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Fifty Years of the Green Revolution and Beyond

Preamble

During his speech delivered on the occasion of receiving the Nobel Peace Prize in 1970, Dr Norman Borlaug prophetically said:

> The Green Revolution has won a temporary success in man's war against hunger and deprivation; it has given man a breathing space. If fully implemented, the revolution can provide sufficient food for sustenance during the next three decades. But the frightening power of human reproduction must also be curbed; otherwise the success of the Green Revolution will be ephemeral only.

While delivering a special 30th anniversary lecture at the Norwegian Nobel Institute, Oslo, in 2000, he reviewed his prophecy and said:

> The world has the technology – either available or well advanced in the research pipeline – to feed on a sustainable basis a population of 10 billion people. The more pertinent question today is whether farmers and ranchers will be permitted to use this new technology. While the affluent nations can certainly afford to adopt ultra-low-risk positions, and pay more for food produced by the so-called 'organic' methods, the one billion chronically undernourished people of the low-income, food-deficit nations cannot. It took some 10,000 years to expand food production to the current level of about 5 billion tonnes per year. By 2025, we will have to nearly double current production. This cannot be done unless farmers across the world have access to current high-yielding crop-production methods as well as new biotechnological breakthroughs that can increase the yields, dependability and nutritional quality of our basic food crops.
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> (Borlaug, 2000a, b)

Dr Borlaug's foresight and realization of the UN's 2030 agenda for Sustainable Development Goals (SDGs) to end poverty while protecting the planet can only happen if agricultural development and world demographic projections are kept in mind by all stakeholders, especially policy makers.

With reference to India, science and technology-based Green, White and Blue revolutions have significantly altered agricultural production and the agrarian economy in the last six decades. Between 1951 and 2017, foodgrain production increased fivefold, from 51 million to 276 million t; horticultural production swelled to 305.4 million t (the second-largest in the world); milk production grew ninefold, from 17 million to 155 million t (the highest in the world), and fish production increased 15-fold, from 0.75 million to 11.4 million t (the second-largest in the world). These unprecedented production gains, coupled with efficacious policies and actions, have resulted in more than halving the number of hungry, undernourished and ultra-poor. The years 2015–2016 marked the golden jubilee of the Green Revolution in India (Alagh, 2015). A review of the history of the Green Revolution, the lessons learnt and the policies pursued for achieving the SDGs in a contemporary context are discussed below.

The Green Revolution – A Snapshot

'In the early 1900s, the projections showed that there would be 6 billion people to feed by the turn of the century. With most of the population inhabiting the less-developed world, there was increasing fear of a world famine' (Paddock and Paddock, 1967). The narrative of the Green Revolution dates back to early 1941, when US Vice-President Henry Wallace toured Mexico as a special ambassador and was appalled by the poor state of Mexican agriculture. Thereafter, he urged the Rockefeller Foundation to look at ways of helping the Mexicans. The Rockefeller Foundation developed the Mexican Agricultural Programme (MAP) to boost Mexican agriculture with a team of four dedicated scientists. The team was headed by J. George Harrar and the other members were John Niederhauser (in charge of potato improvement), Edwin Wellhausen (maize improvement) and a young biologist from Iowa, Norman Ernest Borlaug, in charge of the wheat improvement programme (Borlaug and Dowswell, 2003). As a result of his dedication, ingenuity and use of germplasm from far and wide, Dr Borlaug developed the semi-dwarf-statured, fertilizer-responding 'miracle wheat' in 1954, which was spread by the Rockefeller and Ford Foundations throughout the world in the 1950s and 1960s, including India. Breeders incorporated dwarfing genes that allowed the development of shorter, stiff-strawed varieties of wheat. These varieties devoted much of their energy towards producing grain and relatively little towards producing straw or leaf material. They also responded better to fertilizer application than did traditional varieties. Farmers adopted the new semi-dwarf modern varieties rapidly in some areas, chiefly those with access to irrigation or reliable rainfall, and the new varieties yielded substantially more grain than previous ones (Evenson and Gollin, 2003). The highlights of the Green Revolution in India are given in Box 3.1.

The term Green Revolution was first coined in 1968 by William S. Gaud, an administrator of the US Agency for International Development (USAID), at a meeting of the Society for International Development, to describe the remarkable increases in cereal crop yields achieved in developing countries during the 1960s. The keys to this revolution were new plant varieties that fully utilized improved fertilizers and other new agrochemicals that had become available during the period. When planted using improved irrigation and crop management techniques, these new varieties gave dramatic increases in yield. The success of the Mexican programme prompted the setting up of a similar programme for rice at IRRI in the Philippines, funded jointly by the Rockefeller and Ford Foundations.

