Journal of Agricultural Science and Technology B 8 (2018) 473-482
doi: 10.17265/2161-6264/2018.08.001

Innovations and Revolutions in Indian Agriculture: A Review

Ashok Gulati and Ritika Juneja

Indian Council for Research on International Economic Relations (ICRIER), 110003, New Delhi, India

Abstract: With a population of 1.35 billion to feed in 2018, innovations in Indian agriculture all along the value chains are critical to develop sustainable, productive and profitable agriculture. In this brief paper, focus is laid on innovations in various production technologies, farming practices, policies and institutional engineering that had significant impact in raising production and have been termed as revolutionary. For instance, Green Revolution is identified with significant changes in production of wheat and rice; White Revolution in milk; Blue Revolution in fisheries; Red Revolution in poultry meat and eggs; Golden Revolution in fruits and vegetables; Gene Revolution in cotton. The paper not only looks at these innovations and their impact in the past, but also peeps into innovations that are currently unfolding in other inputs in production processes such as in water use (irrigation), fertilizers usage, maintaining soil health, using farm machinery optimally in a small holder dominated agriculture. The key message of this paper is what can be achieved with small holders when innovations that are science based and are backed by right policies, are adopted.

Key words: Indian agriculture, innovations, revolutionary, small holders.

1. Introduction

The term "innovation" can be defined as a new idea, a new device, a new process or a new product, which breaks into society and/or markets creating more value than the existing ways and products of doing the same thing. But it is not necessarily an invention, which is more fundamental in terms of change [1]. Accordingly, in agriculture, there could be innovations in seeds that give higher productivity, protect plants from pests, are climate resilient, may even contain more minerals, vitamins and proteins; there could also be innovations in application of water (irrigation), fertilizers, pesticides etc., which can give higher value from less quantities/costs. There could be innovations in farming practices that not only give higher productivity, but could save on costs or promote sustainable agriculture that can better withstand climate change [2]. In fact, innovations can go much beyond production technologies and get into the space of institutions that ensures effective implementation of policies, into storage, logistics that could save on massive wastages of food and into better marketing of goods and services bringing higher value. Thus, innovations can spread all along the agri-value chains of food, feed and fiber, from farm to fork, or more aptly in a demand driven system, from "plate to plough" [3].

It is important to recognize that starting from mid-1960s, Indian agriculture has made significant strides in the production of cereals, milk, fisheries, poultry, fruits and vegetables and lately in cotton, where innovations in seed technologies (by public and private sector); innovations in policies and institutions, played instrumental role in driving the transformation. This paper lists major transformations in Indian agriculture and deciphers the nature of innovations that were introduced, along with the politico-economic environment around those innovations and also peeps into innovations that are currently unfolding in inputs and production processes.

Corresponding author: Ashok Gulati, professor, research fields: markets, trade, institutions, water, value chains, innovations.

This paper is a part of larger study for a book on "Innovations in Indian, Chinese and Israeli Agriculture—Lessons for Africa." The support from Syngenta Foundation is greatly appreciated.

2. Innovations and Revolutions

2.1 Green Revolution (Wheat and Rice)

Indian agriculture has been an industry of constant innovations. India inherited acute food scarcity after independence in 1947. In mid-1960s, it was caught in a back to back drought. Grain production dropped by 17 million metric tonnes (MMT) from 89.4 MMT in 1964-1965 to 72.4 MMT in 1965-1966 [4]. Entire foreign exchange reserves of the country could not have bought more than 7 MMT of wheat on commercial basis. Imports of grain from the United States of America under PL 480 touched 11 MMT in 1965-1966 and Indian food situation became “ship-to-mouth” story [5]. It was appealed over the radio to the nation to “miss a meal” every week and save food for those in scarcity-stricken areas [6]. Against this backdrop, India imported 18,000 tonnes of high yielding varieties (HYV) of wheat from Mexico—Lerma Rojo 64-A and Sonora 64, that ushered in the famous Green Revolution in India. Key to success was not only innovative “miracle seeds” developed by Norman E. Borlaug [7] but also institutional reform brought about through creation of Food Corporation of India (FCI) and Agricultural Prices Commission (APC) in 1965. The twin institutions ensured food security for the country as well as remunerative prices to farmers adopting these new seeds [8]. Extensive irrigation and fertilizer usage, along with adaptation of imported germplasm to innovate indigenous varieties like Kalyan Sona and Sonalika aided in the spread of Green Revolution in India. High yielding rice (HYR) seeds—IR 8 developed by Peter Jennings and Henry M. Beachell were imported from International Rice Research Institute (IRRI). In-house crash breeding program under All India Coordinated Research Project (AICRP) worked continuously to further increase rice yields and produced Padma and Jaya, first Indian HYR varieties. IR 8 and Jaya formed the backbone of India’s revolution in rice [9]. Though, the gains in rice production were more gradual and much lower compared to gains in wheat production at all India level but Punjab’s (non-rice eating state) favorable climatic conditions and availability of adequate water resulted in major breakthrough in both rice production and productivity. Nevertheless, India today is the second largest producer of wheat, hitting a century with 99.7 MMT in 2017-2018 and rice with 112.9 MMT (Fig. 1) [10], next only to China, and also the largest exporter of rice with about 12.7 MMT of rice exports in 2017-2018 valued at USD 7.7 billion [11]. Other innovations in seeds and farming technologies especially in rice production such as introduction of early maturity and high valued Basmati (Pusa Basmati 1121 and Pusa Basmati 1509), System of Rice Intensification (SRI), rice hybridization program, direct seeding, zero tillage, etc. are largely contributing towards improved yields and efficient resource management.

