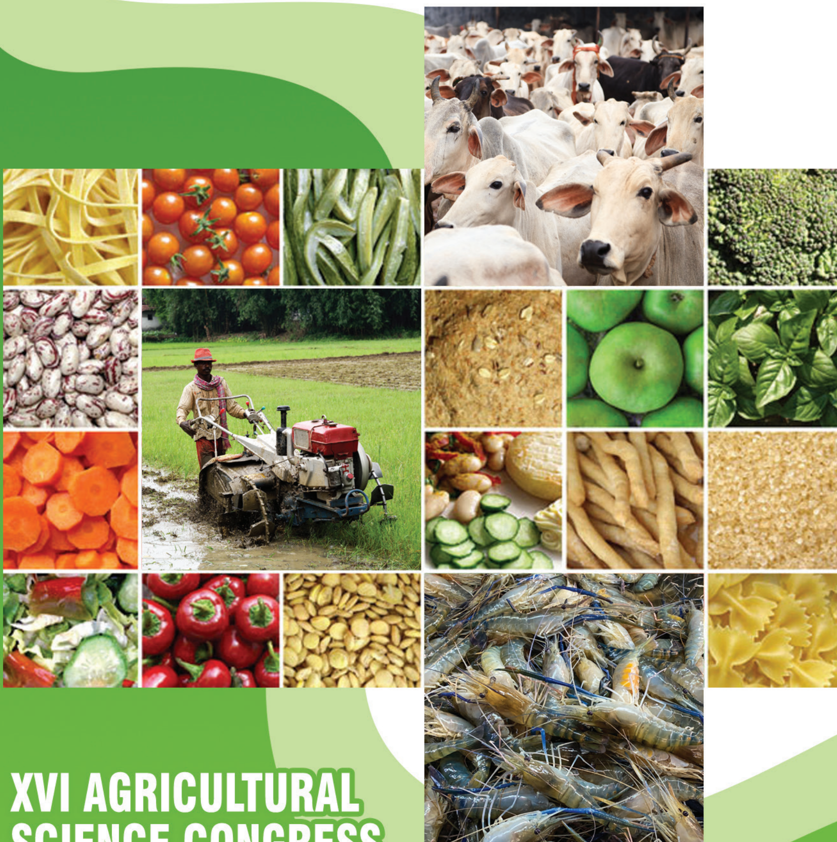
Dr. A.B. Joshi Memorial Lecture

Innovative Agri-Food Systems Technologies for Sustainable and Resilient Agriculture