Prior to the 1960s, India struggled with feeding its increasing population, and famine was a regular feature (e.g. great Bengal famine of 1942–43), resulting from meagre food production, poor distribution, droughts and floods. Two consecutive droughts in the mid-1960s led to a famine situation, which was averted by substantial foodgrain imports from the USA under its Title I Public Law 480 (PL 480) scheme. Foodgrain import steadily rose from 1.5 million t in 1946 to 4.8 million t in 1950, peaking at 10.4 million t in 1966. While branding India with epithets like the 'begging bowl' and 'ship-to-mouth', it was predicted that Indians would die in their millions by 1975 and that no food aid could save them (Paddock and Paddock, 1967).

During the early days of independence, food crop production and productivity were very low, and coverage of high-yielding varieties was less than 5% in all crops except sugarcane, cotton and jute. Traditional wheat varieties grown in India at that time were low-yielding, albeit tall and fairly resistant to several races of rusts (Swaminathan, 1993). The introduction of high-yielding technology to India is attributed to the initiative of the political leader C. Subrahmaniam and the civil servant B. Sivaraman, who took a bold decision to import large quantities (18,000 t) of seeds of the variety Lerma Rajo 64A and Sanora 64 from Mexico in 1966. Prior to that, in 1960, Professor M.S. Swaminathan procured seeds of the semi-dwarf wheat variety 'Gaines', keeping in view its high productivity. In 1960–61, from the wheat-breeding lines received from USDA by the Indian scientists under the International Wheat Rust Nursery, Professor Swaminathan and Dr M.V. Rao identified semi-dwarf lines with long panicle and high yield potential. These lines were traced to the wheat-breeding programme of Dr Borlaug who had incorporated the Norin-10 dwarfing gene to spring wheat.

Box 3.1. The story of the Green Revolution. (Excerpts from Swaminathan, 2016)

Indian independence was born against the backdrop of the great Bengal famine where nearly 3 million men, women and children died. The Bengal famine was partly due to World War II, when Myanmar was under the occupation of Japan. Myanmar used to be a major supplier of rice to India, and that source was cut off during the war. Whatever the cause, there was a great deal of awareness among political leaders of India that agriculture would have to receive priority. In fact Mahatma Gandhi said at Noakhali, 'to those who are hungry, bread is God' and it should be available to every individual in India. Therefore, when India became independent in 1947, Jawaharlal Nehru said, 'Everything else can wait, but not agriculture.' Hence, agricultural progress received attention. The Green Revolution can be divided into three distinct periods.

The first period, between 1945 and 1955, was related to the search for methods of improving the production and productivity of major crops. In the case of rice, this was accomplished by identifying japonica strains of rice from Japan, which could respond to fertilizer and irrigation water more effectively. The indica-japonica hybridization programme was first started at the ICAR-National (earlier Central) Rice Research Institute (NARI), Cuttack, in the early 1950s, which could not lead to the desired results largely because of sterility in the hybrids. Although there were some varieties like ADT 27, identified at Aduthurai and Mashuri in Malaysia, which gave higher yields compared to earlier ones, there was a need to search for new genes for a kind of plant architecture that could help plants not to lodge or fall down even when there is good soil fertility. NARI was the starting point in the search for new genes, new plant architecture, new physiological rhythm and photo-insensitivity. This was followed by importing the Dee-Geo-Woo-Gen dwarfing gene from Taiwan and the International Rice Research Institute (IRRI).

The second phase consisted of introducing genes for a new kind of plant type and plant architecture – dwarf varieties and semi-dwarf varieties that could respond to irrigation and fertilizer well. This was accomplished in the case of wheat by introducing the norin dwarfing genes from Japan through Norman Borlaug in Mexico. Inputs are needed for output, and unless the plant is capable of utilizing more inputs there will be difficulty in producing more. So the second phase consisted of genes for dwarfing. At ICAR-IARI, work was started, and in the very first year it was realized that these new plant types could increase the yield potential of the crop substantially. This created a lot of interest among farmers.

