdf.

[52] The Government of India implemented a centrally sponsored scheme on micro-irrigation in 2005 to improve water use efficiency in agriculture by promoting technologies like drip and sprinkler irrigation technologies. In June 2010, it was scaled up to the National Mission on Micro-Irrigation (NMMI), which continued till the year 2013–14. NMMI was integrated under National Mission for Sustainable Agriculture (NMSA) and implemented as "on-farm water management" (OFWM) during the financial year 2014–15. From 1 April 2015, the micro-irrigation component of OFWM has been included under the Pradhan Mantri Krishi Sinchayee Yojana as the "per drop more crop" component.

The overall area under micro-irrigation is at around 10 Mha, but its penetration (measured as percentage of the area under micro-irrigation to the net irrigated area or equivalent[53]) is very low (14.9%), even lower than the global average of 23.6%, and much lower than countries such as Israel (99.1%), Brazil (77.6%), South Africa (76.9%), Russia (60.7%), the USA (58.0%) and France (52.9%).[54]

Cost–benefit analysis of micro-irrigation: The benefits of micro-irrigation pertain to improving application efficiency to 85–90%, much above that achieved by flood irrigation. Studies also show that fertigation (supplying fertilisers mixed with irrigation water) and the resulting fertiliser saving are added benefit to farmers from the adoption of micro-irrigation techniques. Further, an evaluation study of the adoption of MI technology by sample farmers across states reports that owing to a reduction (saving) in the quantity of irrigation water applied, there is resultant saving in energy (electricity/diesel/solar) needed to pump irrigation water of about 30%. In addition to this, due to an improvement in the efficiency of water and fertiliser use, a significant yield improvement has also been recorded in most crops under micro-irrigation (Table 3.3).

The benefit-cost (BC) ratio of micro-irrigation systems was found to be more than one for almost all crops evaluated across states in the NMMI evaluation study. The benefit-cost estimation of the installation of drip technology in sugarcane in Maharashtra made in an ICRIER study by Gulati and Mohan (2018) showed that, subject to sensitivity analysis, the BC ratio was more than one in all cases, except where the initial investment cost was almost double the government-prescribed installation costs[55] (DoAC&FW 2017d) and farmers had to take out a loan with no subsidy. The ICRIER study also revealed that in all cases where the BC ratio is greater than 1, the

Table 3.3 Benefits from the adoption of micro-irrigation technology as estimated in an impact evaluation study on NMMI in India (2014)

Benefits	% Saving (reduction) or enhancement, as applicable
Power saving	30.65
Fertiliser saving	28.48
Yield enhancement	42.34
Irrigation cost reduction	31.93
Increase in irrigated area	8.41

Source Impact evaluation study on NMMI in India, 2014

[53]Total irrigated area: Irrigated agricultural area refers to area equipped to provide water (via artificial means of irrigation such as by diverting streams, flooding or spraying) to crops (source: FAO). For India, we have taken the net irrigated area as it was found to be the closest equivalent to FAO data.

[54]The task force on micro-irrigation (MI) set up under the Chairmanship of Shri Chandrababu Naidu (2004) estimated that the potential for micro-irrigation in India is around 69.5 Mha with DMI potential of 27 Mha and SMI potential of 42.5 Mha. Thus, the untapped potential of micro-irrigation is still quite large (around 59.3 Mha).

[55]National Mission for Sustainable Agriculture—Operational Guidelines. Ministry of Agriculture, Department of Agriculture and Co-operation, Government of India.

payback period to recover the investment made was less than three and a half years. This indicates the utility of adopting the micro-irrigation system as, in addition to the several benefits, it also ensures income enhancement through a positive BCR.

Innovative Irrigation Models

Solar Pump Sets with Micro-irrigation: The complementary benefits of energy saving and water saving can be achieved by coupling micro-irrigation[56] with other innovations such as solar pumps and underground pipelines. Across India, groundwater is the predominant source of irrigation, covering almost 63% of net irrigated area (NIA). Across the country, different sources of energy are used to pump groundwater. Based on the 5th minor irrigation survey, out of a total of 20.7 million pumps operating in the country that lift water for irrigation, electric pumps (71%) and diesel pumps (25%) dominate. To operate micro-irrigation technology, pressurised water supply is required; this is delivered through sprinklers or applied at the root zone through drippers. The per kwh cost of pumping through diesel pump sets is at least three times higher than through solar pump sets. Replacing all diesel pump sets by solar pump sets would promote cost-effectiveness and would be beneficial for business. However, the initial high capital cost of solar pump sets (about Rs. 4 lakh for a 5 HP pump) is a problem. Given that most Indian farms are small and marginal (less than 2 ha), this cost is exorbitant for them. The government has been giving subsidies to promote solar pump sets, but there is a limit on the overall subsidy funds being given.

The government has also fallen woefully short of achieving its solar power generation targets. It has set a target of 100 GW of solar power generation by 2022 under the National Solar Mission. However, till 30 June 2020, 36 GW solar power (including solar roof top) capacity has been created (MNRE 2020). Overall, up to 30 October 2019, 1.8 lakh solar powered water pumps have been installed in the country under the off-grid and decentralised solar PV application programme. In the 2018–19 budget, the Finance Minister announced a new scheme '*Kisan Urja Suraksha evam Utthaan Mahabhiyan* (KUSUM). The scheme aims to install 10,000 MW of decentralised ground-mounted solar power plants with a capacity of up to 2 megawatt (MW) and 17.50 lakh stand-alone solar-powered agriculture pumps with a capacity of up to 7.5 HP (8250 MW aggregate capacity). Integrating micro-irrigation schemes like PMKSY with the National Solar Mission and KUSUM scheme could help improve agricultural income. Moreover, innovative business models of mobile solar pump sets charging on a service-performed basis, as well as solar trees as a third crop, can make a useful contribution.

Solar as a Third Crop: The model for solar as a third crop in India should be based on a vegetation-centric approach, as maximising agriculture output is the first priority. In such cases, ground-mounted PV panels could be set up while growing cereals and other cash and horticulture crops. Incorporating solar on existing land would help provide an additional stream of income to farmers while reducing the downside

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[56]Micro-irrigation techniques like drip irrigation require lower water pressure (20–25 psi) at the outlet compared to overhead systems (50–80 psi). This reduces power requirement for pumping.

risks in case of crop failure. While sales of excess solar energy generated by PV panels installed for irrigation can be a lucrative way to produce solar energy, its generation capacity can be a constraint. Hence, a separate solar generation system can be developed, which can generate enough energy to emerge as a viable source of income. While the upfront cost may be significant, a co-operative model can be developed for farmers to pool resources and limit individual liability. Solar-powered systems can be either grid-connected or stand-alone off-grid systems. In off-grid solar plants, a mechanism is required to store the energy produced such as batteries, which, having a low shelf life of two to a maximum of five years, may increase overall capital costs. As such, it is critical that any solar power system is connected to the local grid. For the concept of "solar as a third crop" to succeed, it is critical that famers are provided with net-metering[57] facilities so that they can sell excess units to the grid. This will act as an incentive for farmers to judiciously use groundwater resources.