Prof. Panjab Singh
Former Secretary DARE & Director General ICAR



XVI AGRICULTURAL SCIENCE CONGRESS & ASC EXPO

Transformation of Agri-Food Systems for Achieving Sustainable Development Goals

10-13 October 2023 | Kochi, Kerala, India

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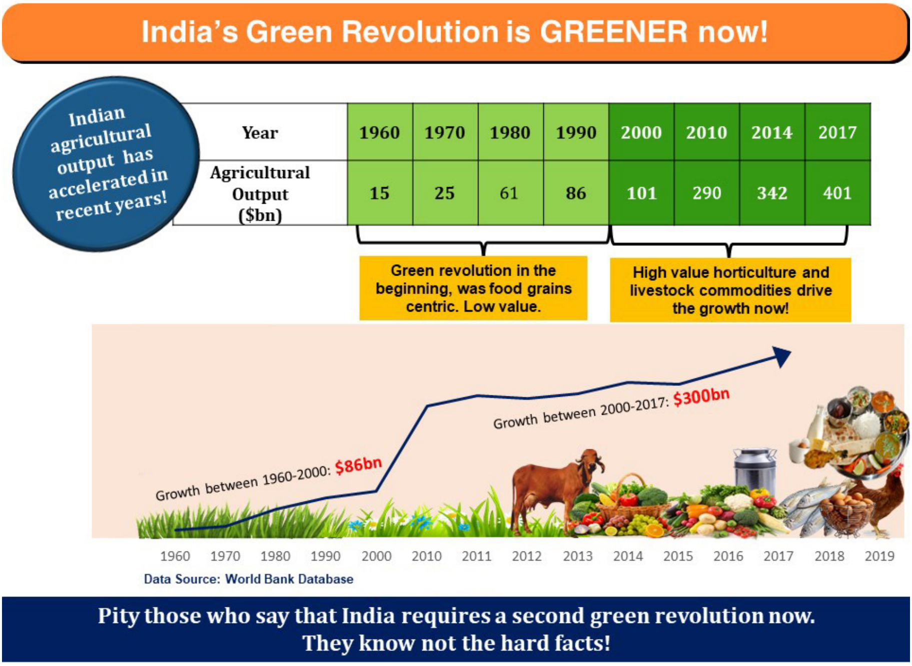
Indian agricultural growth has been impressive and cited as a global success story, which transformed from a food deficit to food surplus, subsistence to commercial and from an import-oriented to export-surplus economy. India today ranks second in the world in agricultural production as the leading producer of food grains, cotton, horticulture, dairy and poultry, aquaculture, and spices. Over the three decades from the 1970s until the year 2001, India's agricultural GDP rose from $25 billion to $101 billion, witnessing an absolute growth of $76 billion. However, during the next 16 years from 2001 to 2017, it leapfrogged from $101 billion to $401 billion, registering a stupendous growth of $300 billion. India's global trade in agriculture also fetches higher revenue for the country than the services and the manufacturing sectors. The growth in Indian agriculture over the last 16 years was 350% higher than the one achieved in the erstwhile period of 30 years (Figure 1).

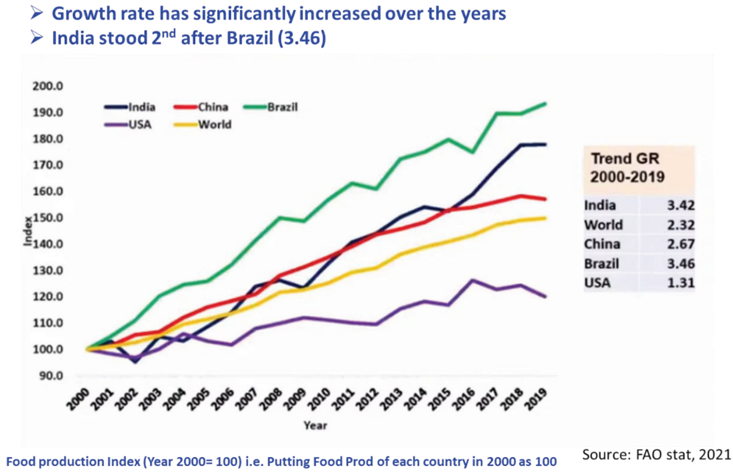
Figure 1: Growth in India GDP since 1960



Source: World Bank Database

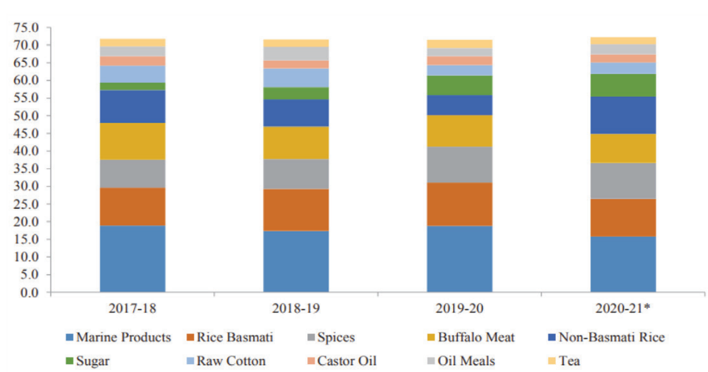
The food production growth rate increased significantly and was next only to Brazil (3.46) and much above China, USA and the world average (Figure 2).