The third phase consisted of appropriate government policies to support technology. The interaction of technology and public policy is now related to input–output and procurement pricing as well as storage and public distribution. Furthermore, it is only assured and remunerative marketing that can help farmers to take an interest in technology. However good the technology is, if the net income is not high, farmers will not take to it. In this third phase many changes took place – much more interest in technology, seed production and the distribution of inputs like fertilizers, seeds etc. As a result, in 1968, wheat production went up to 17 million t from about 7 million in 1947. Between 1964 and 1968 more wheat was added and the wheat revolution was now underway. Since then, the country has never looked back; wheat production is now 97.11 million t (2017–2018). Farmers have tried to do their best under difficult circumstances. Scientists also have been continuously producing new varieties with more resistance to pests and diseases, particularly the three rusts – stem, stripe and leaf. All three are now under control, but stem rust could become a threat again because of climate change. The story of the Green Revolution is condensed in the period 1950–1970 largely because of a new kind of plant architecture. The Green Revolution may be defined as an increase in production through productivity improvements. Hybrid corn of the USA would qualify as the starting point of the Green Revolution, as it was the exploitation of hybrid vigour in corn that started the high-yield movement. But whatever the factors that caused increased production, the Indian Green Revolution was unparalleled. The Green Revolution was the beginning of a new era in agriculture. The reasons for its success were many – technology, public policy, farmers' enthusiasm and assured and remunerative marketing. When all these came together, India made significant progress. Now we talk of the 'Evergreen Revolution', i.e. increase in productivity in perpetuity without ecological harm. We need to see a hunger-free India, an India that will not go with a 'begging bowl' or exist hand-to-mouth.

Later, in 1963, Dr Borlaug visited India. On confirmation that many of the semi-dwarf wheat lines were doing well in the Punjab province of Pakistan, India initiated a major programme to import large quantities of seeds of two semi-dwarf varieties, Sonara 64 and Lerma Rojo 64-A, from Mexico and seeds of large segregating populations from the breeding nursery of Dr Borlaug.

India also developed a five-year road map (1963–1968) for transforming wheat productivity using semi-dwarf spring wheat varieties bred at the International Maize and Wheat Improvement Center (CIMMYT), Mexico (Swaminathan, 1993).

The Indian breeders subsequently bred semi-dwarf wheat varieties using the genetic background of Indian wheat germplasm and released high-yielding varieties with superior yield, quality and resistance to major diseases. The Indian wheat revolution gave rise to record harvests of 16 million t, from 11 million t, during 1967/68. A change of this magnitude became a reality not as a result of high-yielding semi-dwarf seeds alone, but also by the imaginative use of complementary enabling institutional mechanisms, including the organization of demonstrations on the small farms of resource-poor farmers and a ready supply of quality seeds, produced with farmers' active participation.

As in the case of wheat, the Green Revolution story was also unfolding with rice. In 1966, IR 8, a new high-yielding variety (with dwarfing genes sourced from the Taiwanese variety Dee-Geo-Woo-Gen), then described as the 'miracle rice', reached India from the IRRI in the Philippines. This variety, with a unique genotype possessing photoperiod insensitivity, semi-dwarf stature, high fertilizer responsiveness-linked high-yield potential and medium maturity duration offered an unprecedented opportunity for a rice revolution in the country. Subsequently, Indian rice breeders developed several high-yielding varieties, some of them surpassing IR 8 in yield and quality. Interestingly, the rice production revolution came from an unconventional rice area, the irrigated Indo-Gangetic wheat belt during the late 1960s, triggered by the medium maturing, Basmati-derived, high-yielding fine rice varieties bred at the Indian Agricultural Research Institute (IARI) (Swaminathan, 1993; ICAR, 2015).

Undoubtedly, the Green Revolution is one of the great technological achievements of the 20th century, enabling humanity to defy the Malthusian catastrophe, with food production outpacing population growth (Sharma, 2016). The high-yielding varieties of wheat and rice, bred scientifically to respond to the application of fertilizers and irrigation, heralded the Green Revolution in India, propelled primarily by the public research and extension system. Concomitantly, political will, suitable input support, appropriate pricing policies and progressive farmers' participation resulted in the transformation of Indian agriculture from a 'ship-to-mouth' status in the 1960s to a 'right to food' (under the National Food Security Act 2013) situation. It transformed Indian agriculture, while providing a foundation for subsequent strides in overall agricultural production (Fig. 3.1). It helped India triple its foodgrain production between 1968 and 2000 and halve the percentage of food insecurity and poverty (even