Solar Boat and Solar Tree: Farmers in Bihar receive either low or no electric supply, forcing them to depend on expensive diesel pumps for irrigation. For this reason, the Agricultural University at Pusa (Samastipur), Bihar, has developed a boat-based solar pumping system equipped with a 2 HP submersible pump powered by a solar panel that irrigates fields in areas with river water. The university claims that the solar-powered system can irrigate 5–6 acres of land at a time; this can be doubled if micro-irrigation techniques like rain gun, sprinkler or drip irrigation systems are dovetailed with the system. This inexpensive solar irrigation system has an operation cost of about USD0.46 (or Rs. 35) per hour.[58] They have also developed a solar tree (so-named because the design resembles a tree) to save on the land required for solar panels. It has been said that each solar tree can operate a 5HP submersible pump and can normally irrigate 15 acres of land. A combination of a solar tree with a micro-irrigation system is expected to increase the irrigation area by an additional 40%.[59] The university claims that the cost of irrigation through solar tree technology comes to just one-third the cost of irrigation with a normal diesel engine.

[57]Net metering has been a success in Australia, Canada, USA, Italy, Spain and Denmark among others. In 2002, Thailand was the first country to initiate the net-metering policy in the developing world. The very small power producer (VSPP) regulations were aimed at encouraging the use of small-scale renewable generation under 1 MW. The Thailand government mandates the purchase of any surplus electricity generated through renewables at rates that are adjusted every three months. The regulations now cover generation under 10 MW.

[58]Converted in USD at the current exchange rate of USD1 = Rs. 76.62.

[59]https://timesofindia.indiatimes.com/city/patna/rau-develops-solar-tree-for-irrigation-in-areas-sans-power/articleshow/61535756.cms.

3.5 Innovations in the Fertiliser Sector and Soil Management

Backdrop to India's Urea Sector

India is the second largest producer and consumer of urea in the world, next only to China. Urea consumption in India increased from 19.2 MMT in 2000–01 to 32 MMT in 2018–19. On a per hectare (ha) basis, the consumption of urea countrywide increased from 103.5 to 149.3 kg/ha over the same period. Moreover, the price of urea in India is highly subsidised: while pricing reforms have largely (not fully) decontrolled the pricing of phosphatic (P) and potassic (K) fertilisers, urea pricing has remained almost the same for many years.[60] The underpricing of urea compared to the cost of production and imports led to a large ballooning subsidy on fertilisers, almost two-thirds of which is subsidy for urea.[61] At present, the fertiliser subsidy is the largest input subsidy in agriculture and is second only to food subsidies as the largest central subsidy. The fertiliser subsidy has shown a dramatic jump, increasing from USD3.02 billion in 2000–01 to USD10.06 billion in 2018–19. However, the biggest problem in the sector is the imbalanced use of urea in relation to P and K, which leads to soil degradation and massive inefficiency in its use. In certain states like Punjab, the situation is alarming. In addition to this, an imbalance or deficiency of soil nutrients is not limited to primary macronutrients only. Due to the concentrated emphasis on NPK in policies in the country, the deficiency of secondary macronutrients and micronutrients is also causing concern. Among other macronutrients, sulphur deficiency is at 41%, and among micro-nutrients, zinc deficiency is at 48%. Zinc is an essential nutrient, and its absence in food causes stunted growth. Similarly, the deficiency of boron, iron and manganese is found to be 33%, 12% and 5%, respectively. Keeping all these issues in mind, the Indian government launched two schemes—*neem* coating of urea (NCU) and soil health cards (SHCs).

[60]Compared to neighbouring countries, Brazil, Indonesia, China and South Africa and some other rice-producing countries in Asia (rice crop requires urea in large proportion), farmers in India pay the lowest price for urea. In 2017, world urea price was at USD220/MT and Indian farmers paid USD86/MT (after including an extra 5% in price for *neem* coating) while in China, Pakistan, Bangladesh, Indonesia and Philippines, urea was priced at USD253/MT, USD265/MT, USD195/MT, USD135/MT and USD362/MT, respectively. Such low prices in India have led to the misuse of urea, mainly in the form of smuggling to neighbouring countries.

[61]The subsidy on urea was calculated as the difference between retention price and the statutorily notified sale price for each urea unit individually. Under the maximum retail price (MRP) scheme of diammonium phosphate (DAP) and muriate of potash (MOP), the difference between the delivered price of fertilisers at the farm gate level and the MRP fixed by the government was paid out as subsidy. Under the nutrient-based subsidy (NBS) scheme, a fixed rate of subsidy on a Rs./kg basis is announced after taking into consideration factors like international prices, exchange rate, inventory level and the existing MRP of DAP and MOP. Subsidy being fixed, any fluctuation in international prices is reflected in the domestic price of DAP and MOP under the NBS policy. Fertiliser subsidy is mentioned in the union budget every year.

***Neem* Coating of Urea (NCU) Scheme**: For a long time, researchers have been trying to find a way to combat the damage done to Indian soil by excessive and/or disproportionate use of urea and low nutrient use efficiency (NUE). *Neem* coating of urea was found effective as this slows down the release of nitrogen from urea, reducing loss due to leaching. It thus reduced the quantity of urea required by crops. Since it reduces leaching of nitrates in groundwater aquifers, it addresses the problem of groundwater pollution as well. Prasad (1980) developed *neem* cake-coated urea in India with nitrification inhibition properties; i.e. it could slow the process of nitrogen release. Studies suggest that applying NCU increases NUE by around 10% and increases the yield of rice and wheat. On 2 June 2008, the government introduced a policy to encourage the production and availability of *neem*-coated fertilisers by allowing producers to make a maximum of 20% of their production *neem*-coated. Before that, in 2007–08, only 1.5% of the urea produced was *neem*-coated. Due to efforts by the government, in 2010–11, 5.5% of normal urea (NU) produced was *neem*-coated. The government increased the cap to 35% through a notification on 11 January 2011; consequently, neem coating jumped to 15.9% of total urea produced in 2011–12. Considering the positive effect of NCU on productivity, the government removed the cap altogether through a notification on 7 January 2015 and on 24 March 2015, the Department of Fertilisers announced that 75% of all urea produced should be *neem*-coated. Further, on 25 May 2015, the department made it mandatory to *neem*-coat 100% of the urea produced. Entire quantities of domestically produced and imported urea have been *neem*-coated since 1 September and 1 December 2015, respectively.

Impact of NCU—Recent Report: A report[62] submitted by the Agricultural Development and Rural Transformation Centre (ADRTC) under the Institute of Social and Economic Change (ISEC) to the Directorate of Economics and Statistics (DES), Ministry of Agriculture, Co-operation and Farmers' Welfare, in 2017 titled "Impact of *Neem* Coated Urea on Production, Productivity and Soil Health in India" that the application of NCU resulted in an improvement in soil health characteristics.[63] This improvement is reflected in the incremental increase in yield levels of the reference crops. The increase in yield was 38% in the case of soya bean, 34% in red gram, 8% each in paddy and maize, 5% in sugar cane and 3% in jute. The survey found the highest incremental yield in respect to paddy in Madhya Pradesh (17% = 2 quintal/acre) and the lowest in the case of Punjab (1% = 0.28 quintal/acre). NCU resulted in a cost increase of 4% in paddy and 1% in maize; however, there was a reduction in costs in the case of soya bean and jute. It also resulted in reduced costs of pest and disease control for paddy, jute, maize and soya bean. The study recorded

[62]The study intended to analyse the impact of NCU on yield and income and document the status and implementation of the soil health card scheme. The study collected primary and secondary data from six states, namely Karnataka, Maharashtra, Madhya Pradesh, Bihar, Punjab and Assam. The reference period was the 2015 *kharif* season. The six crops considered for the study were paddy, red gram, sugar cane, maize, soya bean and jute.