Figure 2: Highest growth rate in food production



In global trade of agri-products, India's total agri-export basket accounts for a little over 2.5 % of world agri-trade (Figure 3). Since economic reforms began in 1991, India has remained a net exporter of agri-products, with agri-exports touching Rs.2.52 lakh crores and imports at Rs.1.47 lakh crores in FY 2019-20. India's agricultural export has been on the increase in the recent years and crossed US$50 billion in the year 2021-22 (Figure 4). The Indian agriculture market, which was valued at US$ 436 billion in 2022, is expected to exceed US$580 billion by 2028 @CAGR of 4.92% (Digital Journal, April 2023).

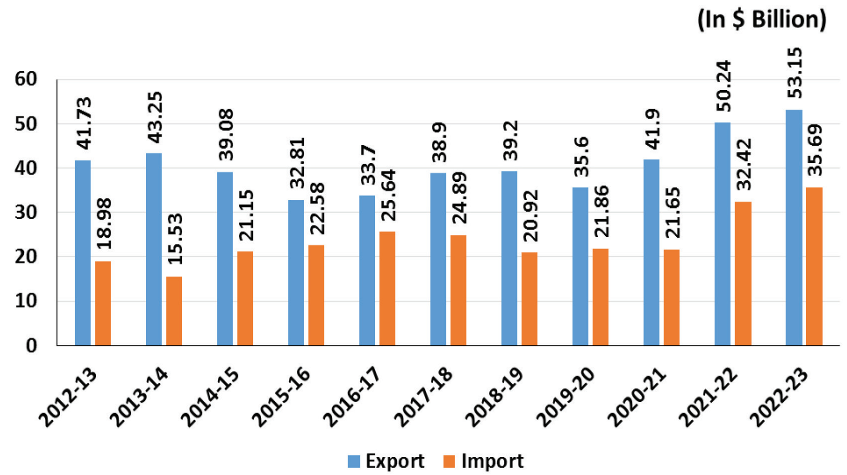
Figure 3: Trends in the share of Agricultural Commodities in total value of Agri-exports (%)



Source: Economic Survey, 2021

- India occupies a leading position in global trade of agri-products, its total agri-export basket accounts for a little over 2.5 % of world agri-trade.
- Since economic reforms began in 1991, India has remained a net exporter of agri-products, with agri-exports touching Rs.2.52 lakh crores and imports at Rs.1.47 lakh crores in FY 2019-20

Figure 4: India's agricultural export



The very special features of Indian agriculture are: it employs 45% workforce; its shares in country's GDP is 17%; provides self-sufficiency of food to 1.38 billion people; about 66% of population in rural areas are dependent on agriculture; and engages about 263 million as agricultural worker. The average household spend 45% income on food; 48.8 % of net cultivated area (140 mha) is irrigated; gross sown area 198 m ha; uses about 85% of the available water; and is a net foreign exchange earner today.

The food grain production increased from 50.82 million ton to 315.72 million tons (>6 times) in the year 2021-22; horticulture from 96.6 to 347.18 mt (3.59 times, between 1990-91 and 2021-22); milk from 17 to 221.06 mt (13 times), fish from 0.75 to 16.24 mt (21.65 times) and egg from 1.8 billion to 129 billion (70.82 times), an unparallel achievement compared to other economies in the world (Table 1).

Table 1: Production of food grains, pulses, oilseeds, milk, fruits and vege-

tables, meat (mt) and eggs (billion)