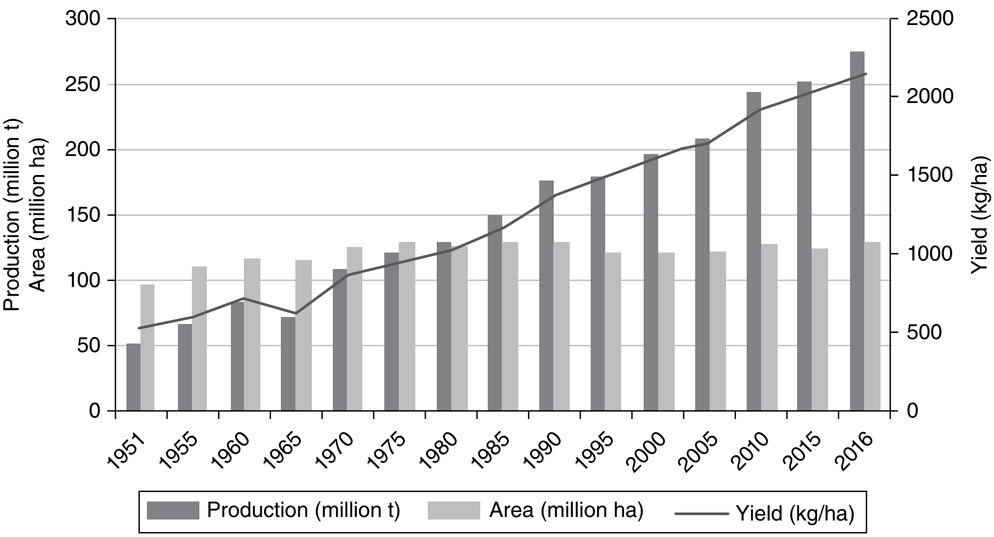

Fig. 3.1. Area, production and yield of foodgrains in India since 1951.

though the population had almost doubled during the same period), thus rendering India a self-sufficient nation at the macro level (Singh, 2014). Green Revolution technologies addressed two important impact indicators – total factor productivity (TFP) and poverty alleviation. The TFP index for crop-livestock reached 290% in 1991/92 from the base year (1964/65 = 100), of which research contributed 48%. The poverty ratio declined from 55% in 1973/74 to 36% in 1993/94, proving a strong positive correlation between research outputs and poverty alleviation (Joshi *et al.*, 2005). This transition was achieved not only through pioneering agricultural research to increase food production but also through political and administrative support of building grain reserves, operating an extensive public distribution system (PDS), protective social security measures like food for work, mid-day meals for children in schools, employment guarantee, land reforms and asset creation measures.

Constraints of Technologies and their Implementation

The Green Revolution strategy for food crop productivity growth was overtly based on the hypothesis that, given appropriate institutional mechanisms, technology spillovers across political and agroclimatic boundaries could be captured (Pingali, 2012); and although Green Revolution technologies averted a famine-like scenario in India, avoiding the conversion of thousands of hectares of land for agricultural cultivation, they also spurred unintended negative consequences. The way in which Green Revolution technologies were applied gave rise to many challenges, not because of the technologies themselves but because of the policies that were used to promote them. A few of these are described below.

Impact of Technologies in Selected Regions

One downside of the Green Revolution was selectivity in impact, remaining confined to the well-endowed, well-irrigated and high-rainfall areas. This was in spite of the fact that international breeding programmes had aimed to provide broadly adaptable germplasm for cultivation in a wide range of geographies; but adoption was highest in favoured areas. Many of the agricultural technologies were not suitable for, or adopted by, small and marginal farmers, especially those in rainfed ecologies. For example, high-yielding varieties (HYV) of wheat provided yield gains of 40% in irrigated areas with modest use of fertilizers, while in dry areas the gains were often no more than 10%, and the technology adoption was strongly correlated with water supply (Pingali, 2012). Inter-regional disparities widened, as did the gap between rich and poor farmers. Technologies in the Green Revolution period did not focus on the constraints to production in more marginal environments, especially tolerance to stresses such as droughts or floods.

