NITI Aayog

सत्यमेव जयते
Ministry of Agriculture & Farmers Welfare
Government of India

Food and Agriculture Organization of the United Nations

## NATIONAL DIALOGUE

# INDIAN AGRICULTURE TOWARDS 2030

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

### Thematic Session: SCIENCE, TECHNOLOGY AND INNOVATION

### Discussion Paper: Science, Technology and Innovation

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## 1. Introduction

India has been successful in building a massive ecosystem of science, technology and innovation (STI)since independence in 1947. Also, globally, STI continuum has been the main driver of agricultural growth, development, and transformation of national socio-economic and agro-ecological milieus, and evolving dynamically to meet the fast changing development goals. Today, in the midst of the unprecedented COVID-19 pandemic, the world is challenged to meet the new and emerging health and nutrition demands along with the United Nations' Sustainable Development Goals - Agenda 2030 (UN, 2015). In this scenario, an effective STI system will be needed to disruptively transform Agriculture-Food Systems to achieve the veritable goal, "leaving no one behind", especially youth and women.

The foremost challenge to the STI in India and other agriculturally-important developing countries is the increase in number of hungry and malnourished people. One-third of the humanity is malnourished and nearly one-fourth of the world's children are stunted– annually costing about 6-10 percent of GDP. Nearly one-fourth of the world's hungry, one-third of the world's stunted children, and half of the world's wasted children are from India (Table 1: FAO, 2018).

Table 1. Number of undernourished people, 2017 (million)

| Geographic entity | Number of undernourished people | Number of children under 5 wasted | Number of children under 5 stunted |
|---|---|---|---|
| World | 821 | 51 | 151 |
| India | 196 | 26 | 47 |
| China | 125 | 1.6 | 6.9 |
| Asia | 515 | 35 | 84 |
| Africa | 257 | 14 | 59 |

*Source: (www.fao.org/state-of-food-security-nutrition-in-the-world)*

In India, STI-led Rainbow Revolution transformed the country from 'ship-to-mouth' status to the 'Right-to-Food Bill' situation, with formidable food-grain export and buffer stocking, making it the second largest agrarian economy in the world. Accounting for 18 percent of the world's population, with only 2.3 percent of the world's land and less than 4 percent of global freshwater, the country's STI effort must be geared to produce ***More from Less for More*** without further damaging the agro-ecological system and accentuating water and carbon footprints.

STI for Development (STI4D) must break the co-existence of food surplus and wastage, and high incidences of hunger and malnutrition; check the high inequities, trade and market distortions; halt unabated depletion of natural resources; stop the accelerated emergence of infectious diseases and aggressive pests; and, of course mitigate the ever - aggravating climate change volatilities posing major challenges to the Indian agriculture today. Another major challenge is to break the asymmetry of low and poorly planned investment in agricultural research, education, and technology generation and transfer. This, despite the fact that investment in agriculture is at least three times more effective than in other sectors in alleviating hunger, under-nutrition, and poverty (World Bank Group, 2020). Hence, moving beyond research and production as usual, an unusual science-technology-innovation continuum must be adopted to meet these challenges, and create zero hunger India (Singh, 2015). Ramesh Chand (2019), Member, NITI Aayog, emphasized the importance of advancement in science-led technology, enhanced role of private sector, liberalized output and active land lease market, and increased input use efficiency along the value chain for transforming Indian Agriculture.

Committed to demand-driven and technology-led revolution to transform agriculture, this chapter discusses the following sub-themes of Science, Technology, and Innovation (STI) towards transforming agriculture-food system to meet the veritable development goals: (i) paradigm shift in agricultural research to address new challenges, (ii) frontier technologies, IPR issues and their application, (iii) indigenous technical knowledge in agriculture, (iv) innovative technology dissemination options, (v) innovations outside agriculture influencing agriculture, (vi) rejuvenating agricultural education system, and (vii) pathways from research to innovation for impact.

## 2. Paradigm Shift in Agricultural Research and Technology to Address New Challenges and Opportunities

While STI have continuously been transforming the agriculture-food-systems in the past, the following major paradigm shifts in agricultural research are needed for making these more efficient, knowledge-based, inclusive, and sustainable, in providing solutions to the new and emerging challenges, and capturing uncommon opportunities.

## 2.1 Smallholder Farmers at the Centre Stage

Smallholder and marginal farmers, accounting for nearly 86.25 percent of Indian farmers, 47.38 percent of the cultivated land and over 50 percent of the total agricultural production, are vital not only for India's agrarian economy ($10^{th}$ Agriculture Census 2015-16), but also for achieving alleviation of hunger and poverty. Over 50 percent of the smallholders, referred to as sub-marginal farmers, possess less than 0.5 ha land. Despite their higher per unit productivity, the extremely small and fragmented holdings are economically non-viable, swelling the ranks of hungry and poor. The bio-diverse, predominantly crop-livestock mixed-farming in India is the key to ensure resilience to climate change and sustainability of smallholder farming agro-ecologies. Recognizing that access of smallholders to technology, land, other production resources, credit, and capital is limited, a holistic pro-smallholder approach and robust policy initiatives are called for. Augmented by new farm reform policies (aggregation of land through contract farming, diversification of cropping system, and remunerative markets as per new Farm Bills, 2020, GOI), effective technologies and innovations are aimed at mitigating vagaries of climate change, while encouraging entrepreneurship and employment..

## 2.2 Nutrition Security to be a Key Goal of Agriculture

Keeping in view the high incidence of hunger and under-nutrition in India vis-à-vis a fact that the country accounts for 20 percent of obese people in the world (Ahirwar and Mondal, 2019), ASTI needs to shift focus on achieving comprehensive nutrition security than just food security. This may be achieved through genetic improvement, bio-fortification, enhanced protein and other quality factors, and/or value addition through post-harvest innovations. Decentralized research approaches will be needed for diverse ecologies, food preferences and market options, which call for region-specific prioritization of research, with due consideration to various socio-economic parameters. For extenuating the emergence of new infectious diseases and aggressive pests, that can often be transmitted along the entire agriculture-food system, from microbe to man, a 'One Health' concept comprising Healthy Soils – Healthy Plants – Healthy Animals – Healthy People – Healthy Environment, would be the preferred approach (Singh, 2019).

In the post-Green Revolution period, agricultural research in India gradually moved from crop-based to farming system - based agriculture integrating horticulture, livestock, poultry and fisheries as essential components to achieve sustainable food and nutrition security and to maximize farm income. For the economic and nutrition security of a largely vegetarian population, dairy animals are of prime importance; and to improve their productivity and climate resilience, a two-pronged approach will be required–strengthening the availability of superior germplasm and enhancing fertility through biotechnological augmentation of reproduction (NDRI, Vision 2030, ndri.res.in/design/document/vision/pdf). Besides expanding the area and production by introducing better production technologies and genetically improved varieties of horticultural crops and breeds of livestock including the small meat animals, particularly in the north eastern region (NER), and poultry and fishes, the present focus needs to be demand-driven, changing from the 'Farm to Fork' approach to the 'Fork to Farm' one to ensure efficient marketing and better price for the farmers (Paroda, 2019a).

The efforts to make this happen comprise inter-disciplinary collaborations in developing innovative production and processing technologies, including nutraceuticals and fortified nutri-foods; cold chains involving refrigerated van using conventional and non-conventional energy sources, and necessary policy support to agro-industries, and all will play critical roles. COVID-

19 pandemic generated considerable public awareness about the nutritional benefits of many indigenous herbs and seed and non-seed spices. Wild food plants (WFPs) have been a vital component of food and nutrition security for centuries. Recently, India and several other countries reported on the widespread and regular consumption of WFPs, particularly by rural and indigenous communities and in urban areas also. These would open new business opportunities for small farm holders. However, technological advancements and better extension would be required for better shelf life, food safety and value addition of these products. Hence, Research, Science, Technology, Innovation (RSTI) framework would need to play a bigger role encompassing six-dimensions of food security: availability, access, utilization, stability, agency, and sustainability. Considering that the majority of the events in agricultural sector are influenced by events occurring in (i) bio-physical and environmental, (ii) technology, (iii) innovation and infrastructure, (iv) economic and market, (v) political and institutional, (vi) socio-cultural, and (vii) demographic domains (FAO, 2020), a paradigm shift is needed to create an agricultural RSTI system, which is demand-driven, but farmer-centric, decentralized, and structured on a bottom-up, participatory, inter-sector, and multidisciplinary approach to provide variable solutions to diverse problems along the entire value chain.

Recalling that "a grain saved is a grain produced", and "unsafe food is no food", "Zero Wastage of food" is one of the five pillars of the Global Zero Hunger Challenge Programme. According to the UNDP, up to 40 percent of the food produced in India is wasted and 50 percent of all food across the world meets the same fate, never reaching the needy. In India post-production losses, especially of perishables and semi-perishables like milk, meat, fish, fruit and vegetables, range from 18-25 percent amounting to INR 50,000 crore (INR 500,000 million) annually (*The Economic Times*, 28 Feb 2019). About 50 percent of these losses are preventable using suitable post-harvest processing technologies. Keeping in view the growing market of processed foods, the future ASTI has to offer innovative options to increase better nutrition and profitability through processing and value addition besides generating new employment opportunities.

## 2.3 Climate Smart Agriculture (CSA)

Indian agriculture-food system economy is greatly prone to climate change consequences. As India is projected to be one of the most negatively impacted countries by the climate change (Table 2), the ASTI efforts are needed to negate the impacts of climate volatilities, and also to create CSA endowed with sustainably enhanced productivity, resilience to climate change stresses (adaptation), and mitigation of climate change. A paradigm shift to imbibe interdisciplinary, participatory, and international collaborative approach can address the multiple challenges caused by climate change while sustaining the desired economic growth (Aggarwal *et al.*, 2018; Singh, 2013, 2014).