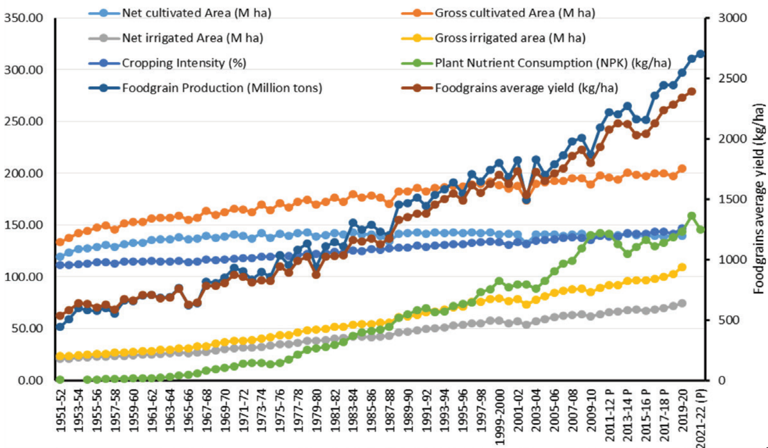
Year	Food grains (MT)	Pulses (MT)	Oil-seeds (MT)	Milk (MT)	Eggs (b)	Total Horti-cultural Pro-duction (MT)	Meat (MT)	Fish (MT)
1950-51	50.82	8.41	5.16	17	1.83	96.6	1.9 (2000-01)@	0.75
2016-17	275.11	23.13	31.28	165.4	88.1	300.6	7.386	11.43
2017-18	285.01	25.42	31.46	176.3	95.2	311.7	7.656	12.59
2018-19	285.21	22.08	31.52	187.7	103.8	311	8.114	13.57
2019-20	297.5	23.03	33.22	198.4	114.3	320.4	8.6	14.16
2020-21	310.74	25.46	35.95	209.9	122	334.6	8.798	14.72
2021-22	315.72 $(6.21)	27.69 (3.29)	37.7 (7.31)	221.06 (13.00)	129.6 (70.82)	347.18 (3.59)	9.29 (4.89)	16.24 (21.65)

$ Figures in parenthesis are the number of times the production has increased compared to the base year 1950-51.

* Base year 1990-91 @ Base year 2000-01

Overcoming food insecurity and hunger was one of the most important challenges before scientific community and policy makers. Increasing food grain production in an uncertain environment with various abiotic and biotic constraints was a daunting task. However, agricultural innovations with government support and policies for increased fertilizer use and increase in gross irrigated area has completely transformed Indian agriculture (Figure 5). The surplus production led to launch of National Food Security Act to supply food grains at a highly subsided rate.

Figure 5: Food production, gross and net cultivated, irrigated area and fertilizer use



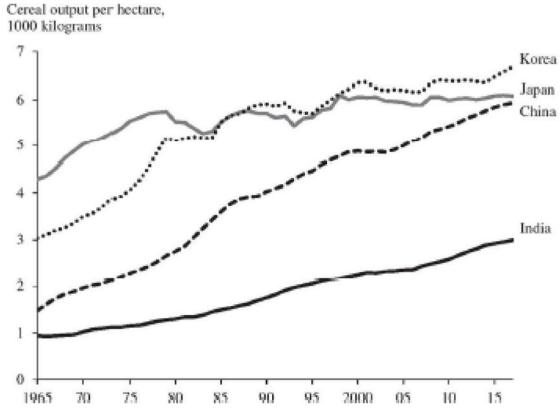
Inspite of ensuring food security to the millions and providing food to 800 million during Covid, nutrition security is of a huge concern in India with the dubious distinction of having largest population of malnourished/wasted children in the world. Since adequate nutrition is the key to an active and healthy life, malnourishment is estimated to be causing a loss of 4% of India's GDP. Table 2 illustrates the seriousness of this problem as the percentage of population affected is still very significant although improvement has taken place over the years.

Table 2: Incidence of nutrition indicators 2005-06 to 2020-21

Indicator	NFHS Year		
	2005-06	2015-16	2020-21
Children under 5 years who are stunted (%)	48.0	38.4	35.5
Children under 5 years who are underweight (%)	42.5	35.8	32.1
Women whose Body Mass Index (BMI) is below normal (%)	35.5	22.9	18.7
Women who are overweight or obese (%)	12.6	20.6	24.0
Children under 5 years who are anaemic (%)	69.4	58.6	67.1
Pregnant women of age 15-49 years who are anaemic (%)	57.9	50.4	52.2