[63]Nearly 52% of red gram (*tur*) farmers and 61% of paddy farmers have found improvement in soil texture, soil moisture retention, water infiltration and soil softness, and reduction in soil compaction.

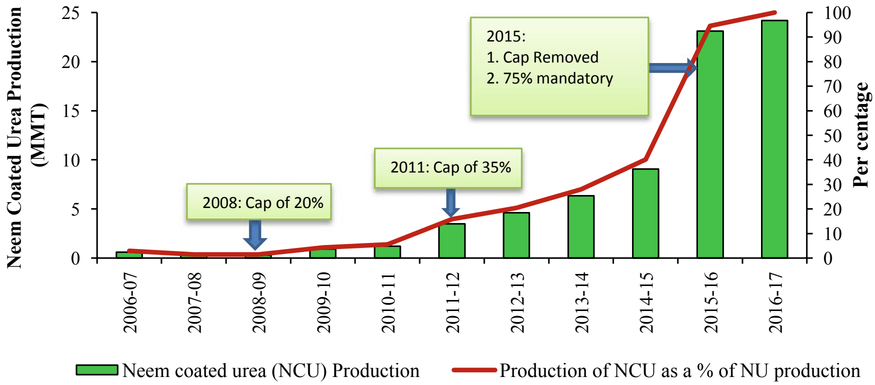

Fig. 3.19 Production of neem-coated urea in India. *Source* Constructed using the data in Fertiliser Statistics 2016–17

that the diversion of urea for non-agricultural use had stopped entirely among the farmers participating in the survey using NCU (Fig 3.19).

Soil Health Cards (SHCs) Scheme: Soil testing is a necessary prerequisite to assess the soil status and recommend fertiliser application. However, as mentioned in a report of the working group of the Twelfth Plan Period (2012–13 to 2016–17), the capacity of soil-testing laboratories was inadequate in the country[64] and "farmers' knowledge regarding the right product, dosage, time and method of application is very limited, leading to inefficient use of fertilisers". According to the report, "Extension agencies should ensure that farmers use the fertilisers in accordance with soil fertility status and crop needs. It will require strengthening of the existing soil testing laboratories by providing facilities for analyzing secondary and micro-nutrients". It also pointed out the need for a national-level centre of soil health monitoring and training under the Department of Agriculture and Co-operation (DAC), which would be equipped with a central soil-testing laboratory (STL) for monitoring the quality of samples, tested and analysed. All this took a major turn when the government announced the SHC scheme on the 19 February 2015. The scheme was approved for implementation in 2015 with an outlay of USD0.08 billion[65] (or Rs. 5.68 billion).

[64]The beginning of soil-testing laboratories in India goes back to 1955–56, when 16 soil-testing laboratories (STLs) were established under the "Indo-US Operational Agreement for Determination of Soil Fertility and Fertiliser Use". After that, 1049 STLs were set up in the country by March 2012 (Press Release 07.09.2012). In 2013–14, 15 more STLs were sanctioned (Press Release 2 January 2017). It was recognised by the working group report that for judicious use of fertiliser by farmers, the role of STLs and fertiliser recommendation is undeniable. Farmers with small holdings require these recommendations even more. Under the National Project on Management of Soil Health and Fertility (NPMSH&F) of the Department of Agriculture and Co-operation (DAC), financial assistance was provided for farmer's training and field demonstrations on balanced use of fertilisers.

[65]Converted to USD using exchange rate of USD1 = Rs. 65.46 in 2015 (RBI 2017–18).

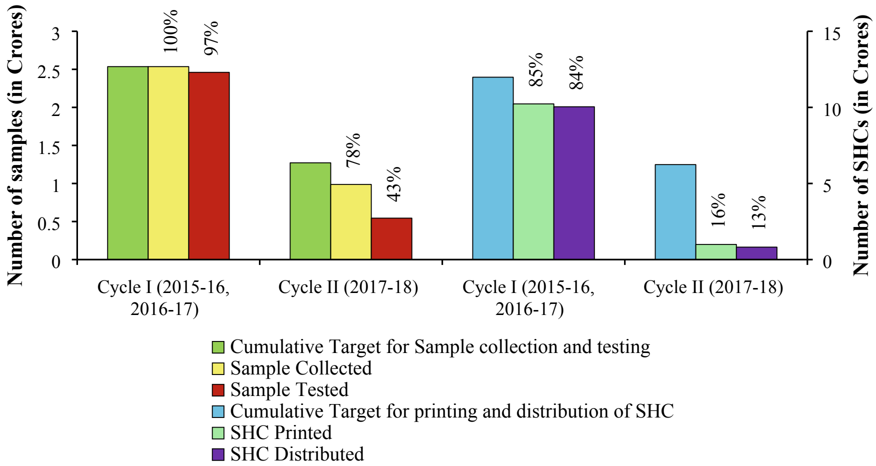

Fig. 3.20 Targets and achievements of SHC Scheme, India. *Source* SHC Website

Achievements vis-à-vis Target: The United Nations (UN) declared 2015 as the "International Year of the Soils". On that note, the government decided to complete the first cycle (sample collection, testing and SHC printing and distribution) in two years instead of three—2015–16 and 2016–17—and the second cycle started in 2017–18. According to the progress report, in the first cycle,[66] 100% of the target was collected and 97% was tested. But SHCs distributed in the first cycle were just 84% of the target. However, in the second cycle, only 13% of the target for SHCs was distributed. It would appear that the government will have to increase the pace of the process in the second cycle if the scheme is intended to be taken seriously. Figure 3.20 presents the targets and achievements of the scheme in terms of sample collection, testing, SHCs printing and distribution.

Impact of the SHC—Recent Report: The National Institute of Agricultural Extension Management (MANAGE), Hyderabad, carried out a study[67] on the "Impact of Soil Health Card Scheme" mandated by the Ministry of Agriculture and Farmers' Welfare (MOA&FW) of the Government of India, for three crops, namely: paddy, cotton and soya bean.[68] According to the report, after following the recommendations of the SHC, the area under these crops declined. This might have been the result of farmers diversifying. There was a decline in the use of fertilisers, with the use of

[66] As on 1 January 2018.

[67] To examine the design of the SHC scheme; assess the modalities of delivery; assess the level of utilisation of SHCs by farmers; and assess the impact of the SHC scheme on the judicious use of fertilisers (bio and organic) as well as cropping choice, cost reduction, farm profitability and sustainability. The study also recommends some measures to improve the overall design of the scheme.

[68] Fertiliser use and productivity before and after, following the recommendations of SHC, were compared.

nitrogenous fertilisers declining at a higher percentage than phosphatic or potassic fertilisers; this is a good sign because it signifies a move towards more balanced fertiliser application. Besides, there was a decline in costs of 8–10% for cost A_1; i.e. all actual expenses in cash and kind are incurred in production by the owner for all crops and around 4% for cost $C_{2,}$ i.e. the comprehensive cost including imputed rent and interest on owned land and capital. Crop yields have increased slightly after having SHC in all three crops at the all-India level (from 2% to 4%) although state-wise values differ. The study recommends various measures to improve the scheme including: rethinking grids considering local soil variability, the need for inclusion of water quality statements in the card, setting up more soil-testing laboratories and focusing on the quality of soil testing at acceptable market prices. Broadly, both schemes suffer shortcomings: there is lack of awareness among farmers about the benefits of using NCU and SHCs; an increase in urea prices after *neem* coating; and a lack of infrastructure and delay in soil sample collection, testing and distribution of SHCs. Although half the farmers have received SHCs on time, only a small portion of them have followed the recommendations properly. This is something that could be addressed by creating greater awareness among farmers.