Table 2. Projected changes, considering 2013-14 as the baseline, in agricultural productivity from climate change at 2050

| Country | Percentage change |
|---|---|
| Australia | -17 |
| Canada | -1 |
| United States of America | -4 |
| China | -4 |
| India | -25 |
| Brazil | -10 |
| European Union | -4 |
| Least developed countries | -18 |

*Source: IPCC*, 2014

## 2.4 Greening the Growth

The ASTI systems developed during the Green Revolution and Post–Green Revolution eras could not be judiciously adopted, leaving serious yield gaps, low total factor productivity and declining benefit-cost ratios. With mere 36-40 percent water use efficiency, India is predicted to become 'water scarce' before 2030 (NITI Aayog, 2018). With widespread deficiency of NPK and the increasing deficiencies of Zn, Bo, Fe, Mn, and S, the nutrient use efficiency is only around 36 to 40 percent for N and about 15 percent for P. Similarly, constant mining of K is distorting mineralogical make-up, resulting in an irreversible deterioration of soil health, which already suffers from low organic carbon content. Achievement Gap Advisory Panel (AGAP) Report (UNAID, 2014) cautioned that with the business as usual only 59 percent of India's demand of food and agricultural production will be met by the year 2030. Obviously, a major paradigm shift adopting a soil, water, and biodiversity-centric approach is required to increase and sustain agriculture-food system productivity and growth that conserves natural resources and mitigates climate change, moving from Green to Evergreen Revolution to Evergreen Economy (Swaminathan, 2007; Singh, 2011).

## 2.5 From Subsistence to Commercial Agriculture

Recalling the country's pledge of Doubling Farmers' Income by 2022/23, a USD 5 Trillion Economy by 2024/25, and Alleviating Wide Inequalities (farmers' average income being one-fourth of that of non-farmers), farming must be treated as an enterprise. Good post-production technologies, robust entrepreneurship initiatives, and establishment of agro-industries in rural areas should foster economic and employment security and attract youth in agriculture-food systems, thus harvesting India's huge demographic dividend and achieving agrarian transformation.

## 2.6 From Green Revolution to Gene Revolution

The classical plant breeding uses deliberate interbreeding (crossing) of closely or distantly related species to produce new crops and varieties with desirable properties. Plants are crossed to introduce traits/genes from a particular variety into a new genetic background. In this, highly heritable oligo genes and exploitation of additive and dominance gene effects and interactions, led to the development of short stature, input-responsive, high yielding varieties (HYVs), often resistant to common diseases and pests, which ushered in the Green Revolution in the country especially in wheat, rice, maize, pearl millet and sorghum. Molecular breeding including transgenics and marker-assisted selection (MAS)-based gene pyramiding, brought incremental as well as transformational genetic gains in the last 20 years.

Genomics and gene editing must be adopted as preferred technologies for precision breeding (Vats *et al.*, 2019). However, to do so, a science-based policy and well defined guidelines need to be placed on priority. In the new era of genomics, phenomics, proteomics and other omics – molecular breeding, the availability of high quality reference genomes of crop plants accelerated the discovery of genes, quantitative trait locus (QTLs) and DNA markers linked to the traits of agronomic importance. This is now being routinely applied in MAS of crop varieties, including those of horticultural species, for increased selection efficiency. The genomic selection approach will be further enriched by technologies haplotype-based breeding, single cell sequencing, Drop Synth technique for synthesizing large genetic libraries etc. Innovative approaches, such as apomictic F1 seed production, now a distinct possibility, can revolutionize the exploitation of hybrid vigor. As horticulture attains high importance, genomics of coconut, mango, banana, aonla, pointed gourd, tuber crops etc. need greater attention. In view of diminishing water availability, development of improved varieties/hybrids for dryland/arid horticulture along with appropriate cultivation technology will be a priority.

In livestock, genome editing has high prospect of enhanced prolificacy and reproductive performance, improved health, increased feed utilization and growth rate, carcass composition, improved milk production and or composition, and increased disease resistance (Bharati *et al.*, 2020). For instance, in pigs, resilience to African swine fever virus, a deadly disease, was achieved through gene editing. Further, using CRISPR/Cas, the generated pigs, was completely protected against porcine reproductive and respiratory syndrome (PRRS) infection. Using this technology in several livestock breeding populations, frequencies of favorable alleles were greatly increased while deleterious alleles removed. Gene-edited livestock (pigs, goats, and cattle), developed jointly by three USA and one UK universities, for the first time, were rendered "surrogate dads", meaning that the sperm they produce holds only the genetic material of donor animals, paving the way for breeding elite livestock with certain desirable traits to boost food production (*The Times of India*, 19 September 2020).

## 2.7 Digital Solutions and Artificial Intelligence (AI) for Evergreen Revolution

Using Big Data Analytics, we can create decision support systems at various levels, including weather forecasting and efficient management of water, pest, and nutrient. Linked with satellite imagery, this can also help in future predictions of produce and price. Importance of ICT for marketing, sales, and pricing as seen in the response to e-NAM, is expected to attract and retain youth in agriculture. Comprehensive and reliable data resources are conducive to augment AI that can bring a paradigm shift by developing smart farming practices using IoT (internet of things) to address the uncertain issues with utmost accuracy that will enable farmers to do more with less, and also provide new business opportunities to youth as well. AI can also be used for high throughput plant phenotyping, monitoring of natural calamities and crop residue burning.

## 2.8 Attracting Youth and Empowering Women in Agriculture

Globally, there is an increasing concern about the generational gap in agriculture, the farmers are getting old, as the youth is not inclined to practice agriculture. Nations with motivated youth engaged in diverse, secondary and specialty agriculture, supported by enabling policies, have progressed well. India, with a median age of 29 years with largest population of youth (356 million between 10 and 24 years age group) in the world (United Nations, 2014) has only 5 percent of the rural youth engaged in agriculture though over 60 percent of the rural people derive their livelihood from faming and allied activities. Hence, a paradigm shift is needed from 'Youth as a Farmer' to *'Youth as Value Chain Developer and Agripreneur'*. Zonal platforms for Motivating and Attracting Youth in Agriculture (MAYA) may be established in different parts of the country to facilitate this shift.

The principle of 'Leaving no one behind' though requires closing the gender gap, the female farmers, representing more than a quarter of the world's population, remain invisible in policy and decision making at every level of agricultural development. They neither have equal rights nor access to assets, information, inputs and services. In addition, women face excessive work burden, much of which remains unrecognized and unpaid (ICAR, 2012; FAO, 2018; Paroda, 2018).The World Bank and FAO recognized that had women enjoyed same access to productive resources as men, they could easily boost production by 20-30 percent raising the overall agricultural output in developing countries by about 4 percent (Paroda, 2019b)**.**Therefore, integrating a gender perspective into STI policies is necessary to effectively address the gender inequity and related socio-economic challenges.

## 2.9 Towards Precision Agriculture

Precision agriculture, which exploits modern tools, technologies and innovations, including genetically enriched seeds, nanotechnology, artificial intelligence (AI), drones, sensors, robots etc. is the way forward to achieve environmentally sustainable Evergreen Revolution. The approach recognizes site-specific differences within fields and adjusts management actions accordingly adopting the concept of *"doing the right thing in the right place at the right time"*. Moving forward, this will be the new normal, addressing: (i) increased land and labour productivity by means of gender neutral technologies, (ii) intensification, diversification and off-farm employment, (iii) institutional arrangement to equitable rights, and (iv) balanced agro-ecological settings compatible with minimum risk (Gatzweiler and Von Braun, 2016).

### 2.10 Measure to Manage – Ensuring Effective Implementation Pathways

India is off-track in meeting the SDG1 and SDG 2 of Agenda 2030, primarily owing to inadequate governance and implementation of the concerned projects/programmes, resulting in wide gaps in technology adoption, yield, and income (Singh, 2019). The availability of comprehensive and quality data would help create science-based indicators Hunger Index, Human Development Index, Social Progress Index (SPI), Science Index etc. for effective monitoring and evaluation of intended outcomes and impact pathways as well as for ranking Agricultural Universities and institutions. Efficacy of the pathways from research to innovation for impact, as envisaged in the last section of the paper, should be assessed by using these indicators. The proposed system should be institutionalized to fix differentiated responsibility and accountability to help in adopting need-based mid-course corrections and alternative pathways to meet the targets.

## 3. Frontier Technologies, Intellectual Property Issues and their Application

For accelerating agricultural GDP growth, reorientation of Agricultural Science, Technology and Innovation (ASTI)is required to focus on greater use of new science and scaling of innovations (Fan, 2013). The tackling of second generation challenges such as factor productivity decline, depleting natural resources, higher incidence of diseases and pests, and increasing cost of inputs, in addition to the rising concerns of post-harvest losses, nutritional quality and safety of food, climate change, declining profits and above all the turbulence caused by COVID-19 pandemic, the use of frontier disruptive technologies and situation-specific innovations will be required to build diversified, secondary and specialty agriculture (TAAS, 2013). Establishment of appropriate regulatory machinery is needed for IPR and the ethical use of new technologies such as CRISPR/Cas-based gene editing, or release of second generation GMOs.