Natural Resource Imbalance

The technology application invariably led to loss of traditional varieties to the HYVs, loss of soil fertility under indiscriminate application of chemical fertilizers, over-exploitation of underground water, soil health degradation (saline or alkaline) with overuse of surface or underground water, and increasing environmental toxicity with reckless use of chemical pesticides. The high response of HYVs to nitrogen encouraged farmers to use urea indiscriminately, completely ignoring the recommendations of organic manure application along with chemical fertilizers. Such practices resulted in soil health loss, including decline in organic matter content, in two to three decades, while promoting incidence of pests, which in turn led to increasing indiscriminate use of pesticides and toxic contamination of food, feed, water and the environment. Unregulated use of irrigation water and unchecked extraction of underground water, aided by subsidized or free electricity together with poor drainage, led to degradation of soil and decline in factor productivity (Swaminathan, 1993).

Incomplete Reduction of Poverty and Food Insecurity

Food security exists when all people, at all times, have physical and economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (Mishra, 2017). The Green Revolution fuelled an increase of food availability per capita with a fall in prices, but poverty continued to limit access to food, leaving hundreds of millions of people undernourished in developing countries (Serageldin, 1999). The 2016 *Global Hunger Index Report* ranked India 97th among 118 countries (GHI, 2016). In 2011, 21.9% of the Indian population lived below the poverty line, while according to the international poverty line of US$1.90/day, India has 224 million people living under poverty (World Bank, 2016; ADB, 2017); and this is in spite of the fact that India has witnessed more than a fivefold increase in its staple cereal production since 1950 due mainly to the gains from the Green Revolution (Fig. 3.1). Thus the Green Revolution alone was not the panacea for solving the myriad complexities of poverty, food security and nutritional problems, because the amount and quality of food available globally, nationally and locally can be affected, temporarily or for long periods, by many factors including climate, disasters, wars, civil upset, population size and growth, agricultural practices, the environment, social status, per capita income and agricultural trade.

Technology Fatigue

Broadly speaking, technologies reached a plateau by the end of the 1980s for many crops and regions. Technology fatigue has been identified as one of the two main reasons for the problems with India's agriculture, which has been going through a difficult phase in recent years with declining rates of growth in agricultural productivity and profitability. Intensive agriculture led to loss of soil fertility due to excessive mining of nutrients, groundwater depletion from overexploitation of underground aquifers, increased soil salinity from poor drainage, reduction of diversity due to monocropping, and threat to environmental and human health due to excessive use of agrochemicals. These effects had been most severe in the intensively cultivated areas of Punjab, Haryana and western Uttar Pradesh, where the technologies were first adopted. Some experts opine that not the technologies per se but injudicious implementation of policies like highly subsidized electricity and water are to be blamed (Sharma, 2016). Agricultural research was also focused on a few selected crops, and participatory breeding (especially involvement of farmers) was inadequate. The overall performance of the agriculture sector in terms of growth suffered a setback for some years, especially after the mid-1990s and this slow-down had several consequences including widespread agrarian distress. The first decade of the new millennium witnessed a growth in production of 2.7% p.a., compared to 3.4% p.a. during the 1990s and 4.7% p.a. during the 1980s. It was a great challenge and a formidable task to arrest the decline and reverse the slowing growth of the agriculture sector. Several initiatives were taken by the central and state governments to reverse the slow-down (Chand, 2014). Since 2004/05, a revival of the growth rate to 3.75% has been achieved. Thus there is an urgent need to rectify the fatigued technologies, remove regional disparities and rejuvenate the agricultural sector afresh to address the issue of food, nutrition and environmental security.

Global Population, SDGs and Food Security

In 1901, the world population was 1.6 billion. It increased rapidly to 3 billion by 1960, 5 billion by 1987 and 6 billion by 1999. By mid-2017 it had crossed 7.6 billion, an addition of nearly a billion during the last 12 years (UNDESA, 2017). Of greater concern is the fact that 60% of the world's people live in Asia (4.5 billion), with China (1.4 billion) and India (1.3 billion) continuing to be the two most populous countries (Fig. 3.2). Within the next seven years, India is projected to overtake China as the world's most populous country and will continue to grow until *c.*2060; its population only starting to decline when it has reached approximately 1.68 billion.