3.6 Innovations in Precision Agriculture: Artificial Intelligence, Internet of Things, Remote Sensing

The use of ICT-enabled smart technologies such as the geographical information system (GIS), drones, the Internet of things (IoT), big data analytics and artificial intelligence (AI) has heralded a new technology package in Indian agriculture, which can have significant impact in due course. By interpreting the data on soil information, weather and environmental conditions for a specific piece of land, a farmer can optimise the choice of crop, and the use of pesticides, water and fertilisers, and can thus decide when and how to spray, till and harvest the crop.

Drones or unmanned aerial vehicles (UAVs) with integrated GIS mapping, sensors and digital-imaging capabilities can play an instrumental role by first analysing soil in order to plan a seed-planting pattern. After that, drone-carried devices can be used to spray the correct amounts of fertilisers, nutrients and pesticides. Time-series images captured through drones can help farmers know the precise development of a crop and reveal production inefficiencies, thus, enabling better crop management. Drones with hyper-spectral, multispectral, or thermal sensors can be used to identify parts of the field that are dry or that need improvement. By scanning the overall health of the crop using both visible and near-infrared lights, farmers can easily spot bacterial or fungal infections, further helping them to apply and monitor remedies more precisely (Mazur 2016). In a recent Pricewaterhouse Coopers (PwC) global report on the commercial application of drone technology, the market for drone-powered solutions in the agricultural sector has been estimated at USD32.4 billion.[69]

[69] https://www.pwc.pl/en/publikacje/2016/clarity-from-above.html.

In the data space, it can often be a challenge to combine and order unstructured or disparate data so that it makes sense. Through sources like the Internet of things (IoT) sensors and social networks, farmers can incorporate data collection, sensor-monitoring, the measuring and reporting of environmental elements, e.g. temperature, pressure, humidity, weather, climate, seismic activity, radiation, light, motion, proximity, etc., to form large amounts of big data. This can then be analysed from any location to lay down the action plan to be implemented in the controlled system. Some IoT application scenarios include smart agriculture, environmental monitoring and forecasting, asset management and logistics and vehicular automation. IoT can provide a means to plan, monitor and control every phase of the agricultural ecosystem.

In India, according to Agfunder.com (2016), over 50 agricultural technology-based start-ups use smart agriculture (NITI Aayog 2018). While a majority of them are in the research and development (R&D) phase, a few large-scale farmers have started implementing innovative products on their farms to improve output, thereby contributing to a booming agro-based economy (Chatterjee 2018).

CropIn Technology Solutions Private Limited, founded in 2010, provides software as a service (SaaS) to agricultural businesses through the "SmartFarm" platform, which helps farmers derive real-time insight into the standing crop based on local weather information and high-resolution satellite imagery. In addition to this, CropIn also provides "SmartSales" technological solutions for input companies to enable them to track sales orders, stocks and payments. This also helps them identify potential sales points to decide on-farm operations and output. Another service provided by CropIn is "mWarehouse" which ensures traceability to the last mile for companies engaged in exports and logistics of agri-produce, including packaging services (Ganguly et al. 2017). The start-up's clientele include PepsiCo, Mahindra & Mahindra, ITC and McCain along with banks, government bodies and development agencies. It has connected with 29 countries across South East Asia, Europe and Africa, has engaged with nearly 2 million farmers holding 3 million acres of land in farm management, crop-cycle monitoring and harvesting, and brings in produce traceability from farm to fork (Ahuja 2018).

Other start-ups have also ventured into IoT applications and are currently establishing a foothold before they begin to commercialise and scale up operations. For instance, "*Opencube Labs (OCL)*" based out of Bangalore is a start-up currently working towards creating open-source, farmer-friendly, IoT-based agricultural handheld devices to check crop health by measuring the normalised density vegetation index (NDVI), a real-time soil vital measurement system to check for soil moisture, nutrient and pH levels in the field, a semi-automated irrigation system and a smart livestock management system that gives inputs to farmers in their local language for better use of resources and predicts yields, revenues and returns on investments even before the end of the season (Chatterjee 2018). Another start-up based out of Punjab—AgNext Technologies—has developed a single solution platform by combining four technologies: IoT, AI-based image processing, weather forecasting and satellite imagery for stakeholders to monitor the occurrence of pests and diseases over a large area and build predictive models for the future. Energy Bots Private

Limited, a Gurgaon-based start-up, has introduced a smart-watering system using soil humidity and moisture sensors and a global system for mobile communication (GSM)-based IoT device. The device gets data from sensors within the controller and microcontroller to take decisions and perform actions that allow farmers to remotely switch on or switch off their motor pump either by giving a missed call or by sending a text, or by scheduling both at specific times of the day. Farmers are even alerted and notified when any action is taken by the device (Chatterjee 2018).

Artificial intelligence (AI) is a computer program in which a machine is equipped with the ability to develop the cognitive functions of a human so that it can make decisions based on interpreting, acquiring and reacting to different situations (on the basis of learning acquired) to enhance efficiency. AI and related technologies have the potential to impact productivity and efficiency at all stages of the agricultural value chain. For instance, AI solutions integrated with data signals from remote satellites, as well as local image capture on the farm, can help farmers take immediate action to restore soil health. AI can also be used to generate advisories for sowing, pest control and input control; image-classification tools combined with remote-sensed information can improve the efficiency of farm machinery. AI tools can be used to transmit more accurate supply and demand information to farmers, thus reducing information asymmetry between farmers and intermediaries. Further, predictive modelling to ensure effective price discovery can be carried out using data from e-NAM, agricultural census, AGMARKET, etc. (NITI Aayog 2018).

Recognising that efforts from the private sector may neither be financially optimal nor efficient on a stand-alone basis, the Finance Minister, in his budget speech for 2018–2019, mandated NITI Aayog to establish the National Programme on AI, to guide research and development in new and emerging technologies (NITI Aayog 2018). As a result, NITI Aayog has adopted a three-pronged approach—undertaking exploratory proof-of-concept AI projects in various areas, crafting a national strategy for building an AI ecosystem and collaborating with various experts and stakeholders. In addition to this, NITI Aayog has also partnered with several leading AI technology players to implement AI projects in critical areas such as agriculture and health.

Microsoft, in collaboration with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), has developed an AI sowing app, which is powered by the Microsoft Cortana Intelligence Suite that includes machine learning and Power BI.[70] The app sends sowing advisories containing essential information such as the optimal sowing date, soil-test-based fertiliser application, farmyard manure application, seed treatment and optimum sowing depth to participating farmers. In addition to the app, a personalised village advisory dashboard provides important insights into soil health, recommended fertilisers and seven-day weather forecasts. In 2017, the programme was expanded to reach more than 3000 farmers across the states of Andhra Pradesh and Karnataka during the *kharif* crop cycle (rainy season) for a host of crops including groundnut, finger millet (*ragi*), maize, rice and cotton. On

[70]Power BI is a business analytics service by Microsoft. It aims to provide interactive visualisations and business intelligence capabilities with an interface for end users to create their own reports and dashboards.

average, a 10–30% increase in crop yield per ha has been witnessed in comparison with previous harvests across crops (NITI Aayog 2018). Companies such as Intello Labs have developed image-recognition software to monitor crops and predict farm yields; Aibono uses agricultural data science with AI providing solutions to stabilise crop yields, and Trithi Robotics uses drone technology that allows farmers to monitor crops in real time and provides precise analysis of their soil.