### 3.1 Innovations for Sustainable Agriculture and New Gains

At present, it is being argued that need of the time is a shift away from cereal-centric Green Revolution technology to diversified farming systems, which are more climate resilient and sustainable (Economic Survey, 2019). This needs to be supported by appropriate policies and programmes. Unlimited opportunities in unexplored frontiers of science exist to make new gains from application of STI for sustainable agricultural development. Important among these are: improved plant varieties using precise molecular breeding and GM technologies; improved livestock breeds and fish culture; conservation agriculture; farm mechanization and precision agriculture, solar power for small farm operations, integrated nutrient management (INM) and integrated pest management (IPM) encouraging use of genuine biofertilizers and biopesticides, post-production technology around value chain, etc. The benefits of frontier technologies when scaled in a mission-mode are immense for increasing income of small holder farmers (Jat, 2017). Establishment of 'Climate Smart Villages', has resulted in adoption of climate resilient technologies resulting in increase in area of direct seeded rice (DSR) particularly in Haryana, Punjab, Odisha, Andhra Pradesh and Karnataka, which would also reduce burning of crop residues. Apart from institutional innovations and right policies, specific actions are needed for: (i) strengthening scientific manpower through more investment in R&D and by forging viable partnerships with other players in the public and private sectors, (ii) revisiting rules and regulations for speeding transfer of technology, including paid extension, and (iii) fostering partnership with private sector for rapid commercialization of available technologies.

### *3.1.1 Genetic Resource Management and Crop Improvement*

The importance of rich genetic resources in crop variety improvement cannot be over emphasized. Germplasm enhancement/pre-breeding using wide gene pools and molecular breeding techniques are to be given higher credence in evolving high yielding, nutritive, biotic and abiotic stress resistant, widely adapted and climate resilient crop varieties/hybrids suited for diverse agro-ecologies. Immediate steps are needed to characterize and evaluate the vast germplasm repository available in national institutes and use the same for genetic improvement. Hybrid technology capable of offering greater climate resilience, better yield and quality, is to be fully exploited to increase crop productivity. Newer approaches for hybrid seed production, including use of doubled haploidy, apomictic and two-line F1 seeds, should be actively promoted to render hybrid seed more affordable.

Cultivation of genetically modified (GM) crops, covering around 191.7 mha globally (http://www.isaaa.org/resources/publications/annualreport/2018/pdf/ISAAA-Accomplishment_Report-2018) benefitted farmers through increased production and reduced use of costly inputs. India too has gained considerably through the release of Bt cotton, covering around 11 m ha benefitting millions of farmers (Reddy *et al*., 2014). It reduced the use of pesticides by almost 40 percent and doubled productivity, making India a leading cotton export nation fetching around USD 3 billion annually. Necessary policy decisions are needed for the release of GM varieties in soybean, rapeseed-mustard, maize, rice, potato, brinjal, tomato, etc., of course, without compromising bio-security, to sustainably enhance productivity, nutrition security, and farmers' income (NAAS, 2011 and 2016). Dispelling existing mistrust among some segments of the society on the regulatory system that deals with GM crops, requires transparent steps to establish a robust system to regulate GM and genetically edited crops.

Ensuring timely availability of quality seed of improved varieties/hybrids of crops to farmers to increase seed replacement rate (SRR) should be a national priority, for which both public and private sectors and farmers' organizations are to work in tandem. To ensure this, more realistic state-wise and crop-wise five-year rolling seed plans must be developed with adequate provision of breeders' rights and incentives.

Biofortification of staple crops is an urgent necessity to address the widely prevailing nutritional deficiency, especially among women and children. Varieties of QPM maize and protein rich wheat, biofortified rice and millets with high iron and zinc, and anthocyanin rich buck wheat, need to be popularized to ensure household nutritional security. On 16th October, 2020, the Prime Minister, Shri Narendra Modi, dedicated 17 biofortified varieties of eight crops, rich in one or more nutri-components such as Zn, Fe, Ca, lysine, tryptophan and protein, to the nation on the 75th anniversary of the Food and Agriculture Organization (FAO).Crop diversification through potential non-conventional crops, viz. underutilized pseudo-cereals, legumes and small millets, which have high nutritional value, resistance to diseases, drought and cold, potential to grow in marginal areas etc. are to be promoted as *'Crops for Future'*.

### *3.1.2 Natural Resource Management*

Conservation agriculture (CA), an innovation for sustainable intensification, is presently practiced in only about 10.3 m ha in the rice-wheat cropping systemin Indian part of Indo-Gangetic Plains (IGP) (Kumar *et al*., 2018). Shortage of farm labor and concern for water scarcity have already raised the area under direct seeded rice (DSR) to 25 percent in Punjab this year (Amid pandemic, direct seeding of rice helps Punjab farmers, *The Outlook*, 12 June 2020), reaffirming its scientific value. Being particularly suitable for rainfed farming, CA would help in arresting soil degradation, improving soil organic C content, conserving water and efficient use of nutrients, besides building resilience against climate risks, reducing the costs of cultivation as well as emission of greenhouse gases (GHGs). Hence, a mission on 'Conservation Agriculture for Sustainable Intensification (CASI)' would be a deciding step.

Organic agriculture (OA) occupies currently 1.5 m ha, which is about 30 percent of the total global area. To promote OA, there is need to develop specialized certified organic farming clusters in the *de-facto* organic eco-regions (hills, rainfed, dryland), such as the tribal belts of West- Eastern and North-Eastern Hill States (all kinds of produce), parts of Rajasthan (spices), Kerala (therapeutic rice, tuber crops, cashews, spices and condiments), Tamil Nadu and Karnataka (coffee, finger millet), Assam and hilly regions of West Bengal (tea), etc. Besides developing varieties suitable for organic production, there is a need to develop guidelines on standards and certification and to establish referral quality testing laboratories. For accelerated adoption of organic farming, "Modern Organic Agriculture Development Initiative (MOADI)" of the government is to be harnessed quickly (Paroda, 2019b).

Protected cultivation has the potential of increasing productivity and income by 3-5 times, and can encourage youth (including women) to become entrepreneurs. The current area in India under protected cultivation is around 50,000 ha, which has scope for at least to 4 times expansion (~200,000 ha) in the next five years (Paroda, 2019b). This requires to: (i) develop varieties of high value crops suited for protected cultivation, (ii) provide technical backstopping, (iii) promote the use of low-cost technologies and structures, viz. plastic mulch, low tunnel, walk in tunnel, naturally ventilated polyhouses, net houses, and environment controlled greenhouses, etc., and (iv) popularize soil less farming viz. hydroponic, aeroponic and aquaculture for high value agriculture.

Micro irrigation can help achieve more-from-less. Out of a total irrigated area of 64.7 m ha, only 7.7 m ha is presently covered under micro-irrigation, with a potential to double in the next decade to grow 'More Crop Per Drop'. For intensively irrigated (North-West), water congested ecologies with sub-optimal water use (Eastern India) and rainfed agro-ecosystems (south, west and central India), a five pronged strategy would be helpful: (i) precision water management practices (micro-irrigation, laser leveling, automation), (ii) reduced water wastage by discouraging flooding, (iii) cropping systems optimization and diversification, (iv) induction of solar pumps, and (v) on-farm rain-water harvesting. Hence, efficient water management technologies (conservation agriculture, raised-bed and furrow irrigation, precision land leveling, micro-irrigation, fertigation, plastic mulching, and field bunding), water pricing and ban on flood irrigation could help in doubling the water productivity. Further, crop intensification, recycling of wastewater, and managing blue water could help increase water availability for agriculture.

Increase in nutrient use efficiency (NUE), needs integrating the climate smart technologies with customized, slow release and liquid fertilization, integrated nutrient management (inorganic fertilizers with biofertilizers, vermi-compost, organic fertilizers, etc), linking fertilizer use to soil health status, and switching over to fertigation system in a phased manner. This necessitates institutionalization of fertilizer research in public-private partnership and a "Fertilizer Subsidy Policy Reform" through rationalized nutrient based subsidy (NBS) linked to soil health card and direct benefit transfer (DBT). Farm mechanization and innovative use of new technologies like bioinformatics, GIS, remote sensing, robotics, use of drones, artificial intelligence and precision farming offer viable options to bring efficiency in agriculture by increasing cropping intensity, attracting youth and reducing cost of production and drudgery of agricultural workers (especially women) (Paroda, 2019b).

### *3.1.3 Integrated Farming for Sustainability*

India is rich in livestock (with 15, 58, 18, 7 and 5 percent of world's cattle, buffalo, goat, sheep and poultry birds' population, respectively) and fishes (6.3 percent of global fish production), which contribute significantly to India's agrarian economy under diverse production systems. Therefore, sustainability of future agriculture would require integrated farming practices, leveraging on the principle of cyclic resource use.

Besides establishing sufficient semen banks for the livestock and production centres for fingerlings and juveniles of fish species, innovative and transformative technologies are must to make animal husbandry, poultry and fishing viable options for small farmers. Important among these are multiple ovulation and embryo transfer (MOET), ovum pick-up, and *in vitro* fertilization in animal breeding; rapid molecular diagnostics for major diseases in livestock, poultry and fish; molecular tagging for traceability; innovative fishing vessels and fish farming and aquaculture technologies such as re-circulatory aquaculture system (RAS), integrated multi-trophic aquaculture (IMTA), pen culture and waste water aquaculture (Paroda, 2019b; TIFAC, 2019) in meeting the dual challenges of climate change and depleting natural resources, while fulfilling the demands of nutritious and safe food products. There is an urgent need to characterize and prepare a comprehensive database of all livestock and poultry breeds in the country for conservation, breed improvement and utilization, including the revival of hardy native livestock breeds.

### *3.1.4 Integrated Plant Protection Strategy*

Annual crop loss due to pests and diseases ranges around 30-40 percent. (https://www.cabi.org/what-we-do/cabi-projects). Effective pest management measures, therefore, are a must, keeping in mind the growing concerns for pesticide residues for domestic and export markets and the long-term impact of pesticides in an ecosystem. The menace of spurious pesticides, which is estimated to be about 25 percent, needs resolution on priority. Cropping system- and location- specific technological innovations, including biological control methods are, therefore, needed for pest management. This also presents a strong case for adopting genetic manipulation technologies for biotic stress resistance in crop varieties through conventional breeding and GM technology. India established its credentials in molecular diagnostics and vaccine development for livestock and fishes. Similar lead is needed in locally developing green pesticide molecules. An active and viable public-private partnership will be the key in making successful market interventions and affordable pricing through competition.