Today considering its size, India is among the densest regions and the most populous nation in the world and is projected to be about 1.7 billion by 2050. How to feed them and preserve our finite production and life support resource systems are issues of highest concern. In 1950, not long after independence, agriculture employed 70% of Indian workers. Over the next half century, the share of workforce in agriculture declined by just 10% points. In Japan's comparable half century, the share of workers on farms fell by 35 points, from 80% in 1880 to 45% in 1930. Workers moved from agriculture to the non-agriculture sector at an even faster pace in subsequent East Asian Development. The share of workers in Korean agriculture declined from 55% in 1965 to 10% in 2000. In China, a poorer country (in per capita income terms) than India until the late 1970s, the share of workforce in agriculture declined from 80% in 1965 to 50% in 2000. In both Korea and China, the transition from agriculture to non-agriculture was especially rapid in the 1990s, a decade in which India stood nearly still according to this metric (Figure 6). In Japan, Korea, and China, the transition from agriculture occurred not just because of expanding job opportunities in manufacturing and services but also because agriculture was dynamic. In Japan, land productivity increased rapidly in post-Meiji years and by the 1960s was among highest in the world. In Korea, land productivity caught up with that in Japan by early 1980s and Chinese productivity caught up in the 2000s. With the land producing more output, farm production grew at a healthy pace while young new job seekers and older farm workers found non-farm jobs. Every advanced nation goes through this classical transition; while India seemed chronically unable to do so.

Figure 6: Indian farmland productivity is higher today than in the past, but is still far less than elsewhere (1000 kg of cereals per ha, 5-year moving averages)



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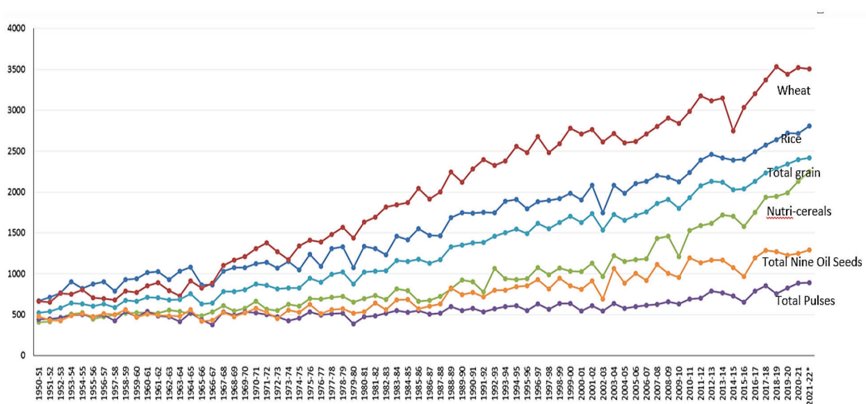
Even in the decade after the 1991 economic "liberalization" 35 million more workers piled in to low-productivity agricultural tasks. From a national perspective, this was a very inefficient use of the workforce. Output (technically, value added) in Indian agriculture was less than one-quarter per worker in non-agriculture work. But because of limited non-agricultural jobs and humiliating urban living conditions, farmers stuck to miserable agricultural lives.

With increasing food demand, the pressure on land, water, and other resources to meet future food and development needs is going to be very intense. Food and nutritional security of India is threatened by issues like severe decline in the health and productivity of the soil leading to decline in total factor productivity, low nutrient content in the food, poor health of the crops predisposing them to severe insect-pests and diseases, ultimately resulting in poor health of human beings and animals. The productivity (yield/ha) continues to be low in all crops but more so in pulses and oil seeds (Figure 7). Currently, India is self-reliant in almost all the major agricultural commodities except oilseeds. Agricultural sector is also a net earner of foreign exchange. However, the share of agricultural export in India's total exports decreased from 13.9 per cent in 2012-13 to 12.3 per cent in 2016-17. It has been estimated that to meet the diverse demands of the population by 2050, land productivity must be increased by 4 times, water productivity by 3 times and labour productivity by 6 times. All this must be achieved with low carbon emission technology and the smallest of ecological footprints.