Indian Council of Agricultural Research (ICAR), through its independent research, has released zinc and iron rich wheat (WB 02 and HPWB 01) with yields more than 5 tonnes per hectare (t/ha), high protein and zinc rice (viz. CR Dhan 310 and DRR Dhan 45) [12]. Globally, HarvestPlus program of Consultative Group on International Agriculture Research (CGIAR) is also doing lot of work in this direction. In Uttar Pradesh, Bihar and Jharkhand, they have released high yielding (HY) zinc rich wheat BHU-3 and BHU-6 (Chitra) that can provide up to 50% of daily zinc needs [13]. Also, a research team from National Agri-Food Biotechnology Institute (NABI), India led by Monika Garg, has pushed frontiers and innovated bio-fortified black, blue and purple wheat (non-genetically modified) through crosses between HY Indian cultivars and colored wheat from Japan and America which are rich in anthocyanins (40-140 parts per million) and zinc (35-38 mg/100 g of wheat) [14].

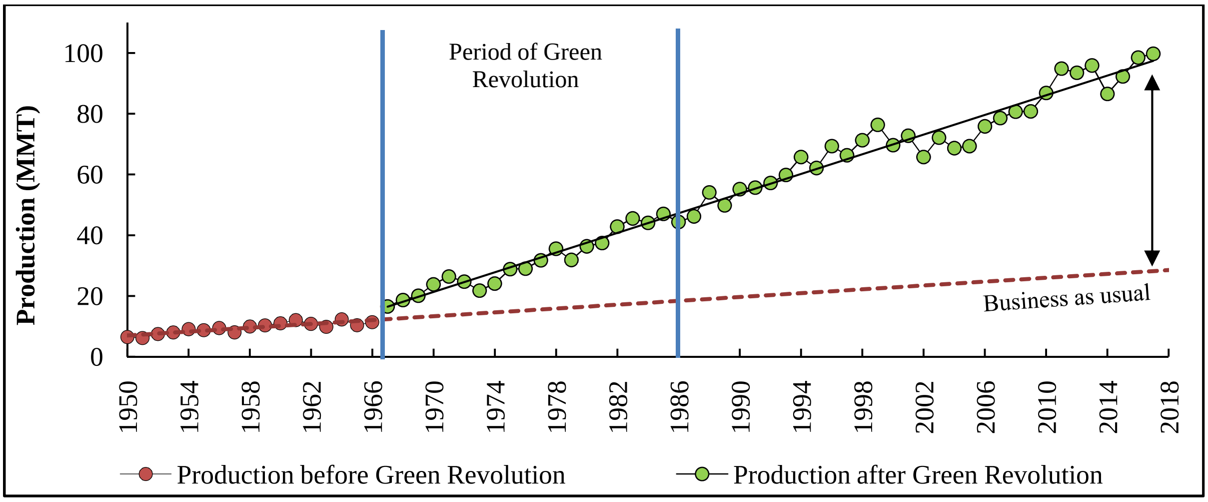

Fig. 1 All India wheat production [4].

This is a great move towards nutritional security, as these innovations in bio-fortified foods can help alleviate malnutrition only when they are scaled up with supporting policies, including augmented expenditure in agri-research and development, with due accountability to deliver. Recently, a group of scientists and breeders around the world under International Wheat Genome Sequencing Consortium (IWGSC) have decoded the complex wheat genome, which is a major scientific breakthrough in the history of agriculture. Genome identification will potentially help countries to develop highly productive, biotic and abiotic stress tolerant, and pest/disease resistant grains. If science is trusted with human face, the best is yet to come!

2.2 White Revolution (Milk)

Another big transformational change in Indian agriculture came through institutional innovation of Operation Flood (OF) that ushered in the White Revolution during 1970s through mid-1990s and policy innovation of de-licensing the dairy sector in 2002, which has made India today the largest producer of milk in the world with 176.4 MMT in 2017-2018, up from 17 MMT in 1950-1951 (Fig. 2), leaving USA (97 MMT) and China (45 MMT) behind [15]. Verghese Kurien, who steered this "Operation Flood", innovated the institutions of small holders for milk collection through a farmers' cooperative structure, putting milk in bulk coolers, pasteurizing and homogenizing that milk through cooperative owned milk plants, and distributing that milk to mega cities through innovative logistics and organized retail distribution network [16].