### *3.1.5 ICT for Knowledge Dissemination and Attracting Youth in Agriculture*

Real time access to knowledge and information is critical for keeping pace with emerging technological development. There is a large gamut of applications and e-Governance workflow systems that can harness the power of ICT in agriculture through appropriate policies and frameworks; need is to promote: (i) Factor Independent Mobile Device Apps, (ii) Internet of Things (IoT) for monitoring and automation of farming activities, (iii) Big Data Analytics and Dashboard for planning and monitoring the impact, (iv) Block chain in agriculture for transparencies and increased trust level, (v) GIS technology for mapping farming activities, and (vi) Artificial Intelligence (AI) for monitoring and forecasting of agricultural commodity prices and global trends in agricultural trade. Further, post-production management, such as low cost primary processing, value addition, cool chains for perishable items, grading and packaging, online marketing through e-NAM etc. would all need efficient ICT support for increasing farmers' income.

Pluralistic and innovative extension approaches are critical for faster delivery of information and technology. Competencies of extension agencies especially youth (including women) as 'Technology Agents' need to be improved by systematic capacity building so as to enable them to respond better to emerging challenges. This achievement is possible only through better knowledge sharing, skill development and mentoring of youth, making them an integral part of "Plough-to-Plate Agri-Food System", promoting agri-preneurship through a dedicated "Agri-Youth Innovation Corpus Fund" for rural start-ups.

### *3.1.6 Innovative Post-Harvest Technologies for Extended Shelf Life and Value Addition*

Innovative primary processing, dehydration and pasteurization technology at the farm gate, for extending shelf-life of farm produce, specially fruits and vegetables, milk and fish using solar power and low cost storage facilities; advance processing technologies for value added and ready-to-use products and nutraceutical development, are some other vital areas that hold promise to increase value from agriculture both in domestic and export markets, as well as providing nutrition security.

## 3.2 IPR Issues and their Application

Pre-requisites for adoption of cutting edge technologies, such as genetically modified and gene edited plant varieties, in agriculture, are the appropriate regulatory system and conducive policy support. Intellectual property (IP) protection for innovation, including Plant Breeder's Rights (PBRs) for varieties/hybrids, and prompt approval of the Biotechnology Regulatory Authority of India (BRAI)are vital in encouraging investments in second generation agricultural innovation.

The recent cases of infringement of IP for Herbicide Tolerant Bt (HTBt) cotton and illegal production and sale of seeds of such hybrids by several unauthorized seed companies brought forth the weakness of the regulatory system in protecting the IP of technology developers. In the cotton seed industry worth INR2,500-3,000 crore (INR 25,000-30,000 million), nearly INR 400 crore (INR 4,000 million) was accounted for by illegal seeds (Federation of Seed Industry of India, personal communication). Owing to this massive misappropriation of the IPR of HTBt, the government lost substantial tax revenue, farmers were denied seed quality assurance and after sale services in spite of paying 50 percent higher price per packet of seed, and the technology developer gained nothing from its huge investment.

On the other end of the spectrum, there are instances of potato farmers, breaching the contract with the technology (variety) developer, under the provisions of Section 39 of the PPV & FR Act, 2001, which allows them to grow, save, exchange, sell or sow the produce of a variety registered with the PPV & FR Authority. The Act does not differentiate between the seed and vegetatively- propagated planting material and their end use. Such concerns may need to be addressed through necessary amendments of the Rules.

Hence, protecting the rights of farmers, incentives to private sector on par with public sector; provision of exclusive rights for public-bred varieties/hybrids for specific regions/states; third party crop-auditing (reliable assessment of actual acreage under different varieties and payments of royalties based on it), and strict implementation of IP regulations are called for. Consequently, for wider adoption of frontier technologies and innovations, institutional and policy reforms such as harmonization of National Intellectual Property Rights (IPR) Policy, 2016, the Protection of Plant Variety and Farmers' Rights Act (PPV & FRA), 2001 and the national Biological Diversity Act (BDA), 2002 would pave the way (Saxena, 2017; Singh, 2019). This will ensure effective access and benefit sharing (ABS) by all those involved in the innovation chain and encourage more investment by the private sector in research and development (R&D). Ministries and statutory bodies concerned with IP protection may revisit existing laws/acts and remove grey areas by bringing in necessary amendments for making regulatory frameworks innovation-friendly and scaling disruptive innovations in agriculture.

## 4. Indigenous Technical Knowledge in Agriculture

Indigenous Technical Knowledge (ITK) has immense value in innovation and plays significant role in agricultural growth. The knowledge inherently acquired by the indigenous communities in different ecosystems is valuable for climate adaptation, natural resource management, processing/preservation, storage, and medicinal value.

Traditional knowledge of farmers in conserving and identifying useful biological material, embodied in biotechnological innovations, offers an effective strategy for achieving sustainable food security (Blakeney and Siddique, 2020).

### 4.1 ITK: A Valuable Resource

The Inter-Governmental Panel on Climate Change (IPCC) highlighted the importance of ITK and indigenous crop varieties in adaptation, climate change monitoring and mitigation (IPCC, 2014). Traditional practices have helped better adaptation such as: (i) raising of short duration drought hardy and heat tolerant crops on marginal lands, (ii) conserving the seeds and use of local landraces with adaptive characteristics over generations, (iii) having knowledge for alternative food, feed, fiber, medicinal resources, etc. available locally in the forest or wild areas to rely when crops fail; (iv) practicing traditional farming to conserve natural resources for better resilience and adaptation; and (v) using traditional knowledge to predict and forecast the extreme events and take precautionary steps to survive extreme vagaries of nature.

A well recognized fact is that traditional varieties and landraces are genetically better equipped to withstand environmental stresses such as scarcity of water, less availability of nutrients and extreme temperature. Tribal areas across the country conserve rich diversity of plants and animals and provide a valuable source of rare germplasm for several species that can tolerate extreme weather and soil conditions and possess novel traits. Moreover, there are several nutricrops such as minor millets, moth bean, cowpea, faba bean, taramira, lathyrus, etc. that have great relevance for adaptation to drought and high temperature. The traditional crop varieties are easily accessible as they come from farmers' own saved seeds and shared with the local communities, with women playing an important role.

## 4.2 Threats to Traditional Knowledge and Initiatives on Protecting ITK

ITK, generally transmitted verbally, in most cases are lost due to lack of proper documentation. It is, therefore, necessary that available ITK is documented, maintained to avoid dissemination loss, validated and refined to make agriculture more sustainable. The Convention on Biological Diversity (CBD) acknowledges the contribution of traditional knowledge in protecting species, ecosystems and landscapes. In India, both the Biological Diversity Act (BDA), 2002 and the Protection of Plant Varieties and Farmers' Rights Act (PPV&FRA), 2001 have included necessary provisions for protection of ITK. The need for access and benefit sharing (ABS), an important instrument in using ITK, was included in these Acts. Perhaps PPV&FRA is the only national legislation in the world, which recognizes farmers as plant breeders. As a result, 1649 farmers' varieties have already been registered as on 11 March 2020 (PPV& FRA, personal communication), although the work to mainstream them in the seed supply chain still remains. However, there exists no provision of incentives for ITK related to other sustainable agricultural practices like integrated nutrient management (INM), integrated pest management (IPM) and organic farming. The context of local knowledge systems in agriculture needs to be understood, tested and given legal protection for scaling.

## 4.3 Using ITKs and Farmers' Wisdom for Agricultural Sustainability

Indigenous people are custodians of traditional knowledge, have different perceptions, and follow varied adaptation strategies to adjust with the ecosystem. There are several good examples of indigenous crops and local cultivation practices to sustain the vagaries of environment. These, integrated with scientific knowledge, can play important role in designing policy for climate change adaptation. Women are excellent source of both genetic and cultural information on plant and animal species, and play a crucial role in developing climate resilient models of agriculture.

Shifting of planting and harvesting dates, crop diversification, integrated crop-livestock-fish farming, and cultivation of drought-resistant crops and varieties are some of the sustainable approaches to climate change adaptation. The practices of mixed farming e.g. Satanaja (7 crops in one field) and Gyarahnaja (11 crops in one field) are still prevalent in tribal belts and also practiced in dryland states to reduce the risk of crop failure. It is estimated that traditional multiple cropping systems provide 15-20 percent of the world's food needs. It not only ensures better yield stability and food diversity, but also decreases the pest risk.

Crop rotation, an ancient practice, has recaptured the global attention to solve a variety of agro-ecological problems such as low WUE and soil erosion (Huang *et al.*, 2003), and promote carbon sequestration (Triberti *et al*, 2016). It also has a potential to reduce the emissions of greenhouse gases (MoSTE, 2015; Theisen *et al.*, 2017). Similarly, there are examples of ITKs relating to dietary innovations having health, therapeutic and medicinal values to humans and animals and *desi*(local) medicines made from organic and inorganic ingredients for pest and disease management (Sarkar *et al.*, 2015).

While the value of ITKs cannot be undermined in this land of *Vedas*, scientific validation through experimental verification, refinement and logical integration will pave the way to sustainable agriculture. Many of these traditional techniques have great potential for meeting the future challenges while reducing use of chemicals which, if are not used judiciously, can harm our food chain and environment (Kumar *et al.*, 2014).

The network of frontline research extension system developed by the ICAR, which operates through its 721 KVKs (Agricultural Science Centres) under 11 Agricultural Technology Application Research Institutes (ATARI), is considered to be a unique institutional model, majority of which function under the state agricultural universities providing a two-way platform between farmers and technology developers. These are also the primary centres for capacity building and adoption of new technologies, as well as for sharing information and planting materials.