Therefore, according to the creators and system integrators in the technological ecosystem, Indian agriculture can achieve a new phase of exponential growth through IoT applications, AI, and UAVs/drones. These can revolutionise the way farmers cultivate, and have an impact on warehousing and waste reduction; they can also ensure higher revenues and profitability for the entire ecosystem (Chatterjee 2018), given that they are offered in an open source, viable and affordable platform that ensures faster adoption.

3.7 Innovations in Sustainable and Protected Agriculture

Soilless Farming Systems *Hydroponics, Aeroponics and Aquaponics*: Hydroponics is the method of growing plants in a water-based, nutrient-rich medium, without soil. This method essentially cuts down the amount of water being used compared to the traditional method of growing plants in soil. This technique is often used to grow vines, tomato, cucumber, capsicum and other crops. Aeroponics is the process of growing plants in a moist environment without soil or an aggregate medium. The plants are suspended in an enclosed setting, and water, mixed with plant food, is sprayed on to the roots. An enclosed environment like a greenhouse enables the user to regulate temperature and humidity accurately with some additional lighting (Calderone 2018). On average, plants grown using aeroponic technology were reported to yield 30% higher productivity compared to soil-growing methods (Calderone 2018). Aquaponics, on the other hand, is an integration of hydroponics (raising plants without soil) and aquaculture (rearing fish). The systems work by using the waste from fish to naturally provide nutrients to nearby water-grown plants. According to the FAO (2018), integrated agri-aquaculture farms can reduce water consumption by 90% compared to traditional agriculture. The practice is likely to benefit countries such as Oman, Algeria, Egypt or North Africa, where there is shortage of both water and good-quality soil.

An example of an emerging start-up in India that has ventured into these novel technologies and is currently at the stage of establishing its foothold is "Triton Foodworks". The company has set up over five acres of hydroponic farms across three locations in India. Their strawberry farm in Mahabaleshwar grows 20 tonnes of strawberries a year, and a 1.25-acre facility in Maharashtra's Wada district produces about 400 tonnes of tomato, 150 tonnes of cucumber, 400 heads of spinach and over 700 bunches of mint (Vaishnavi 2017). According to the company, hydroponic systems enable them to save around 0.22 billion litres of water per year compared to traditional agriculture. Another start-up—the Centre for Research in Alternative Farming Technologies (CRAFT)—has emerged as a leading service provider in alternative farming technologies. The company trains and provides consultancy to people in hydroponics, aquaponics, urban farming and the commercial aspects of the technologies (Vaishnavi 2017). A start-up named "Hamari Krishi" empowers Indian farmers to grow vegetables such as basil, coriander, lettuce, thyme, spinach, vine tomatoes, cucumbers, bell peppers, gourds and water melon throughout the year using non-soil agricultural techniques in aeroponics structures. The company manufactures poly-house and aeroponic structures to a range of specifications and also provides training programmes on how to run a farm efficiently.[71]

Poly-House Farming Systems: Indo-Israeli Agriculture Project: To achieve sustainable holistic development of Indian agriculture along with an intensification of bilateral co-operation, the Government of India and the Israeli government jointly drew up a work plan in 2006 for technology dissemination under the Indo-Israeli Agricultural Project (IIAP) implemented by the Mission for Integrated Development of Horticulture (MIDH) and MASHAV, Israel's Agency for International Development Co-operation. The project aimed to improve crop diversity, productivity, quality and resource-use efficiency through capacity building and transferring innovative applied research and technologies to farmers. To execute IIAP, "agricultural centres of excellence" (CoE) were established, the resources of which were allocated by both the Federal Government (NHM) and individual state governments after the approval of the detailed project report from the central government (MASHAV 2016). These centres of excellence are focal points for Indo-Israeli R&D in agriculture (Kumar 2014). These centres are arranged in clusters such as vegetables, mangoes, pomegranates and citrus, to provide crop-specific training and demonstrations to farmers on a variety of best practices such as protected cultivation, drip irrigation, fertigation, canopy management, nursery production and integrated pest management in order to achieve high agricultural productivity (Aluf 2014). Each cluster is headed by an Indian expert, who is usually the individual who runs the most advanced centre in the cluster. The head of a cluster works closely with their Israeli expert counterpart to adapt the technology to existing local needs (MASHAV 2016). So far, 30 centres of excellence have been sanctioned by MIDH under the Indo-Israeli Action Plan in three phases. The first action plan (phase 01) was implemented during 2008–2011 and focused on Haryana, Maharashtra, Rajasthan and Gujarat. The Action Plan for 2012–2015 (phase 02) expanded the focus to seven states, adding Karnataka, Tamil Nadu and Punjab to the list (Kumar 2014), and phase 03 (2018–2020) is currently in progress (Aluf 2014). A list of these centres is given in Table 3.5 in the Annexure.

The most significant contribution of the Indo-Israeli collaboration was in assisting Indian farmers to reduce the cost of desalination of water in addition to recycling water for irrigation purposes. Acute shortage of fresh water is one of the critical issues faced in India, yet the agricultural sector consumes nearly 78% of water drawn from freshwater sources. It is in this area that Israel has set an example. Despite having less than 200 m^3 per capita water availability (Gulati and Mohan 2018), it has emerged

[71] http://www.hamarikrishi.com.

globally as a well-established leader in water management, desalination and recycling techniques. Under the Joint Declaration for Co-operation in Water Technologies (2012) between the Indian Ministry of Urban Development and the Israeli Ministry of Industry, Trade and Labour (Kumar 2014), Israeli agricultural professionals teach and help Indian farmers in the adoption of water management practices such as drip irrigation and fertigation by demonstrating the effectiveness of these technologies in terms of higher resource-use efficiency. As a result of such countrywide efforts and the central government's micro-irrigation scheme, there has been a reasonable increase in the area under micro-irrigation from 3.1 Mha in 2005–06 to 10.2 Mha in 2017–18.[72] However, penetration is comparatively low at 14.9%, when compared with global average of 23.6%, and with other countries like Israel (99.1%), Brazil (77.6%), South Africa (76.9%), Russia (60.7%), USA (58.0%) and France (52.9%). All of this suggests that India has a long way to go in developing advanced water management technologies.[73]

Israel is also supporting India in fulfilling food requirements by exporting new crops, hybrid seeds and products, which are tested in the centres before adoption by farmers. The Indo-Israel Vegetable Centre of Excellence in Gharaunda, Haryana, has made substantial gains in terms of the annual number of seedlings grown by state farmers—from half a million in 2011 to six million in 2015[74]—using innovative plug-seedling technology[75] (MASHAV 2016). The seedlings include hybrid seeds of tomatoes, cherry tomatoes, coloured capsicum, cucumbers, eggplant, chilli peppers and more. Farmers from Punjab, Rajasthan and Himachal Pradesh also use the facility. In addition to this, the Israeli innovation of "protective cultivation" has successfully demonstrated increased crop yields, reduced pesticide use and prolonged harvesting. Protected cultivation, including structures such as the hi-tech greenhouse, naturally ventilated poly-houses (NVPH), the anti-insect net house (AINH) and walk-in tunnels, has shown a dramatic increase in crops within three years of operation. As a result, the yields in the state have increased significantly for cucumber from 3.5 t/ha to 45 t/ha, for capsicum from 12 t/ha to 72 t/ha and for tomato from 16 t/ha to 96 t/ha, along with a prolonged harvesting season: from 3 to 9 months (MASHAV 2016). In addition to the increase in crop productivity, there was a reduction of 65% in water use. At present, farmers all over Haryana grow over 1400 ha of protected vegetables, with the numbers rising annually. Although the technology, as well as construction of greenhouses and poly-houses, is expensive, government subsidies have ensured that interested farmers take the plunge (MASHAV 2016). The Indo-Israel Centre of Excellence for Sub-Tropical Fruits (ICESTF) in Ladwa, Kurukshetra,

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[72] PMKSY (http://pmksy.gov.in/microirrigation/Physical_Report.aspx).