Further, to keep pace with rising demand for milk from rapidly growing population, innovations in productivity augmentation of in-milk animals through artificial insemination and more recently through selective sex semen technology are becoming popular. The selective sex semen technology is about predetermining the sex of offspring by sorting X and Y chromosomes from natural sperm mix. In a country like India where less than 50% cows/buffaloes are productive, this innovation is of great relevance as it can help farmers grow their herds internally by reproducing female progeny. This in turn will reduce dairy animal population and save rearing costs by eliminating the birth of male offspring on one hand and by increasing production of genetically improved, high milk producing females at a faster rate on the other [17]. Under the strategy female cattle are produced with more than 90% probability, instead of 50% in case of unsorted semen, and the conception rate is around 45% [18].

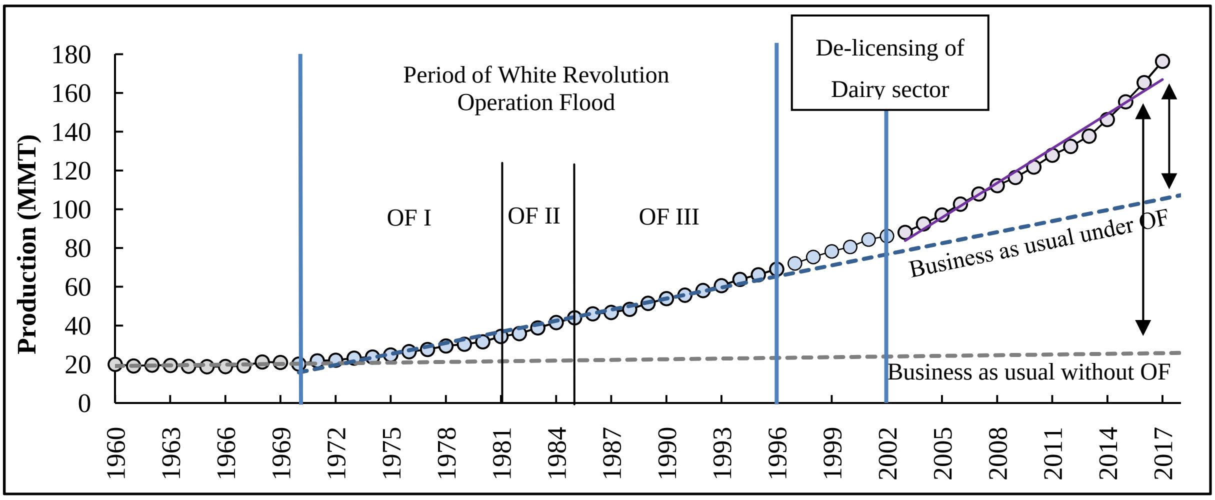

Fig. 2 All India milk production and phases of Operation Flood (OF) [15].

2.3 Blue Revolution (Fisheries)

During late eighties, India experienced its Blue Revolution in fishery sector. India has a long coastline that stretches over 8,129 km encompassing an exclusive economic zone of 2.02 million square kilometers and varied fisheries resources comprising rivers and canals (191,024 km), reservoirs (3.15 million hectares), ponds and tanks (2.35 million hectares) etc. [19]. The real turn around in fisheries came from innovations in the development of genetically improved brooding stock, which led to the emergence of intensive carp culture (especially common carp—rohu, catla, mrigal, trout and mahseer) during mid-1980s [20]. In marine segment, innovations in motorization of indigenous crafts and mechanization of boats with trawl nets led to scaling up of operations. But inland fish production witnessed much higher growth compared to marine fish production. Total production touched 11 MMT during 2016-2017 up from 0.75 MMT during 1950-1951 (Fig. 3) [21]. With the introduction of *Litopanaeus vannamei* (Whiteleg shrimp) cultivation in India during 2008-2009, export demand of marine products picked up. At present, India is the second largest producer of fisheries in the world and sea food exports constitute the second largest share in the total agri-exports from India after rice, accounting for more than USD 7 billion in 2017-2018 [21], which gave a real boost to fishery sector's growth.

2.4 Red Revolution (Poultry Meat and Eggs)

Since 2000-2001, India's poultry industry experienced significant shift in the structure and scale of operation leading to Red Revolution. Policy innovations such as liberalization of imports of grandparent poultry stock [22], vertical integration of poultry operations and contract farming model between large integrators and small farmers, transformed the poultry sector from a mere backyard activity into a major organized commercial one [23, 24]. Globally, India is today the number three in layers (eggs) production at 88 billion eggs (accounting for 5% of the world production) and number five in broilers (poultry meat) production at 3.4 MMT (accounting for 3% of the world production) (Fig. 4), with almost 80% production coming from organized commercial farms [25].

In addition, the poultry meat consuming population in the country has risen dramatically from a meagre 8% in 1993-1994 to 38% in 2011-2012 [26].