## 5. Innovative Technology Diffusion Options

Developing innovative technologies is only the halfway to meet the challenges in agriculture, their timely and targeted diffusion completes the goal. In spite of increased investments in agricultural research and extension in the past decades, the impact on the livelihoods of small farmers had not been significant, as mostly the improved technologies did not reach them. Therefore, well-functioning agricultural extension and advisory services are essential for translating technological achievements into tangible gains (Babu *et al*., 2019).

Innovative technologies suggested in the previous sections will help increase the income of small and marginal farmers by enhancing the value of farm output and reducing the cost of operations. These would be integral to a sustainable model of profitable agriculture across the divergent scenario in the country. Effective diffusion of such innovations holds the key to achieve success in agriculture. It is also important that with the growing presence of pluralistic extension system with varied approaches, a robust research framework and methodology is put into practice (NAAS, 2017).

During the COVID-19 pandemic, several new multi-dimensional challenges emerged impacting food and rural livelihood security; these are going to affect the food and nutrition security of the country, and also the livelihoods of over 50 percent of the population depending on agriculture, directly or indirectly (*The India Today*, 4 May 2020). Transformational innovations in agriculture, therefore, have to be affordable, profitable, rugged and user-friendly, and supported by an efficient diffusion strategy.

The Green Revolution showed the importance of an efficient agricultural extension and advisory services. Conventionally, agricultural extension is in the domain of public sector, comprising State Extension machineries including line departments and Agricultural Technology Management Agency (ATMA), ICAR institutes and SAUs including the KVKs. However, it still left big gaps between the technology development and dissemination on one hand and developing need based technologies on the other. As a result, it could cater to only about 15 percent of the total mandated area of extension system, leaving majority of small farmers deprived of all resources including information and appropriate technology. However, the scope of innovative technology development and their diffusion has undergone significant changes in the last 10 to 15 years, with the involvement of a range of service providers including the private sector, NGOs, farmer organizations, civil societies and independent professionals. This was further boosted by a revolution in communication technology. Mobile-based agro-advisory models delivering information based on real time conditions, and farmers' participatory programmes undertaken by the private sector and NGOs are complementing the existing extension services for a better last mile penetration. These have brought forth some efficient and cost effective extension models such as Indian Farmers Fertilizers Co-operatives *Kisan Sanchar* Limited (IKSL); e-Chaupal of ITC, and aggregated vegetable farming and seed production by small farmers by SFI and BAIF (Mittal *et al*., 2019).

There are several innovative technologies ready to be scaled up and scaled out (*see* Box below), where skilled intermediaries can act as effective links between the technology providers and farmers. However, for the available extension machinery, better coordination among different players and active participation of private sector and paid service providers are going to be vital. Indian farmers demonstrate high levels of ingenuity in devising grassroots innovations, and re-engineered innovative technologies using local resources, which are valuable in solving situation-specific problems in cost-effective manner. Therefore, farmer-led innovations also need to be assessed, validated, refined and out scaled to harness their full benefits, and adopted in a participatory mode involving all stakeholders (Paroda, 2019a).

- Hybrid technology(maize, *bajra*, sorghum, rice)
- Biotechnology - GM crops(soybean, mustard, maize, brinjal)
- Conservation agriculture (3.5 to 20 m ha)
- Protected cultivation (expand area from 50000 ha to 2.00 m ha)
- Micro-irrigation (discourage flood irrigation) –at least 10 m ha
- Bioenergy/biofuel (use of sugarcane and maize - initially 20%)
- Biofortified crops (QP maize, Fe and Zn rich rice, Fe rich *bajra*, Zn rich wheat)
- ICT for knowledge sharing, ex. e-Chaupal

(Paroda, 2019b)

Since the customers are typically resource poor in agricultural sector, following the principle of making profit at the 'Bottom of the Pyramid', diffusion model need to target a large number of users who can use such innovations at a reasonable cost. Options are suggested here for effective diffusion of innovative technologies.

## 5.1 Integration and Coordination among Different Departments

Agricultural extension is primarily a State subject, though the Government of India provides both technical and financial support through ICAR and various other programmes, such as Agricultural Technology Management Agency (ATMA) scheme, which is operating in 676 districts, RKVY (National Agriculture Development Program), Technology Missions.

Some of the initiatives by the Ministry of Agriculture and Farmers' Welfare, like Attracting and Retaining Youth in Agriculture (ARYA), Value Addition and Technology Incubation Centres in Agriculture (VATICA),National Repository of Information for Women (NARI), Mera Gaon Mera Gaurav (MGMG),National Skill Qualification Framework, knowledge systems and homestead agricultural management in tribal areas, climate smart villages, web and mobile advisory services have helped in the faster adoption of sustainable innovations (Paroda, 2019a), and also laid focus on engaging women and youth. Similarly, several programmes by the Department of Biotechnology (DBT) and National Innovation Foundation (NIF) have helped faster adoption of innovative technologies and promoting entrepreneurship.

Effective integration is required among various government institutions and departments to identify technology gaps and offer most appropriate technologies, leveraging on government schemes and incentives. Revamping organizational set up, employing contractual skilled staff, preferably from the same locality, as technology agents and undertaking farmer-led participatory schemes should hold the key.

## 5.2 Public-Private Partnership

Unlike consumer goods, innovations in agriculture face a higher market risk if the product basket is limited. With a large portfolio of innovations, only a few successful ones can more than pay for failures; whereas with a small portfolio it may only incur loss, profitability, and their diffusion is typically left to the state and federal extension machinery. Government policy may consider an option of putting a reasonable cap on the MRP of agriculture technologies on case to case basis, if required, instead of blanket orders but providing a level playing field for all players, to let the best technology spread. Agrinnovate India Ltd of ICAR- an interface with the private sector, can provide such a platform (Saxena, 2017). However, the requirements of smallholder farmers must critically be assessed through on-farm testing while planning for either up-scaling or out-scaling new innovations (Gulati *et al.*, 2006; Swarup, 2017 and Pal *et al.*, 2017).

Partnering of corporate houses with public institutions or local bodies at village/block level, be it a local Farmers' Group, Self Help Group (SHG), NGO, or a village level Start Up, needs to be encouraged for quick and effective dissemination of knowledge and technology transfer. Leveraging Corporate Social Responsibility (CSR) offers an effective option for popularization of innovative technologies. While others can run on business models of rural entrepreneurship, partnership between the state agriculture departments with private technology providers can result in quick diffusion of innovative technologies providing sustainable solutions (https://www.business-standard.com/article/pti-stories/cropin-/4 March, 2019).

## 5.3 Local is Vocal

Diversity in agricultural systems, crops and other farm products is an untapped resource for uplifting rural economy which needs to be showcased and made popular by linking farmers, especially women SHGs, with corporate sectors through innovative marketing strategy. For instance, traditional crops and varieties, having special quality attributes, special food preparations and household items can be brought main stream and popularized as unique local products through ethnic food festivals and branding, in line of *"One village One product"* movement championed by Japan and adopted by Thailand and Sub-Saharan Africa (www.odi.org/publications). As most of these local crops/ varieties are not only rich in nutrients, but by default, are also amenable to organic cultivation, necessary policy support and financial incentives for their cultivation and consumption would also help build nutrition security and promote local products in domestic as well as export markets.

## 5.4 Technology Parks, Custom Hiring Centres and Agri-Business Hubs as Active Platforms for Technology Diffusion

Establishing '*Technology Parks*' and agri-business hubs would serve as innovation platforms, and also encourage rural graduates, entrepreneurs and young professionals to start businesses and bring technological and managerial expertise to rural areas. Policy support and financial incentives can drive establishment of ancillary agri-businesses, startups and small scale enterprises (MSMEs), such as those based on post-harvest value added products, Agri-Clinics, Agri-Input centres, farm gate storage, sorting and grading houses and cool chain facilities. Since agriculture based startups experience difficulty in finding venture capital, incentives and credit availability on easy terms (Saxena, 2017) can boost the scope of such businesses. As farm mechanization and precision farming are going to be indispensable in agriculture, Custom Hiring Centres (CHC) need to be established in every block and village under the Sub-Mission on Agricultural Mechanization (SMAM) scheme of GoI (Farm Mechanization in India, 2015.http://www.agricoop.nic.in/). Similarly, 'Uberization' or affordable rental of farm-friendly vehicles for quick transport of farm produce and inputs is a promising option. The CHCs and rental services could be vital in bringing the benefits of mechanization to small farmers, as well as in overall knowledge dissemination, and attracting youth in agriculture.

## 5.5 Innovation and Incubation Centres

Model Innovation Centres should be established at SAU campuses linking farmers, agriculture and agri-food professionals, agribusiness, and entrepreneurs through digital communication channels to trigger new opportunities and harnessing best of the science and technology in serving farmers. This will provide an opportunity to young graduates to work as interns gaining hands-on experience that will jump start their careers. The incubators for start-up companies will help convert innovations into commercial businesses and boost the Startup India initiative.

## 5.6 Farmer-led Extension

In the wake of COVID-19 pandemic, the country has experienced an unprecedented reverse migration of farm labour, most of which have acquired new skills and knowledge while working in different regions and diverse farming systems. With some formal training, these farmers can be made *Technology Champions* for testing and lateral diffusion of innovative technologies. Support at state level is needed to engage these farmers to diffuse technology, while creating employment and checking migration.

Creation of self-managed Farmers' Groups in village clusters or blocks could be another effective model, where each farmer pays a small membership fee to benefit from knowledge bank, advisory services and innovation repository. These may be interlinked (but not compulsorily so) with 100 such groups in other clusters, blocks and districts. These will also have direct links with input dealers, market nodes, veterinary service providers, market aggregators, CHCs and financial institutions. Principally, following ATMA model, these can run like a commercial activity, with formal or informal aggregation at the base of functioning.