[73] Italy, France, Iran: International Commission on Irrigation and Drainage 2016-17; *Total of the 46 countries considered by ICID in their annual report 2016–17; FAO Aquastat data, DES, GOI.; China: Correspondence with CNCID—Chinese National Committee on Irrigation and Drainage; USGS (United States Geological Survey): https://water.usgs.gov/watuse/wuir.html, http://databank.worldbank.org.

[74] http://timesofindia.indiatimes.com/articleshow/53292394.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst.

[75] Young plants grown in small, individual cells, ready to be transplanted into containers or a field.

established for mango in 2016, is another major success story and showcases some of the most advanced Israeli agricultural technologies adapted for Indian conditions by local experts such as new mango demonstration fields, nurseries, introducing new Israeli mango varieties like the salinity-tolerant M-13-1, Maya and Sheli, as well as demonstrating best practices such as high-density plantation, canopy management and rejuvenation of senile orchards. As a result, there has been a significant increase in output along with improved fruit quality: in just two years, the treated trees produced fruit with greater weight and better colour and harvesting was easier with fewer post-harvest losses (MASHAV 2016). Although the centres of excellence have played a key role in effectively disseminating technology through training and demonstrations, the cost-benefit analysis of such operations and technologies under IIAP still needs to be evaluated by a third party to assess its commercial viability. Moreover, its spread to farmers' fields at a respectable scale is yet to take place. Only when it has scaled up on farmers' fields, IIAP can be considered a true success story.

3.7.1 Research and Development and Education in Indian Agriculture

Agricultural research and development (R&D) is the engine for both the sector's growth and poverty reduction in the country. The evolution of R&D in Indian agriculture started with the establishment of agricultural colleges in 1905 and the Indian Council of Agricultural Research (ICAR) in 1929. This was followed by the inception of the state agricultural universities (SAUs) during the 1960s and 1970s, which marked a significant shift towards growth in state funding (Pal 2017). Today, India has one of the largest agricultural research systems in the world. Led by the ICAR, the public research system has five multidisciplinary national institutes, 45 central research institutes, 30 national research centres (NRCs), four bureaus, ten project directorates, 80 All-India Co-ordinated Research Projects (AICRPs)/networks and 16 other projects/programmes. In addition, there are 29 state agricultural universities (SAUs) and one central agricultural university, which operate through 313 research stations (Gulati et al. 2018). The AICRPs involve about 1300 centres, of which about 900 are based in agricultural universities and 200 in the ICAR institutes. They act as the main link between the ICAR and the SAUs. The ICAR also has zonal research stations (ZRSs) and 200 substations (Gulati et al. 2018). The National Academy of Agricultural Research Management (NAARM) is another institution under the ICAR; it conducts research and training in agricultural research management. The ICAR has also established eight trainers' training centres (TTCs) and 611 *Krishi Vigyan Kendras* at the district level as innovative institutional models for assessment, refinement and transfer of modern agricultural technologies (Gulati et al. 2018).

It is worth noting that India's spending on total agriculture R&D in real terms (2011 prices) has increased from USD1904 million in 2000–01 to USD3298.37 million in

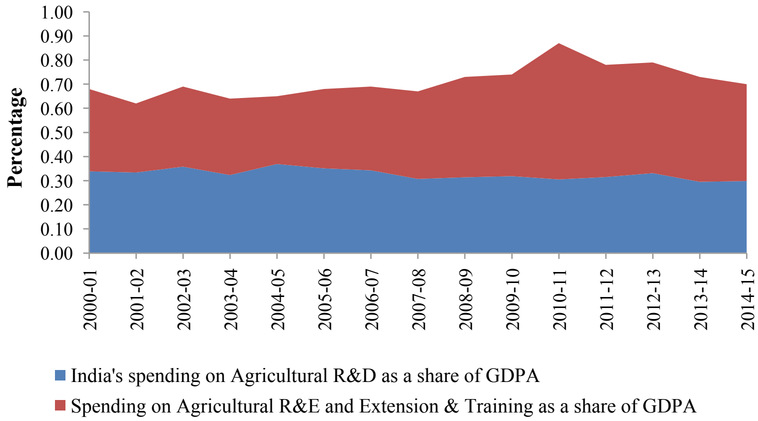

Fig. 3.21 Agriculture R&D and R&E and extension training (R&E and XT) expenditure as a share of GDPA in India. *Source* (ASTI 2016) and (Gulati et al. 2018)

2014–15 (ASTI 2016).[76] At the same time, R&D intensity, which is agricultural R&D expenditure as a percentage of gross domestic product from agriculture (GDPA), which was at 0.34% in 2000–01 increased marginally to 0.37% in 2004–05 and finally settled at 0.30% in 2014–15 (ASTI 2016). It is also observed that agriculture research and education (R&E) expenditure as a percentage of GDPA remained steady at 0.5% between 2000–01 and 2007–08; after that, it rose significantly and reached 0.7% of GDPA in 2010–11, settling down at 0.54% in 2014–15 (Gulati et al. 2018). The combined total public sector expenditure on R&E and extension and training (R&E and XT) as a percentage of GDPA stands at 0.7% of GDPA for the period 2014–15 (Fig. 3.21).

India's investment of 0.30% of the GDPA in agricultural research in 2014 compares poorly with that in countries like Bangladesh, China and Brazil. It was lower than in neighbouring Bangladesh (0.37%) and only half that invested by China (0.62%). Brazil invested a much higher share of 1.82% of GDPA in agricultural research (ASTI, IFPRI, various issues). While the government has set a target to invest 1% of GDPA on agricultural R&D, the target is unlikely to be met within the stipulated time frame (ASTI 2016) (Fig. 3.22).

Returns on R&D and Education Expenditure: The literature clearly highlights that compared to input and food subsidies, expenditure incurred on agricultural R&D and education and infrastructure is more powerful in alleviating poverty and spurring agricultural growth as this type of investment enables higher productivity. In a recent study by Perez and Rosegrant (2015) on investment in agricultural R&D, it is shown that strategies that incorporate R&D have the potential to raise agricultural total factor productivity (TFP) by 2% and lower the world prices of cereals and meat by as

[76] Data on privately performed agricultural research in India are not available; so it is excluded from the analysis.