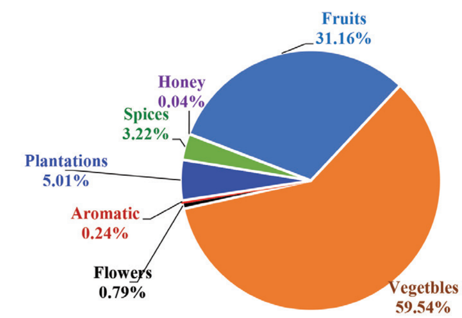
Figure 7: Average yield (per/ha) of selected crops-India



Currently, India's harvest of horticultural crops is 342.33 million tons. Globally, India ranks the 2nd largest producer of fruits and vegetables, contributing respectively 12.4 and 13.3% to the total world's fruits and vegetables production. In India, fruits and vegetables together contribute to >90 per cent of total horticultural production (Figure 8). Fruits raised on 6.9

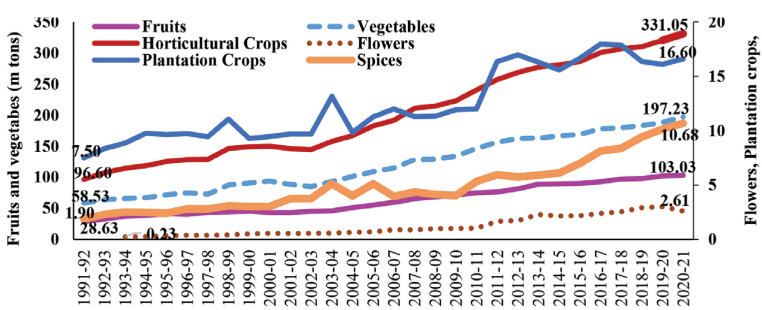
million ha yield 103 million tons, and vegetables covering about 11 million ha yield about 197 million tons.

Figure 8: Production Scenario, 2020-21



In 2021-22, fresh and processed fruits and vegetables, flowers, medicinal and aromatic products, and horticultural seed/ planting material earned India a foreign exchange equivalent of Rs. 226.9 billion. In2017-18, the country had netted about US$ 330 million from the export of herbs and nearly US$ 456 million from value-added extracts of medicinal herbs/herbal products. Horticulture sector in total contributes to nearly 33% to gross value of agricultural outputs. More significant is that this sector supports about 20% of country's agricultural workforce. Apart from nutritional security, horticulture sector has generated a second wave of rural employment and income through diversification of farm activities and value-added products. Horticulture production over years has increased mainly through increase in area, technological innovations, policy support from the government and active private sector participation. The production trends during the last three decades of different components of horticulture are shown in Figure 9.

Figure 9: Growth trends in production of horticultural crops

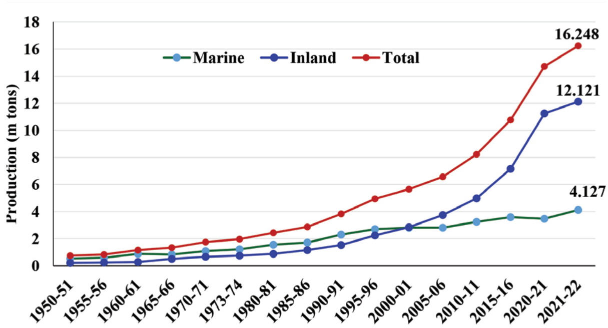


India has a huge population of different livestock species, and they are raised in mixed farming systems. The country is the largest producer of milk. In 2020-21, it produced 210 m tons of milk. Livestock contribute over 33% to the total value of the agricultural output and are an important livelihood source for the two-thirds of the rural household. Driven by sustained rise in per capita income, fast-growing urban population, changing lifestyle and improvement in logistics and in supply chains, the demand for the animal-source foods has been increasing faster than those of staple food grains. If these trends continue, then by 2050, the demand for animal-source foods would be more than double of 2009.