## 5.7 Innovation Agents – Role of Skilled Youth and Women in Agriculture

Like para-medics, there is need for a band of skilled technology providers as Innovation Agents, at village cluster levels covering services from knowledge share, input supply, market links, machine hire and/or use, care of farm machineries, maintenance of horticultural nurseries, technology support to the livestock, poultry and fisheries enterprises. Engagement of *Mausam Mitra* and *Mausam Didi* in the lines of *Kisan Mitra / Pashu Mitra* and *Kisan Didi/ Pashu Didi* model of ATMA may also be considered to spread weather based Agromet Advisories in the rural areas.

### 5.8 New Models for Capacity Building

Application of many new innovations may require a new set of skills or up-gradation of the existing ones. Indian youth, including the rural population, are fairly tech savvy and eager to learn. The first and foremost requirement for adoption of innovative precision technologies is training of local youth for vocational skills. Short Diploma courses offered by institutions accredited by ICAR or AICTE and intensive hands-on training of farm technologies by the KVKs are the need of the hour. Though the traditional methods of training involving instructor-led approach works well, yet it has limitations of penetration and access, especially in COVID-19 scenario and reaching the far flung and difficult to reach areas. In these situations, use of Extended Reality (XR) simulation platforms could be an option. Effective linkages will be needed with the programmes supported by the Agriculture Skill Council of India (ASCI) for skill development of local youth and NAERS, including some of the private colleges and deemed-to-be universities. The existing network of KVKs spread across the country can be identified as nodal points for imparting hands-on experience, evaluation and up-gradation of local skill levels.

### 5.9 Agriculture Innovation Board

A National Agri-Innovation Board may be created for quick development of need-based technology, up-scaling and out-scaling of agri-innovations and their quick adoption, in the MoA&FW under the chairmanship of an eminent agricultural scientist with members drawn from other sectors and concerned ministries (Paroda, 2019a). The board should develop an Agricultural Knowledge and Innovation System (AKIS) for (i)accelerating knowledge flows and strengthening links between research and practice, (ii) strengthening all farm advisory services and fostering their interconnections within the AKIS, (iii) enhancing cross thematic and inter-disciplinary innovation, and (iv) supporting the digital transition in agriculture. The Board could extend funding support in the form of venture capital a must for agri-startups.

## 6. Non-Agricultural Disruptive Technologies Influencing Innovations in Agriculture

Massive cross-sectoral, interdisciplinary technological shifts are of common occurrence in the present scenario. Agriculture is no exception. Though, it is not considered an industry *per se*, agriculture contributes ~17 percent to the national GDP, directly feeding to several major industries, including FMCGs. It is also expected that for increasing the profitability in agriculture, mechanization, automation, use of resource conserving technologies, data management and ICTs will be the order of the day in the coming years. Hence, several technological innovations in non-agricultural sectors would be influencing the core agricultural innovations in the years to come. Some such examples are discussed here.

## 6.1 Blockchain Technology- from Crop Management, Marketing and Procurement to Certification and Traceability

Besides its huge application in the value chain for on line transactions, as Blockchain or Distributed Ledger Technologies (DLT) that permits entry and data check at every 'node point' and allows the use to be tracked, it can be extremely useful for establishing 'farm to fork' traceability in food commodities and in processes like Organic Food and Seed Certification, which are crucial in fixing the accountability in case of poor quality of a food product or unsatisfactory performance of a seed lot, respectively. Similar applications are envisaged in a number of other input use and product quality management.

## 6.2 Application of Biosensors in Agriculture and Allied Fields

With growing concerns about air, water and soil pollution, effective diagnosis of pathotypes, rapid, precise and cost effective analysis, and monitoring of food and other agricultural products are assuming greater salience. Biosensors (analytical devices that convert a biological response into an electrical signal, including enzymes, antibodies, nucleic acids, microorganisms etc.), in this way are being used in medicine and healthcare. It may be considered for a wide array of application in agriculture and allied industries.

## 6.3 Use of Non-Fossil Fuel – a Win-Win Option

India is making rapid advancement in the use of non-fossil fuel for various purposes, mainly transportation, agriculture, domestic and industrial use. India has bred excellent sugarcane varieties both for tropical and sub-tropical regions, with high sugar recovery, and maize and sorghum varieties suitable for bioethanol production. Many engineering institutions, independently and in collaboration with international institutions as well as industry partners (e.g., IIT, Madras and ExxonMobil, https://timesofindia.indiatimes.com, 14 Oct 2019) are engaged in developing affordable technology for bioethanol production. Several pre-treatment processes are already perfected to bring down the production cost of biofuels (Chundawat, 2020), and more refined technologies are in the offing. By adopting a viable technology, India can easily substitute 20 percent or more of its fuel use by bioethanol. This will reduce our C footprints, and also offer better remuneration to farmers cultivating biofuel crops.

## 6.4 Solar Power for Sustainable Agriculture

Use of renewable energy sources, particularly solar power is vital in agriculture. Though these are being promoted for a very long time, their use is limited and localized due to the high initial investment and lack of affordable and efficient power storage system (power grid and batteries). The costs of panels have come down substantially, but India is still tech-dependent on other countries in affordable battery manufacturing. Solar powered pumps are already being promoted by the GoI through various schemes and incentives; and special scheme for farmers for the installation of solar pumps and grid-connected solar power plants targets to add 25750 MW of combined solar capacities by the year 2022 (*The Economic Times*, https://economictimes.indiatimes.com/ Updated 23 August 2019). Advancement in this sector is going to directly impact almost all activities related to agriculture.

### 6.5 Waste Management and Agriculture

Urban waste management is one of the top priorities in India, both for controlling environment pollution and maintaining sanitation, as well as for creating wealth from waste. The S&T institutions under CSIR, ICAR, IITs, DRDO, private sector agencies and NGOs are working towards finding practical solutions (TERI, 2015). For India, which uses 70 percent of its water for agriculture and also faces poor soil health problem due to low organic C content, effective waste management (solid and water based) technologies could not only solve the civic woes, but also prove a boon to agriculture. Models developed by the IITs and other engineering institutions (viz. zero chemical Continuous Aerobic Multi-Stage Soil Biotechnology (CAMUS-SBT) for waste water treatment developed by IIT, B) are addressing the water needs in agriculture and sustainable ways to meet it (www.thebetterindia.com/210034/iit-bombay-wastewater-treatment-technology-sustainable-startup-india, Jan 20, 2020). Such technologies need to be spread fast with necessary policy support and public-private partnerships.

## 7. Rejuvenating Agricultural Education System (AES)

### 7.1 State of the Agricultural Education System

Agricultural education system in India is based on the Agricultural Universities (AUs), which are structured on the Land-Grant pattern of the USA - integrating teaching, research, and extension. Starting with GB Pant University of Agriculture and Technology, Pantnagar in 1960, today sixty three State Agricultural Universities (SAUs), three Central Agricultural Universities (CAUs), four Deemed Universities (DUs) and four Central Universities with Agricultural Faculty, together comprise the 74 Agricultural Universities of the country. Added to the above educational institutions, 106 ICAR institutes, 11 ATARIs, 721 *Krishi Vigyan Kendras* (KVKs or Agriculture Science Centres), 57 All India Coordinated Research Projects (AICRP), and 25 Network projects constitute the National Agricultural Research and Education System (NARES) – the largest in the world. The AUs and ICAR institutes have been harbingers of the Green and the Rainbow Revolutions, and generating the needed scientific manpower, teachers, technologies and transferring these to transform India from 'Ship-to-Mouth' situation to the 'Right-to-Food' status.

### 7.2 Asymmetries and Shortcomings in the AES

The Rainbow Revolution notwithstanding, India's agrarian progress during the past few years has slackened and serious asymmetries are noted in science-led growth of agriculture. This could partly be attributed to the decline in quality and responsiveness of agricultural education system in the country, resulting from the following shortcomings:

i) Inadequate investment and declining financial resources in agricultural universities/colleges; opening of new institutions without matching resources and norms; unmindful splitting of agricultural universities, poor resource planning, and poor coordination between Centre and States;

ii) Disconnect among agricultural education, employment, and industries' requirements; lack of adequate skill, entrepreneurship and experiential learning; overall poor employability of agricultural graduates;

iii) Extensive inbreeding; low access of agricultural education to rural students, especially to the tribal and socially-deprived communities;

iv) Inadequate academic rigor and contextualization of emerging challenges and opportunities; erosion of Basic Sciences from agricultural courses; poor quality and insufficient academic staff (inbreeding and unfilled faculty positions); widening disconnect between education, research, and extension resulting in knowledge deficit; limited internalization of relevant international trends and developments; indifference of youth towards agriculture; and

v) Poor system of evaluation, monitoring, impact assessment, accountability and incentive systems; limited digitalization; and inefficient governance.

## 7.3 Alleviating the Asymmetries for Rejuvenating the System

Towards resolving the above asymmetries and rejuvenating India's agricultural education system, the following approaches and actions, mostly arising from the NAAS's XI National Agricultural Science Congress (Singh, 2014; NAAS, 2014) and the Fifth Deans' Committee Report (ICAR, 2016), should be adopted.