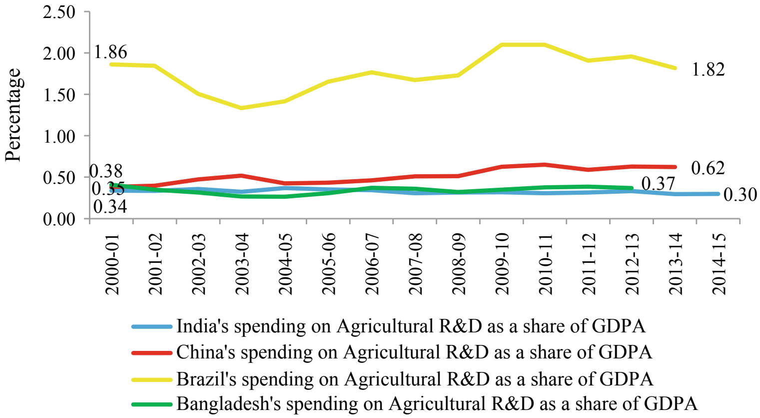

Fig. 3.22 Agricultural research intensity in India, China, Brazil and Bangladesh. *Source* ASTI, IFPRI (2016), various issues

much as 17% and 15%, respectively (Gulati and Terway 2018). Besides this, Gulati and Terway (2018), using a simultaneous equation model, discovered that marginal returns in terms of the number of people brought out of poverty to investments in research and education (R&E), roads and irrigation outweigh the benefits from input subsidies in power, fertiliser and irrigation. The number of people brought out of poverty per million rupees spent on fertiliser subsidy is only 26 compared to 328 people if an equivalent amount was to be spent on agricultural R&E. Similarly, the return on agricultural GDP per rupee spent is 0.88 for fertiliser subsidy as compared to 11.2 in agricultural R&E (Gulati and Terway 2018). Instances of enormous returns from agricultural R&D investments include Pusa Basmati 1121 and 1509, an innovation in basmati rice variety by the public research system, which yielded basmati exports of between USD4 and USD5 billion annually. Besides this, innovation of the sugar cane variety Co-0238 in Uttar Pradesh also yielded impressive returns. It led to a significant increase in the recovery ratio from about 9.2% in 2012–13 to more than 11% in 2019 (Gulati 2019a).

Role of the Private Sector in Agricultural R&D: In India, the private sector plays a vital role in agricultural transformation, accounting for 81.2% of gross capital formation (GCF) in agriculture in 2016–17 compared with an 18.8% contribution by the public sector. In a survey sponsored by the Syngenta Foundation (2011), it was found that 71 companies were active in research and agricultural product development in India: 22 in seeds, 19 in agrochemicals, ten each in fertiliser solutions and mechanisation (including irrigation), and ten in other areas, including agronomic research on specific crops. It is believed that these numbers have increased since then (Ferroni and Zhou 2018). Further, a study by Pray and Nagarajan (2012) estimated total private expenditure on agricultural R&D by local firms and multinationals in India at USD155 million and USD96 million, respectively, in 2008–09 (at 2005 prices) (Ferroni and Zhou 2018). Globally, private agri-business companies invest heavily in agricultural R&D. A study by Ferroni and Zhou (2016) estimated that the world's leading firms spend about 10% of their annual revenue in this area, of which the six largest companies spent USD7 billion on R&D in 2014. Monsanto leads the way, followed by Syngenta, Bayer, DuPont, BASF and Dow (Ferroni and Zhou 2018).[77]

Thus, given the higher marginal returns to every rupee of investment on R&D as compared to input subsidies, the government should first double the investments in agricultural R&E and infrastructure in the next five years to boost farm yields and alleviate poverty from the country in order to have a higher rate of agricultural growth on a sustainable basis. Private sector investments should also be encouraged by providing breeder's right and plant biotechnology protection with a favourable regulatory environment for widespread adoption of available technologies. This would benefit the country by unleashing innovation and the country's vast untapped agricultural potential (Ferroni and Zhou 2018).

3.8 Concluding Remarks

In this paper, we have tried to list the type of innovations in production technologies with large-scale impact on productivity that Indian agriculture has experienced in the past, and also those innovations that have been unfolding in recent years such as genome decoding, sequencing editing, precision agricultural practices, artificial intelligence, soilless farming systems, intensification in the case of rice and wheat, innovation in valuable broodstock and poultry farm management, which may influence Indian agriculture in the years to come. In particular, we have focused on innovations in seed technologies that led to the green and gene revolutions in India, innovations in institutions and technologies related to the logistics of milk that led to the white revolution and innovations in fishery and poultry, by importing high-yielding stocks and cross-breeding, and developing institutions of vertical integration and contract farming, etc., which have transformed these sectors. Further, we have looked at fruits and vegetables (F&V), especially innovations in UHDP in mangoes and bananas, and, in the case of bananas, the critical role of tissue culture that made India the largest producer of both bananas and mangoes. Similarly, in potatoes and onions, we have focused on how innovations helped increase production. These innovations have already had a large-scale impact on agricultural productivity and transformed Indian agriculture. The innovations that are now unfolding relate to the better use of water for irrigation (micro-irrigation), better use of fertilisers, especially urea; better use of farm machinery through "Uberisation" and the custom hiring model; the adoption of climate-smart, sustainable agricultural practices such as hydroponics, aeroponics, aquaponics and poly-houses; and the contribution of agricultural R&D and education in implementing these innovations. These innovations only give a flavour of what is happening in Indian agriculture. There is a

[77]Monsanto is now taken over by Bayer.

lot more on the ground where significant changes have occurred. This is reflected in the production of maize through hybrid seeds, and the "pink revolution" in the bovine meat sector that has made India the second largest exporter in the world. The bottom line is that these innovations in production technologies and institutions have turned India from a food-deficit country to one that is not only self-sufficient but also emerged as a net exporter of agricultural produce.

The innovations that have been unfolding in recent years and that are likely to accelerate in the years to come focus not only on increasing productivity and overall production, but also on better usage of water, fertilisers and farm machinery, so that efficiency can be promoted along with sustainability. Precision agriculture using UAVs/drones, the Internet of things and artificial intelligence is also making in-roads, though somewhat slowly.

Given the transformational role these innovations have played in the past and are likely to play in future, it is time for India to accord higher priority to research and development and education in the agricultural sector to allow dissemination of technologies to Indian farmers in a more systematic and affordable manner. The first step calls for an increase in investments (both public and private) in agricultural R&D and education, supported by appropriate policies and incentives. Secondly, to achieve a new phase of exponential growth, there is a need to support and adopt global technologies with conducive policies and regulations that protect innovators' interests as well as ensure farmers' access to the best technologies around the world.

Not only within India but also in a smallholder economies like Asia and Africa, where agriculture has been considered the backbone of the many countries, there is ample scope for replicating and scaling up these innovations to achieve holistic and inclusive growth in agriculture across such countries. Africa faces challenges such as diverse, rain-fed farming, far less irrigation potential and fertiliser consumption, poor infrastructure, low investment levels, limited access to markets and fragmented supply chains. Therefore, to increase productivity, ensure food security and improve cost efficiency, there is need to invest in fundamentals such as rural infrastructure, irrigation, agricultural research and extension, and climate-resilient technologies. Solar-driven irrigation models could be effective in building sustainable agriculture. The economics of solar as a third crop can be checked to enhance a farmer's income. To combat the deficiency of micro-nutrients in diets, innovations in bio-fortified staples could prove to be a game changer. Overall, to develop competitive agriculture, Africa should undergo marketing, as well as trade reforms. This will ensure better prices for farmers for their produce and enable them to cope with higher technological adaptation costs.

Appendix

See Table 3.4.