2.5 Gene Revolution (Cotton)

In case of fiber, release of Bt cotton technology in 2002, the only genetically modified (GM) crop released so far in the country, paved the way for the Gene Revolution. It has made the country, the largest producer with an estimated 37.2 million bales production

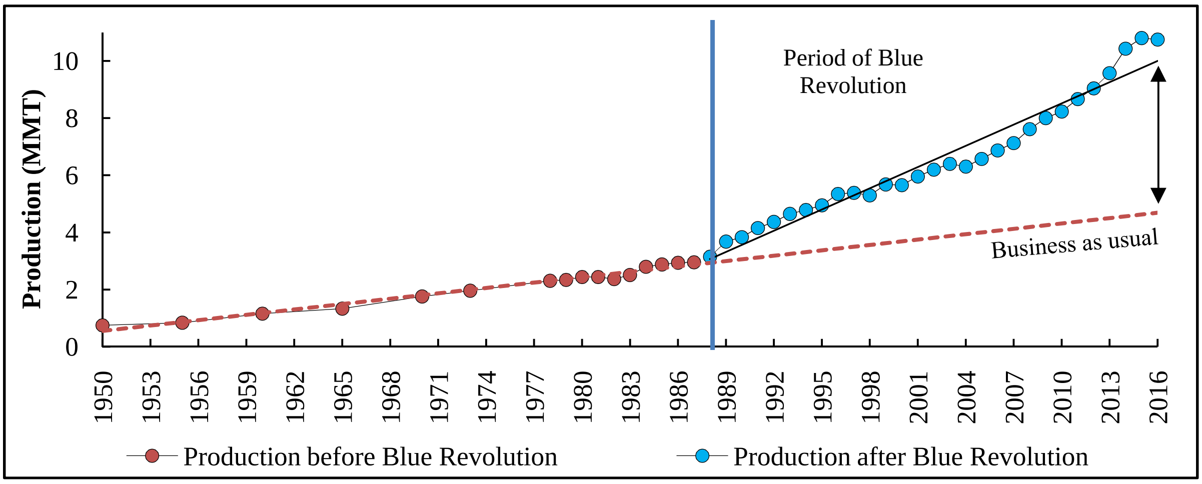

Fig. 3 All India fish production (inland and marine) [15].

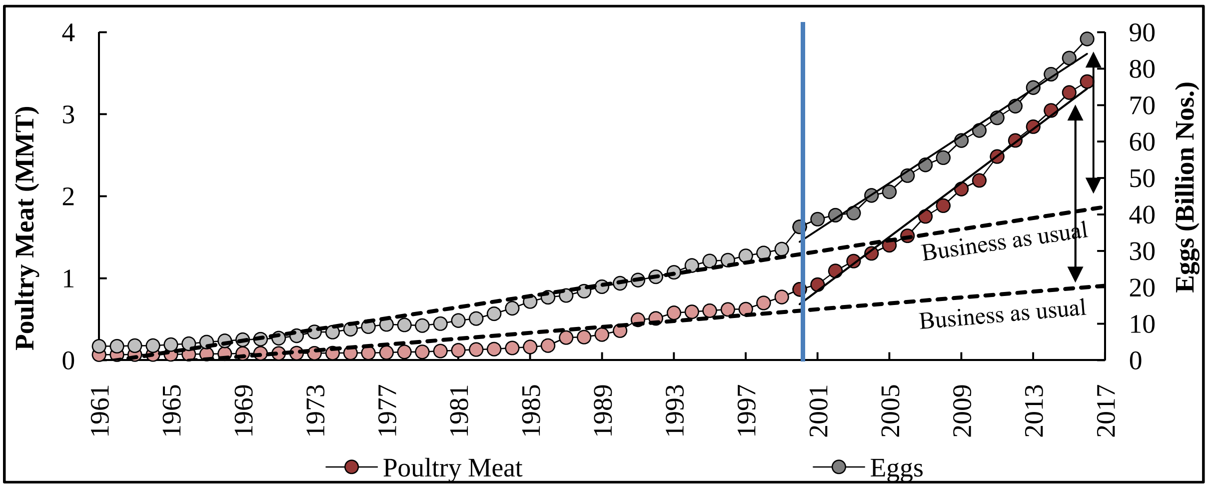

Fig. 4 All India egg and poultry meat production [15].

in 2017-2018 (Fig. 5) [27, 28] and second largest exporter of cotton in the world with 93.14% cotton area is under Bt cotton [29]. In an ongoing impact evaluation study by Indian Council for Research on International Economic Relations (ICRIER), it is estimated that the cumulative gain from import savings, extra raw cotton export and extra yarn export—compared to the business-as-usual scenario—between 2003-2004 to 2016-2017 is USD 67.4 billion at the all-India level [30].