Over the time, research related to animal health, feed and nutrition, genetic enhancement through artificial insemination, cloning and biotechnology, has made a significant progress. It is quite apparent in the case of vaccines and diagnostics, and their integration with epidemiological investigations, which have led to the eradication of the economically important diseases i.e., African Horse Sickness (AHS) in 1976, Contagious Bovine Pleuropneumonia (CBPP) in 2007, and Rinderpest (RP) in 2011. Along with several diseases of livestock and poultry have been controlled — Foot and Mouth Disease, Haemorrhagic Septicaemia, Enterotoxaemia, Anthrax, PPR, Sheep pox, Goat pox, Classical Swine Fever, Newcastle Disease, Fowl pox. Achieved visible success in animal breeding (e.g., AI, cloning) and nutrition (feed formulations and mineral mixtures).

India ranks second in fish-production in the world. The production increased from a mere 0.75 m tons in 1950-51 to 5.66 m tons in 2000-01 and reached a record level of 16.25 m tons in 2021-22. According to the Economic Survey of India 2021-22, the fisheries sector has grown at an annual rate of 10.87% since 2014-15. Traditionally, marine fisheries were the main source of growth (share ~70% in 1950s) but with the increased focus on aquaculture during the past 3-4 decades, the scenario has changed tremendously. At present, 75% of the total fish production is being contributed by inland capture and aquaculture. The coastal states of Andhra Pradesh and West Bengal have been the major fish producers followed by Karnataka, Odisha, and Gujarat (Figure 10). Non-coastal states, Uttar Pradesh, Bihar, and Chhattisgarh also contributed significantly to fish production, typically through aquaculture and inland capture fisheries.

Figure 10: Trends in fish production



Also, despite impressive agricultural growth, the per capita food grain availability hovered around 200 kg per annum between 1983-84 to 1909-10 and the availability of cereals has been around 185 kg per annum. The per capita availability of non-food grain food commodities viz. vegetables, fruits, milk, egg, fish witnessed a considerable increase which helped in catering to the diversified food needs of the households (Table 3).

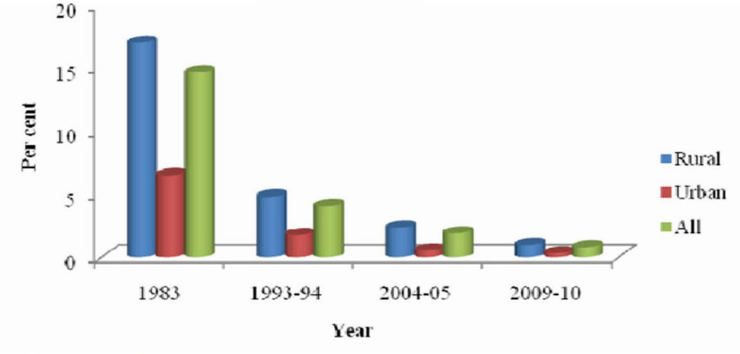
Table 3: Per Capita Production or Availability of Different Food Commodities in India

Year (TE)	Foodgrains	Cereals	Pulses	Vege-tables	Fruits	Milk	Eggs	Fish
1983-84	198	181	17	56	31	52	17	35
1993-94	206	191	15	68	33	67	27	51
2004-05	184	172	12	86	45	84	39	59
2009-10	198	185	13	113	60	94	49	62

Source: Agricultural Statistics at Glance (various years)

Increased food production, its better availability and favourable policies have helped reduce acute hunger from 17 per cent in 1983 to mere 1 per cent in 2009-10 in rural India and from 6.5 per cent to 0.3 per cent in urban India (Figure 11, Anjani Kumar, et al., 2012).