The Green Revolution helped India to achieve some of the MDGs, including the target for reducing poverty and hunger by half (Goal 1). However, progress was uneven, as poverty became increasingly concentrated in poorer states. Since the mid-2000s, the economic growth, including in agriculture, as well as increased social spending on interventions such as the

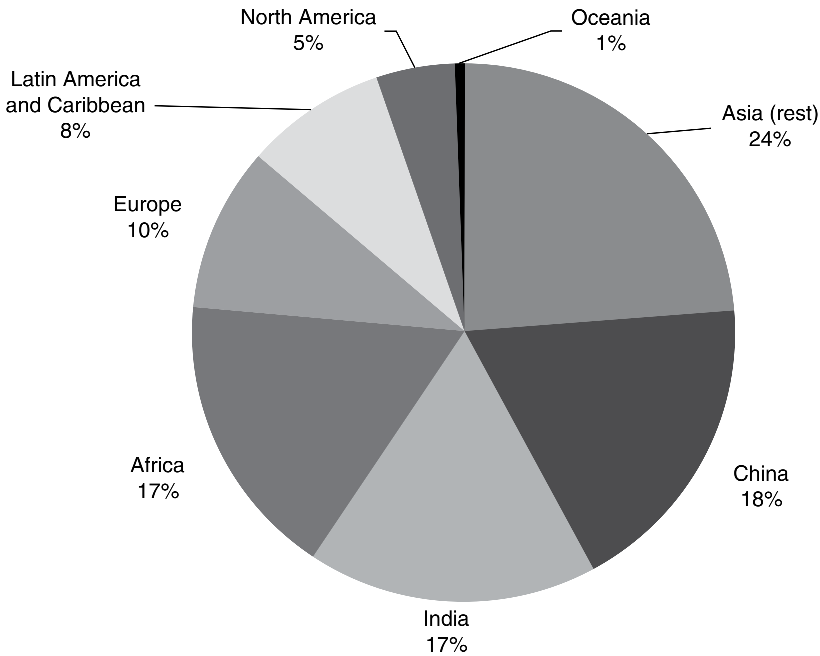

Fig. 3.2. Distribution of the world's population (2017).

Mahatma Gandhi Rural Employment Guarantee Act (MGNREGA) and the National Rural Health Mission (NRHM) facilitated India to halve the incidence of poverty from the 1990 level. However, it is apparent that the tasks of meeting the consumption needs of the projected population are going to be more difficult, given that previous strategies of generating and promoting technologies have contributed to serious and widespread problems of environmental and natural resource degradation. This implies that in future the technologies that are developed and promoted must result not only in increased agricultural productivity levels but also ensure that the quality of the natural resource base is preserved and enhanced. In short, they lead to sustainable improvements in agricultural production.

The 17 SDGs of the UN, also known as the Global Goals, are an inclusive agenda to make the right choices now to improve life, in a sustainable way, for future generations (UN, 2017). They build on the successes of the MDGs while including new areas such as climate change, economic inequality, innovation, sustainable consumption, peace and justice, among others. They provide clear guidelines and targets for all countries to adopt in accordance with their own priorities and the environmental challenges of the world at large. The SDGs offer a unique opportunity to put the whole world on a more prosperous and sustainable development path.

The 2017 edition of *State of Food Security and Nutrition in the World* is an important benchmark to gauge hunger and malnutrition prevalent today and actions required to attain the targets of the SDGs, specifically those of ending hunger (Target 2.1) and all forms of malnutrition (Target 2.2) (FAO *et al*., 2017). According to the report, in 2016 the number of chronically undernourished people in the world is estimated to be 815 million (10.7% of the world's population), up from 777 million in 2015, though down from 900 million in 2000. This increase is alarming, and is ascribed to situations of conflict combined with droughts, floods and climate change, particularly in parts of sub-Saharan Africa, south-east Asia and western Asia.

With reference to India, endemic hunger continues to be a challenge, with over 200 million men, women and children estimated to be undernourished, largely due to inadequate purchasing power arising from inadequate opportunities for skilled employment. The population of India is growing at a rate of 1.2% per year. If this trend continues, the population will be doubled in less than 40 years. The decade between 1990 and 2000 was characterized by globalization, macroeconomic reforms and trade liberalization in India, which impacted the hitherto protected Indian agriculture. Unfortunately, economic reforms were minimal in agriculture, impacting exports considerably. A strong need was voiced for a second Green Revolution. By the turn of the 20th century, high price volatility, shortages of food and increasing rates of farmer suicides had become prominent issues in Indian agriculture. To address the agrarian crisis a National Policy for Farmers (NPF) was formulated to increase the net income of farmers. Overall, there has been national-level (macro) food security and a boost in overall GDP growth in India, but agricultural production and rural income growths have slowed down considerably, outstripped by the population growth rate (Singh, 2014).There is still a widespread mismatch between production and post-harvest technologies. In perishable commodities, such as fruits, vegetables, flowers, meat and other animal products, this mismatch is often severe, affecting the interests of both producers and consumers. Out of every 3 ha of cultivated land in India, almost 2 ha are under rainfed agriculture. With little reduction in the number of undernourished and poor people, the country has to accelerate the pace of reforms for achieving the SDGs. The *State of Food Security and Nutrition in the World 2017* report sends a clear signal that eradicating hunger and malnutrition by 2030 is a challenging task requiring renewed efforts through new ways of working; it advocates that only if agriculture and food systems become sustainable can the issue of food insecurity be addressed adequately (FAO *et al.*, 2017).