2.6 Golden Revolution (Fruits and Vegetables)

During 2004-2005, with the implementation of the National Horticulture Mission (NHM), India experienced Golden Revolution in its fruits and vegetable segment of agriculture, but not as significant as compared to the Green Revolution of mid-1960s and the White Revolution of 1970s. Total fruits and vegetables production increased from 28.6 MMT in 1991-1992 to 97.05 MMT in 2017-2018 and from 58.5 MMT in 1991-1992 to 179.7 MMT 2017-2018, respectively, jump of 68 MMT in fruits and 122 MMT in vegetables in just 26 years [31]. Systematic research work under public institutions such as ICAR, Indian Institute of Horticultural Research (IIHR), Central Institute for Subtropical Horticulture (CISH) etc. led the way towards cultivation of HY hybrid fruit and vegetable crops [32]. Innovations in tissue culture, ultra high density plantation (UHDP), drip fertigation,

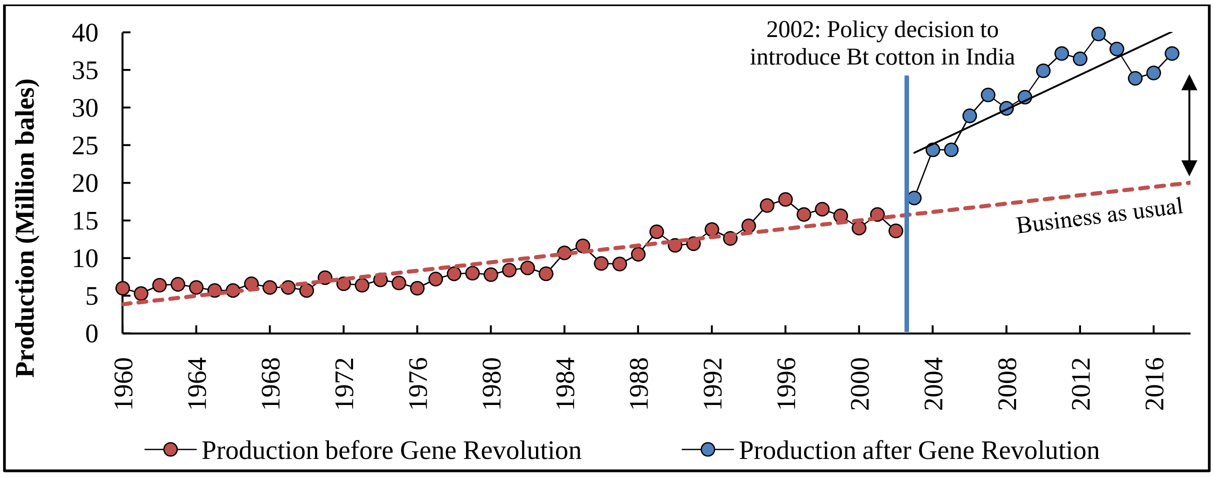

Fig. 5 All India cotton production [27, 28].

aeroponic system, etc. contributed majorly to this structural shift and record setting production [32]. Globally, India today has the second place in production of fruits and vegetables, next only to China. Also interestingly, India's horticulture production (306.81 MMT in 2017-2018) exceeds its grain production (284.83 MMT in 2017-2018) [33].

Further, under Indo-Israeli Agricultural Project (IIAP) implemented by Mission for Integrated Development of Horticulture (MIDH) and MASHAV—Israel's Agency for International Development Cooperation, innovations in protected and precision agriculture in India have been prioritized. About 30 centres of excellence have been set up across the country (some are operational while others in pipeline) that are run collaboratively by Indian and Israeli experts for different horticulture crops [34].

These are likely to show an impact in the years to come once their economic viability is ensured. This model, if it succeeds, can also be a model for several African countries.

3. Innovations in Input Technologies

3.1 Micro-irrigation

In India, almost 54% of area faces high to extreme water stress. Of the total fresh water resources of the country, agriculture consumes more than 78% of water [35]. Given the extent of water stress and severely low water use efficiency (as low as 40%-49%) under surface and groundwater irrigation through conventional application practices like flood irrigation in the country, innovations in micro-irrigation technologies (such as sprinkler and drip), accompanied by solar pump sets, hold the potential for improving water use efficiency (85%-90%) and saving energy. A good beginning in this direction has already been made with a steady growth in micro-irrigation (penetration of drips and sprinklers) at the rate of 9.07% annually from 2005-2006 to 2017-2018, with more than 10 million hectares area under micro-irrigation in 2017-2018. In the extensive field trials conducted by Jain Irrigation Systems Ltd. (JISL) on more than 25 economic and cash crops using drip irrigation and fertigation technology, it was reported that the water requirement of water guzzling crops like, rice sugarcane, banana and cotton under drip has been reduced to 45%-50% less than what it is under flood irrigation. JISL also demonstrated that "more than 50% water could be saved as compared to conventional flood irrigation and yield can be increased to 25%-30% more" [36]. But more and better innovations in water use are yet to come.