Table 3.4 Climate-resilient wheat and rice varieties released at central level

Wheat variety	Year of release/notification	Breeding institute	Characteristics	Recommended area	Source
HD 2987	2011	IARI Regional Research Station, Indore	Medium late maturing. Drought tolerance	N. Karnataka, S. Maharashtra. A.P and Tamil Nadu	https://nfsm.gov.in/StatusPaper/Wheat2016.pdf
HD 2985	2011	IARI Regional Research Station, Indore	Medium early maturing. Heat tolerance	Punjab, Haryana, Delhi, Rajasthan, Western Uttar Pradesh, parts of J & K (Jammu & Kathua Dist.) and parts of H.P. (Paonta Valley and Una Dist.	https://nfsm.gov.in/StatusPaper/Wheat2016.pdf
WH 1080	2011	CCS HAU, Hisar	Semi-dwarf, medium late, medium bold Seed rust resistance, drought tolerance	Punjab, Haryana, Delhi, Rajasthan, Western Uttar Pradesh, parts of J & K (Jammu & Kathua Dist.) and parts of H.P. (Paonta Valley and Una Dist	https://nfsm.gov.in/StatusPaper/Wheat2016.pdf
HD 3043	2012	IARI Regional Research Station, Indore	Medium late maturing, semi-dwarf, bold seed. Drought tolerance and resistance to leaf and yellow rust	Area stretching from Eastern UP onwards up to the far eastern states, viz. Bihar, Orissa, West Bengal, Assam and plains of NE region	https://nfsm.gov.in/StatusPaper/Wheat2016.pdf
AKAW 4627	2012	PDKV, Akola	Early maturing, medium dwarf, medium bold seed. Drought tolerance	Hilly regions of J & K (except Jammu & Kathua Dist.), hills of H.P. (except Paonta Valley and Una Dist.) and Uttarakhand	https://nfsm.gov.in/StatusPaper/Wheat2016.pdf

(continued)

Table 3.4 (continued)

Wheat variety	Year of release/notification	Breeding institute	Characteristics	Recommended area	Source
DBW-107	2014	DWR, Karnal	Tolerant to heat stress; higher disease resistance.	Area stretching from Eastern UP onwards up to the far eastern states, viz. Bihar, Orissa, West Bengal, Assam and plains of NE region	https://nfsm.gov.in/StatusPaper/Wheat2016.pdf
HDCSW 18	2015	ICAR	It has genetic yield potential of more than 7t/ha. It is resistant to high temperature at seedling stage. It escapes high temperature at maturity due to early seeding	NCR/Delhi state	https://icar.org.in/node/3972
Rice variety	**Year of release/notification**	**Breeding institute**	**Characteristics**	**Recommended area**	**Source**
Shabhagidhan (IR 74371-70-1-1-CRR-1)	2011	CRRI	High drought tolerance and average productivity of 3.8–4.5 t/ha	Jharkhand and Odisha	https://crri.icar.gov.in/popular_var.pdf
Jayantidhan (CR Dhan 503)	2011	CRRI	Can tolerate up to one metre water stagnation	Coastal saline area of Odisha	https://crri.icar.gov.in/popular_var.pdf
Phalguni (CR Dhan 801)	2017	ICAR	Submergence and drought tolerant	Andhra Pradesh, Telangana, Odisha, Uttar Pradesh, West Bengal	https://crri.icar.gov.in/popular_var.pdf

Source ICAR-IARI (2018), NICRA (2018)

See Figs. 3.23 and 3.24.

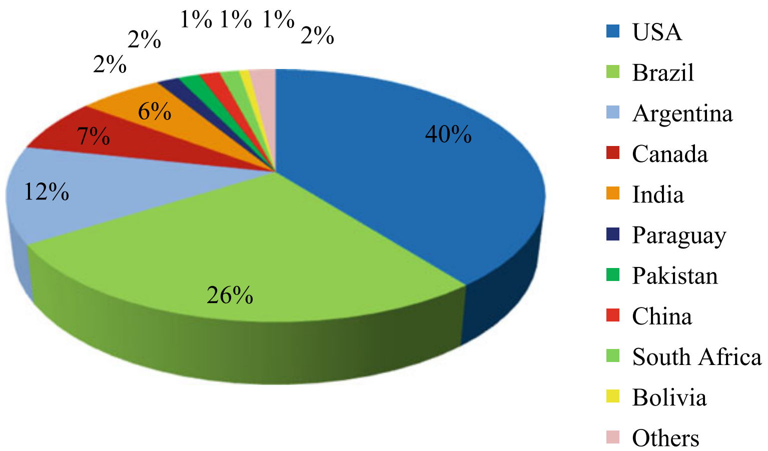

Fig. 3.23 Country-wise share of global area under biotech/GM crop. *Source* ISAAA (2017a, b, c)

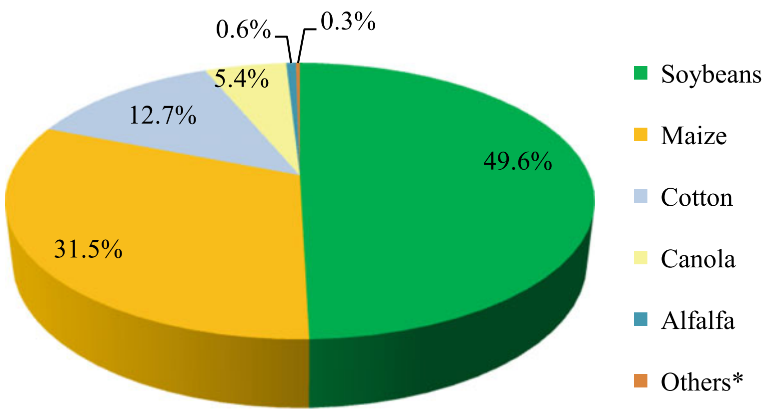

Fig. 3.24 Crop-wise share of global area under biotech/GM crops (total area under biotech/GM crops = 189.8 Mha). *Source* ISAAA (2017a, b, c). *Note* Others include biotech squash, potato, eggplant, papaya, sugar beet and apples

See Table 3.5

Table 3.5 List of agricultural centres of excellence under the Indo-Israel Agricultural Project (IIAP)

State	District	Produce
Bihar	Vaishali	Mango and litchi
	Nalanda	Vegetables
Gujarat	Junagadh	Mango
	Vadrad, Sabarkantha	Vegetable-protected cultivation
	Nani Reladi, Bhuj	Date and banana-palm post-harvest management
Haryana	Gharaunda, Karnal	Vegetables
	Mangiana	Fruits
	Kurukshetra	Beekeeping
	Hisar	Animal husbandry and milk
	Ladwa	Mango
	Hisar	Flowers
Karnataka	Kolar	Mango
	Bagalkot	Pomegranate
	Dharwad	Vegetables
Maharashtra	Dapoli	Alfonso mango
	Nagpur	Citrus
	Rahuri	Pomegranate
	Aurangabad	Kesar mango
Punjab	Ghanora and Hoshiarpur	Fruits
	Jalandhar	Vegetables
Rajasthan	Kota	Citrus
	Bassi	Pomegranate
	Jaisalmer	Date Palm
	Bassi	Vegetables
Tamil Nadu	Thally and Krishnagiri	Flowers
	Reddiyar Chathram, Dindigul	Vegetables
Uttar Pradesh	Basti	Vegetables
	Basti	Mango
	Kannauj	Vegetables

Source MASHAV (2016)

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