Indian Agricultural Research and Development beyond the Green Revolution

The welfare of farmers and farm workers not benefitted by the Green Revolution depends on extending the boundaries of the Green Revolution. A major accomplishment of Independent India is the development of a dynamic National Agricultural Research, Education and Extension System (NARES). A well-established network of SAUs, national research institutions, all-India coordinated research projects and Krishi Vigyan Kendras (KVKs) is supported by ICAR. Productivity gains during the Green Revolution were largely confined to relatively well-endowed areas. Thus, during the 1970–1990s, research priorities and agendas shifted towards conservation and improvement of genetic resources to raise productivity, development of HYV seeds for more crops like pulses and oilseeds, sustainable natural resource management, diversification, post-harvest management, human resource development and infrastructure strengthening. During this period, NARES contributed to usher in a milk, egg, fruit, vegetable, fish and oilseed revolution. Subsequently, in the decade 1990–2000, research agendas and priorities included dryland horticulture, ideal cropping systems, PPPs, HRD and strengthening front-line extension activities through further expansion of KVKs. Emphasis was also laid on tapping new technologies in the field of biotechnology and genetic engineering, molecular biology, remote sensing etc. During the years of the 21st century, NARES's policy agenda and research priorities included the development and diffusion of agricultural technologies, more efforts in biotechnology, strengthening research in natural resource management and climate change, PPP and more international collaboration.

The Green Revolution benefits in economic terms notwithstanding, Indian agriculture still suffers from low productivity, low quality awareness and rising imports. Agriculture imports have increased six times faster than exports in the past 20 years. Large imports in 2016–2017 have been edible oil (US$10.9 billion), pulses (US$ 4.2 billion) and apples, kiwi fruit, almonds and cashews (US$3 billion). These three groups account for 73% of India's agriculture imports, although it has the required soil and climatic conditions to cultivate them indigenously. India accounts for 4% of global production of grapes but its share in global exports is only 1.6%. The case of bananas is even more abysmal; India's share of global production is 30% but its share of exports is less than 0.4%. It is apparent that India needs to focus on continued agricultural growth through strong national and international research programmes to increase agricultural productivity, improve input-use efficiency, high-value agricultural products and adoption of a package of technologies that would enhance farm income.

Looking Ahead

Changes are needed urgently to respond to the new demands of agricultural technologies. These include increasing pressure to maintain and enhance the integrity of degrading natural resources, changes in demand and opportunities arising from economic liberalization, unprecedented opportunities arising from advances in biotechnology, the information revolution and the urgency to reach the poor and disadvantaged who could not be insulated by the Green Revolution technologies. The gap between potential and actual yields is high in a majority of crops under different farming systems. Further, in view of deriving benefits under the WTO regime, a targeted approach, which accords adequate attention to export commodities and frontier sciences, so as to reduce cost and improve quality, is needed. Future growth needs to be more rapid, more widely distributed and better targeted. The new-generation technologies will have to be much more site-specific, based on high-quality science and an increased opportunity for end-user participation. These must be not only aimed at increasing farmers' technical knowledge and understanding of science-based agriculture but also must take advantage of opportunities for full integration with indigenous knowledge. They will also need to take on the challenges of incorporating the socioeconomic context and the role of markets. Hence, the following initiatives are proposed with a view to transform the Indian agricultural sector and make it resilient, sustainable and profitable for farmers and other stakeholders.