Solar pump sets, replacing diesel pump sets, could be a game changer innovation in saving costs of irrigation and improving profitability in cultivation, as the per kWh cost of pumping groundwater through diesel pump sets is about four times higher than through solar pump sets. But the problem is the initial high capital cost associated with the solar pump sets (about Rs 4 lakhs for a 5 HP pump). Here, innovation in uberization or custom hiring of solar pump sets operating under the principle of "pay as you go" makes better economic sense. This model is operational in some districts of Bihar running by a company named Claro Energy. Claro claims that savings in irrigation cost in mobile solar pumps in comparison to the diesel pumps comes to around 30%-60%. Solar trees as the third crop on farmers' fields could also be a promising innovation in this regard.

3.2 Uberization of Farm Machinery

In India, small holding land size (1.08 ha in 2015) pose serious challenges for adoption of modern technologies and farm mechanization. Given that agriculture labor is becoming expensive, India is at an inflexion point of making major strides in the use of farm machinery. After rental cars and bikes, the on-demand business model of "Uberization" of farm machinery and equipments, such as harvest combines and tractors, etc. is an innovative arrangement that make mechanization accessible and affordable to small farmers on the basis of "pay as per use" principle [37]. As part of the Sub Mission on Agricultural Mechanization (SMAM) guidelines brought out in 2014, Government of India (GoI) has introduced Custom Hiring Centres (CHCs) comprising of set of farm machinery, implements and equipments (such as tractors, power tillers, combine harvesters, etc.) for renting out to farmers. Government provides subsidy (40% up to one million) for each CHC to the entrepreneurs willing to set up these CHCs who are required to invest margin money and the remaining amount is financed through bank loans [37, 38]. Till 2015-2016, 711 CHCs have been established across India. Additionally, 41 hi-tech machinery hubs for high value crops like sugarcane, cotton, etc. have also been set up [38]. At the state level, government of Karnataka, Andhra Pradesh, Madhya Pradesh, Uttar Pradesh and Punjab are promoting CHCs on public private partnership (PPP) model with rising start-ups namely EM3, Trringo, FarMart, TAFE, etc. coming forth [37].

3.3 Soil Nutrient Management

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 2000-2001 to 29.6 MMT in 2016-2017 [39]. On per hectare (ha) basis, consumption of urea at all India level increased from 103.5 kg/ha to 149.3 kg/ha over the same period [40]. However, the imbalanced use of nitrogen in relation to phosphate and potash leads to environmental problems such as soil degradation, water pollution and greenhouse gas emission. To combat these challenges, GoI launched two schemes: one, Neem Coating of Urea (NCU) and two, Soil Health Cards (SHCs). According to the experts, application of NCU slows down release of nitrogen from urea and reduces loss due to leaching. It thus economizes the quantity of urea required by crops and improves nitrogen use efficiency (NUE) of the soil. As per data from the fertilizer statistics, production of NCU supported and driven by policy change has recorded an exponential growth over a period of 10 years from 0.6 MMT in 2006-2007 to 24.2 MMT in 2016-2017 [40]. As to further encourage production as well as availability of neem coated fertilizers in the country, GoI on May 25, 2015 made it mandatory to neem coat 100% of urea produced and imported—India is perhaps the first country to do it. In a study titled "Impact of Neem Coated Urea on Production, Productivity and Soil Health in India (2017)", conducted by the Agricultural Development and Rural Transformation Centre (ADRTC) under Institute of Social and Economic Change (ISEC) for Directorate of Economics and Statistics (DES), Ministry of Agriculture, it is observed that NCU led to an increase in yields by 38% in soybean, 34% in red gram, 8% each in paddy and maize, 5% in sugarcane and 3% in jute crops.

On the other hand, under the SHCs scheme (announced by GoI on February 19, 2015), soil samples are to be collected twice a year—when there is no standing crop in the field, generally after the harvesting of Rabi and Kharif crops. Thereafter, samples are drawn from grids using Global Positioning System (GPS) tools and revenue maps. After testing the status of soil, recommendation on the dosage of fertilizers are made. During cycle I (2015-2016 and 2016-2017), 100 million SHCs were distributed. In the impact assessment report (conducted for three crops namely paddy, cotton and soyabean) submitted by the National Institute of Agricultural Extension Management (MANAGE) to GoI, it was analyzed that fertilizer use declined after the intervention and the percentage decline in nitrogeneous fertilizers is greater than the percentage decline in phosphatic or potassic fertilizers. Therefore, both the approaches (NCU and SHCs) are working towards ensuing improved soil management and efficient use of fertilizers. However, more impact evaluation studies by the third party are needed to further quantify impact of these innovations.