- Embrace agricultural education for development (AE4D) as an integral component of the national agricultural policy in creating a world-class agricultural university system attuned to face local, national, and international challenges and opportunities
- Build integrated, multi-faculty, and multi-disciplinary institutions; Ensure and institutionalize transparent governance, autonomy, meritocracy, judicious allocation of resources, and accountable systems of evaluation (measure to manage)
- Minimize inbreeding and promote institutional linkages, focusing on standards, norms, and accreditation; strengthen basic and emerging sciences in agricultural education and research; nurture centers of excellence
- Strengthen and streamline Centre-State partnership with differentiated but reiterative responsibilities
- Revamp teaching/learning processes and pedagogy to attract best of talents for preparing the "Youth for Leadership in Agriculture"
- Institutionalize skill development, entrepreneurship and experiential learning programmes, and invest on non-formal education and vocational training in agricultural technologies
- Support development of active and long-term international cooperation, rejuvenate and replicate successful collaboration models, and launch South-South, South-North and trilateral collaborations.

## 7.4 Quality Assurance in Education

Quality assurance in higher agricultural education, pursued by ICAR/DARE/SAUs, involves accreditation, framing of minimum standards for higher education, academic regulations, personnel policies, review of course curricula and delivery systems, support for creating/strengthening infrastructure and facilities, improvement of faculty competence and admission of students through All India Examination. The ICAR's Fifth Deans' Committee Report (ICAR, 2016) restructured the course curricula to underpin relevant practical skills, entrepreneurial aptitude, self-employment, leadership qualities and confidence among graduates, and attracting and retaining youth in agriculture. Further, the Committee recommended that all degrees in the disciplines of Agricultural Sciences should be declared as professional course degrees, and sought to achieve global level of academic excellence. It also suggested norms for establishing new colleges.

In order to harness regional specialties and to meet region-specific needs, certain optional courses such as Coastal Agriculture, Hill Agriculture, Tribal Agriculture etc. were formulated. New degree programmes and courses were recommended in emerging fields like genomics (biotechnology), nanotechnology, GIS, precision farming, conservation agriculture, secondary agriculture, hi-tech cultivation, specialty agriculture, renewable energy, artificial intelligence, big data analytics, mechatronics, plastics in agriculture, dryland horticulture, agro-meteorology and climate change, waste disposal and pollution abatement, food plant regulations and licensing, food quality, safety standards and certification, food storage engineering, food plant sanitation and environmental control, emerging food processing technologies, sericulture, community science, and food nutrition and dietetics.

The ongoing World Bank supported National Agricultural Higher Education Project (NAHEP), built on the preceding World Bank projects, particularly NATP and NAEP, is poised to– strengthen capacities of faculty and other staff at all levels, foster linkages of the national system with global knowledge economy, facilitate International Experiential Learning, promote learning-centred education, and fortify partnership with private industries.

In compliance with the Student READY programme launched in 2015, the Committee has designed one year programme in all the UG disciplines comprising (i) Experiential Learning, including International Experiential Learning wherever feasible; (ii) Rural Agriculture Work Experience; (iii) In-plant Training/ Industrial Attachment; (iv) Hands-on Training (HOT) / Skill Development Training; (v) Students Projects, and (vi) the Agricultural Science Pursuit for Inspired Research Excellence (ASPIRE) programme.

## 7.5 Paradigm Shifts Needed for Rejuvenating Agricultural Education System

In the spirit of *Reform, Perform and Transform*, paradigm shifts are needed for rejuvenating India's Agricultural Education System and change from Land-Grant to World Grant system, as local and global are no longer independent. The new curricula, courses and contents should keep evolving, dynamically encompassing the new global initiatives, such as Global Green Economy; Knowledge Economy; Global Zero Hunger Challenge; UN International Year themes etc. Reiterating the role of Agriculture (A)as a pivotal agent of change, it is suggested that agriculture be amalgamated with science, technology, engineering, and mathematics (STEM), thus transforming ***STEM*** into ***STEAM***. India should move towards ranking of its universities, including AUs, for raising the level of knowledge domains, meritocracy and governance as per the indicators suggested by the National Academy of Agricultural Sciences (NAAS), making our students globally relevant.

Synergizing excellence and relevance, new approaches towards building qualified human resources, for instance, custom-designed Massive Open Online Courses (MOOC) and establishing Model Innovation and Incubation Centres, are being popularized in NARES. It also prepared a roadmap for mentoring, emphasizing the need for matching the experience and wisdom of mentors with the learning needs of mentees, thus building bridges across the hierarchy levels, empowering change management, enhancing work ownership and sharing of responsibility, and expanding learning ecosystem and good practices. This is in line with the programmes of the Department of Science and Technology (DST), especially Innovation in

Science Pursuit for Inspired Research (INSPIRE), and of the Ministry of Human Resources Development (MoHRD), particularly its support to the Global Initiatives of Academic Network (GIAN). Thus, rejuvenated agricultural education would transform the agrarian economy, and attract foreign students, rendering the Government's Study in India initiative a success.

The above transformational changes will be boosted by the New Education Policy (NEP)2020, adopted by the Union Cabinet headed by the Prime Minister on 29 July 2020. The Prime Minister elaborated the aim of the Policy at the education conclave held on 7 August 2020 and led the pledge to implement it effectively, including allocation of Rupees hundred thousand crore to begin with. The NEP envisions an educational system that makes good human beings with skill and expertise contributing directly to transforming our nation sustainably into an equitable and vibrant knowledge society, by providing high quality education to all, making our students a global citizen, thus rendering NEP as the foundation for New India. Retraining, up-skilling, and retooling of teachers, students, and related staff, bridging gap between education and research by adopting a holistic approach, strengthening of vocational education, autonomy to institutions, and establishing a self-sufficient domestic ranking system for Indian educational institutions, are the main planks of NEP 2020. Consequently, the Ministry of Human Resource Development (MoHRD) has been renamed as the Ministry of Education (MoE, GoI, 2020).

## 8. Pathways from Research to Innovation for Impact

The UN Inter Agency Task Team (IATT, 2020) had underpinned that science, technology, and innovation, the key means for achieving the Agenda 2030, must be coherently integrated to meet economic, social, and environmental aspirations in line with the SDGs. The UN Guidebook for the Preparation of STI for SDGs Roadmaps has emphasized integrating STI and the SDG Plans with the National Plan. Emphasizing that, 'The Future is Now: Science for Achieving Sustainable Development", IATT suggested six key steps and three core inputs for developing STI for SDGs roadmaps, as elucidated in Figure 1.

The UN, in collaboration with World Bank, other international organizations, and multilateral donor agencies, is pilot testing the guidebook approach with India, as one of the initial five participating countries.

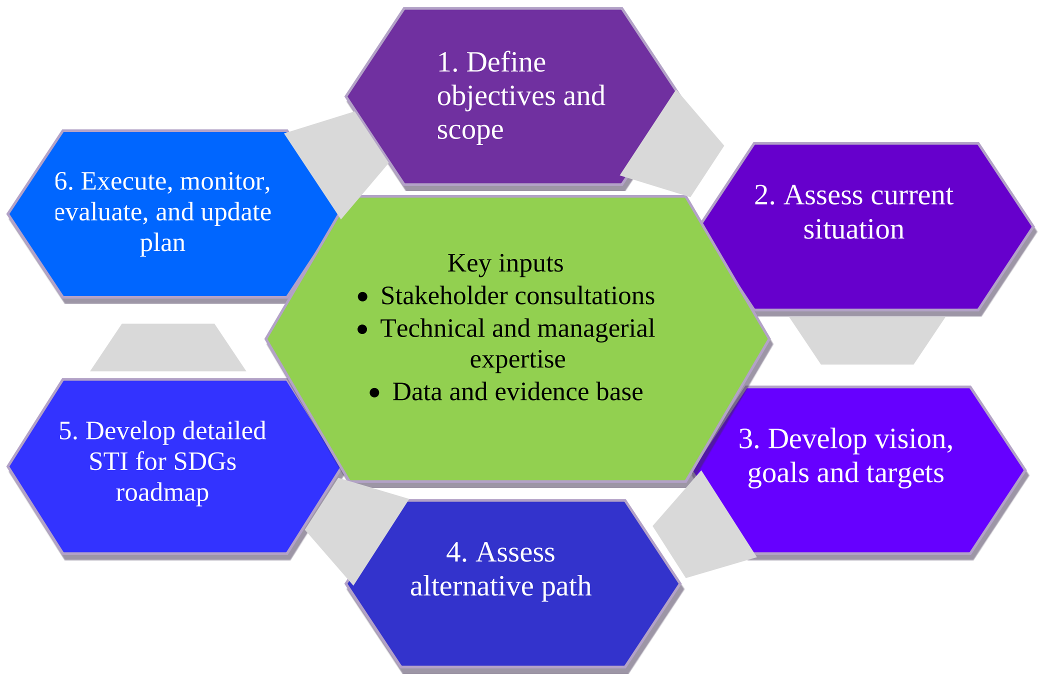


Fig.1. Process flow of six key steps in the development of STI for SDGS roadmaps

*Source: Guidebook for the Preparation of Science, Technology and Innovation (STI) for SDGs Roadmaps (IATT, 2020).*

In India, the Office of the Principal Scientific Adviser, NITI Aayog, and other concerned offices, underpinning the current policy and strategy frameworks, jointly prepared the STI for SDGs Roadmaps, emphasizing agriculture, energy, water, biodiversity, and comprehensive food, nutrition, health, livelihood, and environmental securities - One Health One World inter-linkages, multi-disciplinary and system approaches, inclusiveness, digitalization, climate smart agriculture, and resilience to biotic and abiotic stresses. It underpins the essentiality of coupling of funding with technology transfer as also envisaged in the Multilateral Fund under the Montreal Protocol, Green Climate Fund, GEF, and UNFCC, which are supporting the STI for SDGs global movement. The Roadmap suggests: (i) establishing a Technology Facilitating Mechanism, (ii) adopting new models for incentivizing innovations for global public goods and enhancing access to them, and (iii) integrating STI cooperation into strategies for the achievement of the SDGs.