Research

- A new paradigm of regionalization of research, based on well-defined agroclimatic regions, application of frontier sciences, participatory and proprietary approaches in research and strengthening research–extension links is urgently needed.
- Public agricultural research systems need to be shaped into an innovative system structure that is well-organized, efficient and results-oriented.
- An international network of scientists in both the public and private sectors must work together to provide seeds and plants to farmers and commercial plant breeders for further crossing and testing in different environments. The research community, therefore, must pay specific attention to the development of locally adapted varieties that meet the needs of the world's poorest farmers.
- There is a need for researchers, farmers and extension scientists to come together for location-specific testing and verification of technologies that are scientifically sound, socially appropriate and environmentally relevant. Results from genomics and agronomic research must be connected to the communities that are responsible for evolving new varieties of crops.
- The bureaucratic system needs to be made a more flexible and liberal system of administration. Scientists can be educated in business skills and other knowledge. There is a dire need to bring in an assessment culture in agricultural innovation systems.
- Basic science has generated enormous advances in our understanding of crop/animal biology, stress tolerance, pathogen resistance and many other fields of science. This understanding should lead in due course to improvements in agricultural technologies. Development agencies, faced with public suspicions of new agricultural technologies, and perhaps eager to find shortcuts to development, have tended to shift funding away from agricultural research towards other priorities. This trend needs to be reversed.
- In most of the crops, the present average yield is just one third of the achievable yield. Therefore a massive effort is required to launch a new revolution in farming through cost-saving and efficient input-use technologies both for production and post-harvest management.
- It is necessary to develop and introduce appropriate technologies coupled with sound delivery systems that ensure economic and

ecological sustainability and optimum use of local resources emphasizing capacity-building and technological empowerment, particularly of small and marginal farmers. Top priority should be given to improving the productivity and stability of rainfed agriculture, and more efficient and sustainable use of increasingly scarce land, water and germplasm resources.

Education

- Convert the top ten SAUs into 'centres of excellence'. They will make region-specific strategies to raise crop yields, advise on the creation of integrated supply chains and prepare a plan to promote exports and cut imports.
- ICT and cutting-edge technological tools need to be accessible to small and marginal farmers. They create capacity among community groups and farmers to produce videos on topics that are relevant to local farmers, featuring farmers as the main contributors.

Development

- There is an urgent need to adopt integrated natural resource management so that present production does not erode future prospects. This is particularly required in the traditional Green Revolution areas to defend the gains already made, and to extend the gains to areas bypassed with respect to improved technologies.
- The need for making new agricultural gains is urgent. This can be achieved by utilizing the available agroclimatic/soil maps, watershed/wasteland atlases, GIS mapping and remote-sensing capabilities for developing improved and integrated crop-livestock-fish farming systems, and for developing infrastructure for value addition to farm products at the village level. These changes will provide opportunities for off-farm employment and income generation.
- There is a need to establish at least 2000 farmer centres, one in each sub-district. These agri-clinic centres should be a 'one-stop shop' for all farmers' needs, such as meeting representatives from banks, insurance companies, seed and equipment suppliers and buyers, and input/technology providers. Farmer centres would integrate with the electronic national agriculture markets (e-NAM) to help farmers sell directly to the consumer. Each centre will also have free water-, soil- and nutrient-testing laboratories.
- Ensure active monitoring of government schemes; for example, many of the 35 million farmers who opted for the Pradhan Mantri Fasal Bima Yojna (Prime Minister Crop Insurance Scheme) in the last *kharif* season got their compensation late, as more than half the states did not pay the premium on time. The e-NAM, another useful initiative, needs to check wrong reporting. Many mandis show normal sales as e-NAM sales.
- Institutional and infrastructural support is essential for higher agricultural production. There is an urgent need to provide efficient irrigation, power supply, rural roads, cold storages, godowns and food-processing units, especially in the eastern and north-eastern regions, supported by assured and remunerative marketing.
- Instead of flood irrigation, efficient micro-irrigation practices need to be promoted to increase the area under irrigation through increased productivity and higher water-use efficiency.

Conclusion

The time is ripe to initiate action to ensure household food security and eliminate hunger. The opportunity for a productive and healthy life for every individual depends on the success of achieving an 'evergreen revolution'. The FAO has projected that by 2030 most developing countries will be dependent on imports from developed countries for their food requirements; hence, greater efforts to sustain the gains of the Green Revolution through resource-use-efficient technologies are needed in a 'mission mode' approach. The second-generation problems of the Green Revolution are a 'ticking timebomb' requiring transformation of Indian agriculture. Doubling farmers' incomes in the next five years, though a big challenge, can be an apt metaphor and goal for much-needed agricultural transformation. A farming system that produces high yields, makes a good living for farm families, protects natural resources and improves the environment, whilst still producing good, affordable food, is what is required. In return, a rising agricultural sector will improve the lives of millions of people who live on the margin. The results will transform the entire fabric of the nation.

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