4. Conclusions

In this paper, emphasis has been laid on the types of innovations in production technologies that Indian agriculture has experienced in the past with large scale impact, and also those innovations that are unfolding in recent years, which may influence Indian agriculture in the years to come. In particular, focus was on innovations in seed technologies that led to Green Revolution and Gene Revolution in India; innovations in institutions and technologies related to logistics of milk that led to White Revolution. Innovations in fishery and poultry, by importing HY breeding stocks, developing institutions of vertical integration and contract farming, etc., which have transformed these sectors. Further, the paper also looked at fruits and vegetables, especially innovations in UHDP in mangoes and in case of bananas the critical role of tissue culture, making India the largest producer of bananas as well mangoes. Similarly, in potatoes and onions, how innovations have helped increase their production. These innovations have already shown large scale impact and transformed Indian agriculture. The innovations that are unfolding now relate to better use of water for irrigation (micro-irrigation), better use of fertilizers, especially urea, and better use of farm machinery through “Uberization” model. These innovations give only a flavor of what is happening in Indian agriculture. There is a lot more on the ground where significant changes have occurred. One can see that happening in the production of maize through hybrid seeds, Pink Revolution in bovine meat sector that has made India the largest or 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 a net exporter of agri-produce. The innovations that are unfolding in recent years and that are likely to accelerate in the years to come are focused not only in increasing productivity and overall production, but also ensuring better usage of water, fertilizers and farm machinery so that efficiency can be promoted along with sustainability. Precision agriculture in poly houses is also making in-roads, though somewhat slowly.

Given the transformational role that innovations have played in the past and likely to play in the future, it is high time for India to give a higher priority in developing “innovative models and packages” that can be disseminated to farming community in a more systematic manner not only within India but also to say farmers in Africa who have small holdings and much less irrigation and fertilizer consumption.

Acknowledgments

The authors express their gratitude to Rajat

Kathuria, director and chief executive, ICRIER, for providing the opportunity to work in this area. They would also like to thank Dr. Arun Kumar Joshi, CIMMYT Asia Regional Representative; T. Nanda Kumar, former chairman, National Dairy Development Board (NDDB) and former secretary, Ministry of Agriculture, GoI; Dr. Sujit Nayak, additional commissioner, Poultry, Ministry of Agriculture, GoI; Dr. R. P. Gupta, chief consultant, Horticulture Division, Ministry of Agriculture, GoI, for their guidance and assistance in collating integral information.

References

[1] Business Dictionary. 2018. "Innovation Definition." Accessed December 7, 2018. http://www.businessdictionary.com/definition/innovation.html.

[2] Monsanto. 2018. "Moving Agriculture Forward with Innovation." Accessed December 12, 2018. https://monsanto.com/innovations/.

[3] Initiatives of Change Centre for Governance (ICCfG). 2016. "Issues in Agriculture." Lecture Series 15. New Delhi.

[4] Directorate of Economics and Statistics (DES). 2016. "Agricultural Statistics at a Glance." Ministry of Agriculture and Farmers Welfare, Government of India, New Delhi.

[5] Chopra, R. 1981. "Evolution of Food Policy in India." Macmillan India Limited.

[6] Sherman, T. C. 2013. "From 'Grow More Food' to 'Miss a Meal': Hunger, Development and the Limits of Post-Colonial Nationalism in India, 1947-1957." *Journal of South Asian Studies* 36 (4): 571-88.

[7] Gulati, A. 2014. "Grain of Truth: The Green Revolution." Agrikhalsa.

[8] Maitra, R. 1991. "How India Became Self-Sufficient in Food." *Executive Intelligence Review (EIR)* 18 (27): 22-30.

[9] Dalrymple, D. G. 1985. "The Development and Adoption of High-Yielding Varieties of Wheat and Rice in Developing Countries." *American Journal of Agricultural Economics* 67: 1067-73.

[10] Agricultural Statistics Division. 2018. "Fourth Advance Estimates of Producution of Commercial Crops for 2017-18." Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, Government of India, New Delhi.

[11] Agricultural and Processed Food Products Export Development (APEDA). 2017. "India Export of Principal Commodities." Accessed September 12, 2018. http://agriexchange.apeda.gov.in/indexp/18headgenReportmonth_combine.aspx.

[12] Indian Council of Agricultural Research. 2017. "Bio Fortified Varieties: Sustainable Way to Alleviate Malnutrition." Government of India, New Delhi.

[13] HarvestPlus. 2017. "HarvestPlus Improves Nutrition and Public Health in India by Promoting Pearl Millet That Provides More Iron and Wheat That Provides More Zinc in the Diet." Accessed October 29, 2018. https://www.harvestplus.org/where-we-work/india.

[14] Sharma, S., Chunduri, V., Kumar, A., Kumar, R., Khare, P., Kondepudi, K. K., Bishnoi, M., and Garg, M. 2018. "Anthocyanin Bio-fortified Colored Wheat: Nutritional and Functional Characterization." *PLOS ONE* 13 (4): e0194367. doi: 10.1371/journal.pone.0194367.

[15] Department of Animal Husbandry, Dairying and Fisheries. 2017. "Basic Animal Husbandry and Fisheries Statistics." Government of India, New Delhi. Accessed September 20, 2018. http://www.dahd.nic.in/sites/default/filess/Tables%20of%20BAH%26amp%3BFS%202017%20%281%29.pdf.

[16] Kurien, V. 2005. "I Too Had a Dream." Roli Books Pvt. Ltd., New Delhi.

[17] BAIF Development Research Foundation. 2015. "Application of Biotechnology for Enhancing Dairy Production." *The BAIF Journal* 39 (1): 6-8.