An Agri-Food system-based approach has been adopted for addressing the large and systemic challenges the country is facing. The food systems lens should secure that research and innovations in sub-systems are clustered, monitored, and evaluated from the overall food systems viewpoint. It will identify leverage points for improving a specific outcome without compromising other desirable outcomes. India's roadmap is designed to build inclusive food systems (IFPRI, 2020) to wipe off the Indian enigma of being food surplus and also home to about one-fourth of the world's hungry and poor, majority being smallholder and marginal farmers. This inclusive growth system should promote SMEs and participation of smallholders all along the value chain. Policies and regulations should be in place to ensure– land tenure security, access to credit, training, technical assistance, and resilience-enhancing social protection. Income of the farmers thus enhanced will improve their access to education and information, which in turn will increase their inclusiveness in the food systems, breaking the inter-generational cycle of poverty, hunger, and malnutrition.

Keeping in mind the frameworks and guidelines suggested above, the following integrative pathways from research to innovations for impact are suggested.

- **Science-Technology-Innovation Continuum to be Farmer-centric and Demand-driven.** The cutting edge and innovative technology can bring agricultural transformation only if it addresses the problems of small and marginal farmers. While integrating basic and applied sciences, focus should be on being demand-driven (local being vocal) and adopting pluralistic delivery of innovations. Collaboration among all stakeholders is needed at the niche, regime, and landscape levels in compliance with regulatory requirements. The implementing actors must explore various contextual conditions and work with potential adopters to situate new innovations within local socio-ecological practices. Along with capacity building and skill development, socio-political ambience should nurture local leadership to champion innovations (Shilomboleni and Deplaen, 2019).
- **No more 'Closed Jacketed' Approach.** Encourage Agri-Food system-based multi-institutional, inter-disciplinary research, leading to rapid problem solving. Innovations to tackle COVID-19 pandemic have brought forward the advantages of dissolving boundaries in science to develop effective technologies leveraging expertise at various levels. This should be adopted as the norm by linking fundamental science to applied research; innovations at technology development and their diffusion; and partnership among the public and private sectors and civil societies. New initiatives of synergizing Science Social Responsibility (SSR) with Corporate Social Responsibility (CSR), can bridge the gap between private and public sectors. Agri-Startups should help solve agribusiness problems, promote entrepreneurship, and provide products, services, applications, etc. enhancing competitiveness.
- **Invest in Agri-Food Research and Development (ARD).** Studies showed that among all major components, investment in R&D gives the highest returns in agriculture, in socio-economic and ecological terms. In India, expenditure intensity in agricultural research has remained around 0.4 percent and in agricultural extension only around 0.16 percent for the past 15 years or so (Table 3). Against this, the intensity in USA and Australia is over 3.0 percent. Hence, in India both public and private funding need to be more than doubled as an immediate measure and a long-term strategy by bringing complementary convergence in funding from different sources and extending tax rebates, proportionate to the scale of investment. The National Education Policy, 2020 has proposed a common National Research Foundation (NRF), to minimize overlapping in funding, break barriers between various S&T Departments and create beneficial linkages. A similar approach is needed for ARD, with at least 0.2 percent of GDP invested, equaling about 1.0 percent of Agricultural GDP as has repeatedly been recommended in the past.

Table 3. Expenditure Intensity in R&D in India

| Expenditure Intensity in India (percent) | | |
|---|---|---|
| | Research | Extension |
| 1983 | 0.25 | 0.10 |
| 1993 | 0.31 | 0.15 |
| 2003 | 0.39 | 0.14 |
| 2014 | 0.40 | 0.18 |
| 2018 | 0.39 | |

*Source: NIAP, 2017-18*

- **Make the Education System Scientifically Sound and Professionally Competitive.** The agricultural education must maintain a Gold Standard ensuring that agricultural graduates from India are professionally well equipped to handle national as well as international challenges as enunciated in the NEP 2020 (GoI, 2020). The NARES should assess the manpower needs of the fast transforming, knowledge-intense agriculture to make necessary adjustments in curricula and skill development, emphasizing on experiential learning and exposure to national and international issues. More technological interventions are likely in the disciplines of ICT, digitalization, biotechnology, nanotechnology, agro-processing, precision agriculture and systems simulation, hence the associated manpower demand and shift in the pedagogy are to be brought in. Pluralistic approach and public-private partnership focusing on business/marketing/income orientation are needed for making the local extension sensitive to the challenges at micro level, strengthening the feedback mechanism, and setting the right priorities. Promoting entrepreneurship and Agri-Startups, encouraging market-led extension strategies, and intensive use of electronic media should be duly covered in the educational programmes.

- **Agriculture is Integral to Ecological Balance.** Agriculture being a risky (weather and market dependent) and low income occupation, make farmers follow the cropping systems having assured market, resulting in serious depletion of resources, deterioration of soil health and ecological imbalance. Leveraging the growing preferences for nutri-foods, policy decisions, regulatory framework and incentives will be needed to reverse the trend. Steps taken by some state governments, such as discouraging certain crops or promoting others, or fixing the sowing dates for rationalizing water use, showing promise. Long-term policies both for domestic and export trade, and support through subsidies linked to balanced use of natural resources and inputs can pave the way. Eco-friendly models of farming system, integrating natural, technical, economic, and social aspects are needed to promote resource-use efficiency, sustainable intensification, climate smart agriculture, zero food waste/loss, and enhanced food safety.

- **Small can be Bountiful.** More than 85 percent of farmers belonging to small and marginal categories primarily depend on agriculture for subsistence. Excessive fragmentation of farm lands, low factor productivity, vulnerability to climate change, poor value chain, and lack of viable agro-industries are some of the key reasons for low profitability from agriculture in India, forcing millions to migrate to far off places in search of farm/non-farm employments. To reverse this trend by creating rural employment opportunities, an integrated approach is needed to aggregate small farms through reforms, digitization, need-based farm mechanization, creation of aggregation/collection centres, affordable transportation, and market links. Shifting of some of the non-farm industries to rural areas also need to be considered as a long-term strategy to –provide steady and equitable income to rural population, decongesting the cities, and containing labour migration without affecting the economy. Dynamic retooling and retraining of the human resources would be essential.

- **Harnessing the Treasure of Traditional Knowledge**. An effective integration of traditional knowledge with modern agricultural technology will be desired for increasing the productivity while addressing the adverse impacts of climate change. To reap the benefits of ITK, we need sustained efforts in: (i) Collection and documentation of traditional knowledge relating to sustainable agricultural practices to build a National Database; (ii) A comprehensive policy framework to protect and utilize traditional knowledge and practices and facilitate better exchange, documentation, and conservation of available agro-biodiversity; (iii) Provisions for incentives and rewards to the saviors of ITK as well as access and benefit sharing (ABS); and (iv) Translational research with focus on identification, validation and adoption of traditional agricultural practices. An apex body at the national level may be established to create wide awareness and acceptance of ITKs and to coordinate between various stakeholders for their adoption and mainstreaming.
- **Respect the Intellectual Investments in Innovations.** Generating new technologies and innovations to meet emerging challenges by the public and private sectors need to be encouraged through commensurate policies and necessary IPR regime. In this context, National Intellectual Property Rights (IPR) Policy, the Protection of Plant Variety and Farmers' Rights Act (PPV&FRA), and the Biological Diversity Act (BDA) of the Government of India need to be harmonized to ensure a win-win situation and to accelerate the pace of developing new innovations, and their quick access in the interest of farmers.
- **Take Technology to the Doors of the Farmers**. Following Dr Norman E Borlaug's advice, a turnaround in the agricultural extension system will need to be brought in. There is a need to strengthen the existing extension system through partnerships with the private sector, NGOs, farmers' organizations, civil societies etc. imparting greater role to youth (including women) as Technology Agents and input providers. For showcasing and scaling of innovations, there is a need to establish Technology Parks and encourage farmer-led and paid extension work that is more efficient and accountable.
- **Scale up and Scale out.** Professionals, farmer producer organizations (FPOs), farmer producer companies (FPCs), self-help groups (SHGs), cooperatives and NGOs are to be effectively involved for scaling of innovations with an easy access to technology, policy and financial support and hand-holding from the research institutions. Thus, financing on easy terms, risk management, and incentives from state administration will attract entrepreneurs to establish successful start-ups. Land reform act, including land tenure, rent contracts, and land leasing should be streamlined to facilitate farms aggregation.
- **Empowering Women and Attracting Youth in Agriculture.** Urgent action is called at the national, regional and international levels to encourage women leadership at all levels and build collective advocacy to recognize their contribution towards agricultural

development. For this the agricultural research for development (AR4D) agenda needs to be made gender-sensitive. Concerted efforts are needed to develop women friendly machineries, tools and technologies. It must be ensured that the institutions and legal support system promote women's ownership and equitable share in resources. To utilize India's human capital in agricultural development by attracting youth (including women), agri-education system needs to be reoriented towards farm innovations and agri-preneurship, by introducing high quality vocational/ non-degree courses and by providing funding on easy terms to set up agri-business. Accreditation of skilled service providers in specialized fields will open up enormous scope of entrepreneurship and self- employment.

- **Build Back Better (and Differently).** To overcome the unprecedented disruption caused by the COVID-19 pandemic, a holistic approach will be needed with agriculture at the centre stage of the national rebuilding process. To address the large and systemic challenges, inclusiveness and rapid conversion of knowledge into needed and commercial products will be the key to innovative and affordable solutions. Promoting the policy of Zero Hunger India, Make-in-India, *Swasth Bharat*, One Health, *Atmanirbhar Bharat*, and the like, technical and financial support to strengthen entrepreneurship, start-ups, Ministry of Micro, Small and Medium Enterprises (MSME), and other concerned Ministries and Departments will synergistically integrate their efforts to build a green and strong India.

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Language Editing by Dr Aruna T. Kumar