[18] Mohteshamuddin, K. 2017. "Sexed Semen Technique: A Revolution in Indian Dairy Industry." *Agrotechnology* 6 (3): e117.

[19] National Fisheries Development Board. 2016. "About Indian Fisheries." Government of India. New Delhi. Accessed June 01, 2018. http://nfdb.gov.in/about-indian-fisheries.htm.

[20] Mahapatra, B. K. 2014. "Dr. Hiralal Chaudhuri—Legendry Father of Induced Breeding of Fish is No More." Fishing Chimes, 6-7.

[21] Press Information Bureau (PIB). 2017. "India Becomes Second Largest Fish Producing Country in the World." Ministry of Agriculture and Farmers Welfare, Government of India, New Delhi. Accessed May 13, 2018. http://www.pib.nic.in/newsite/mbErel.aspx?relid=173699.

[22] Mehta, R. 2003. "The WTO and the Indian Poultry Sector." Asia Pacific School of Economics and Government.

[23] Mehta, R., and Nambiar, R. G. 2007. "The Poultry Industry in India." The Food and Agriculture Organization (FAO), Bangkok.

[24] Manjula, K., and Saravanan, G. 2015. "Poultry Industry in India under Globalised Environment—Opportunities

and Challenges." *International Journal of Scientific Research* 4 (8): 391-3.

[25] Department of Animal Husbandry, Dairying and Fisheries. 2017. "National Action Plan for Egg and Poultry—For Doubling Farmers' Income by 2022." Ministry of Agriculture and Farmers Welfare, Government of India, New Delhi.

[26] Gulati, A., and Verma, S. 2016. "From Plate to Plough: A Clear Trend towards Non-vegetarianism in India." The Indian Express. Accessed September 15, 2018. https://indianexpress.com/article/opinion/columns/india-diet-indian-palate-non-vegetarian-vegetarianism-3099363/.

[27] United States Department of Agriculture (USDA), Foreign Agricultural Service. 2017. "Production, Supply and Distribution Online Data." Accessed July 9, 2018. https://apps.fas.usda.gov/psdonline/app/index.html#/app/downloads.

[28] Agriwatch. 2018. "Cotton News: USDA Estimates 2018-19 India's Cotton Output Down by 2%." Accessed February 21, 2019. http://www.agriwatch.com/newsdetails.php?USDA-estimates-2018-19-Indias-Cotton-output-down-by-2%&st=NEWS&commodity_id=24&sid=471851.

[29] Directorate of Cotton Development. 2017. "Status Paper of Indian Cotton." Ministry of Agriculture and Farmers Welfare, Government of India, Nagpur.

[30] Gulati, A., and Juneja, R. 2018. "From Plate to Plough: Timidity and Technology." The Indian Express. Accessed December 6, 2018. https://indianexpress.com/article/opinion/columns/indian-cotton-growers-farmers-cotton-crop-cotton-farming-narendra-modi-govt-5292899/.

[31] National Horticulture Board. 2018. "Area and Production of Horticulture Crops—All India, 3rd Advance Estimates." Government of India, New Delhi.

[32] Chadha, K. L. 2016. "Horticultural Sciences." In *100 Years of Agricultural Sciences in India*, National Academy of Agricultural Sciences, New Delhi, 522.

[33] National Horticulture Board. 2017. "Horticulture Statistics at a Glance." Department of Agriculture Cooperation and Farmers Welfare, Government of India, New Delhi.

[34] MASHAV. 2016. "The Indo-Israeli Agricultural Project." Israel's Agency for International Development Cooperation, New Delhi.

[35] Sharma, B. R., Gulati, A., Mohan, G., Manchanda, S., Ray, I., and Amarasinghe, U. 2018. *Water Productivity Mapping of Major Indian Crops.* NABARD-ICRIER Report, New Delhi.

[36] Soman, P., Prasad, M. S., Balasubramaniam, V. R., Singh, S., Dhavarajan, C., Patil, V. B., and Sanjeev, J. H. A. 2018. "Effect of Drip Irrigation and Fertigation on the Performance of Several Rice Cultivars in Different Rice Ecosystems in India." *International Journal of Agriculture Sciences* 10 (14): 6672-5.

[37] Ganguly, K., Gulati, A., and Braun, J. V. 2017. "Innovations Spearheading the Next Transformations in India's Agriculture." Center for Development Research, University of Bonn, Germany.

[38] Mechanization and Technology Division. 2014. *Sub-Mission on Agricultural Mechanization—Operational Guidelines, Twelfth Five Year Plan*. Department of Agriculture, Cooperation and Farmers Welfare, Government of India, New Delhi.

[39] Gulati, A., Ferroni, M., and Zhou, Y. 2018. "Supporting Indian Farms the Smart Way." Academic Foundation, New Delhi.

[40] Gulati, A., and Banerjee, P. 2015. "Rationalising Fertiliser Subsidy in India: Key Issues and Policy Options." Working Paper 307, Indian Council for Research on International Economic Relations, New Delhi.