Figure 11: Trends in incidence of hunger: 1983 to 2009-10



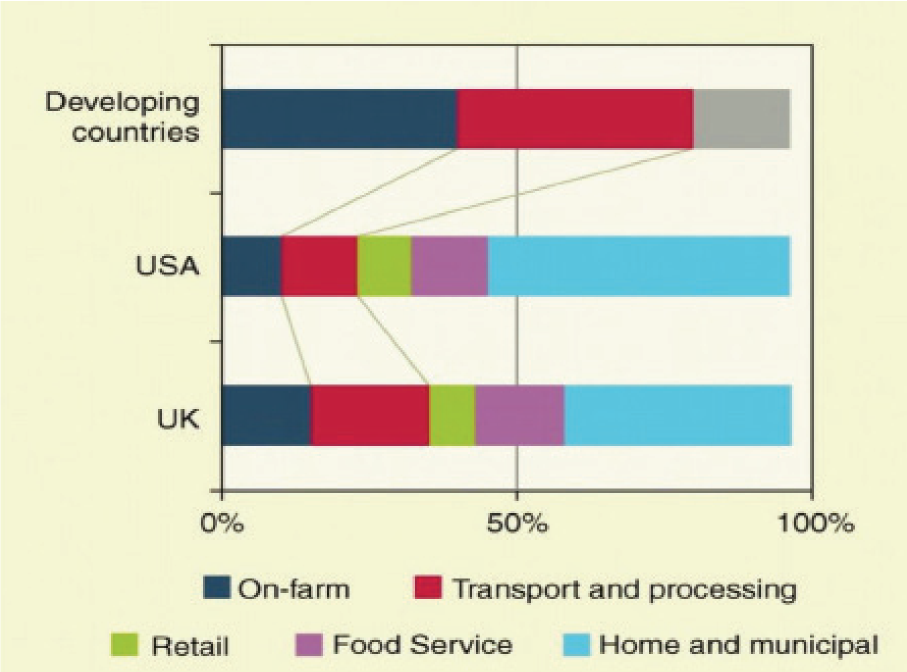
Our effort should be to defend the productivity gains so far made, extend the gains to semi-arid and marginal environments, and work for new gains using blends of frontier technologies and traditional ecological prudence. The problem of generating adequate purchasing power to enable families living in poverty to have economic access to food will still confront us. This is where a job-led economic growth strategy based on micro-level planning, micro-enterprise and microcredit will be of great help. Integrated production and post-harvest technologies and on-farm and off-farm employment strategies will be needed to provide livelihoods for all in rural areas.

The challenges facing today are both sustainable food and nutritional security and ensuring food safety. This includes adequate quantity, dietary quality, and meeting diversity in food demand. Availability and access to food especially to those below poverty line and live on day-to-day survival in the lower strata of population with adequate food and water continues to be a challenge. It is more challenging today than ever before because of increasing human and animal population exerting and competing for limited land, water and other natural resources making production increase much more difficult and complex. Superimposed on this is the threat of the climate change which is a reality now and will have serious consequences on livelihoods of the populations especially small and medium scale farmers. As of now one is growing at the cost of other whereas for achieving sustainable food security, production/productivity increase and improvement in production and production resources viz. land, water etc. must be simultaneous and not one after the other. All technological innovations must focus on this aspect. In brief one would say that growing human and livestock population, climate change, infertile soils, unsustainable food production system, huge food waste across globe, shrinking water and land resources are big challenge and against all these we are to manage through proper technological innovations and interventions. Agricultural development will have to be, therefore, guided not only by the compulsion of improving food and nutritional security, but also by the concerns for eco-restoration including conservation and harnessing of biodiversity, long-term sustainability, and profitability under the pressure of global climate change scenario. In this context, food supplies are evidently a key issue, and the correlation between this and other concerns viz. political, social, economic stability, poverty, and environmental and resource protection, beyond the main problem of population growth, is becoming increasingly clear.

In the past primary solution to food shortages has been to bring more land into agriculture. But today the competition for land for other human activities and degradation makes this increasingly unlikely and costly solution. Thus, more likely scenario is that more food will need to be produced from same or less land. The challenge is to have technological solutions to problem in Agri-Food System. There is need to focus on low-income people for consumption and on local food system and community food security for production. It is now widely recognized that food production systems should address to the principle of sustainability and the use of resources at rate that do not exceed the capacity of earth to replace them.

Reducing food waste is another very important aspect in the whole issue of sustainable food security. Roughly 30-40 per cent of food in both developed and developing world is lost to waste, though the causes behind this are very different (Figure 12). In the developing world, the losses are mainly attributable to absence of food chain infrastructure and lack of knowledge or investment in storage technologies on the farm. In developed world, pre-retail losses are much lower but those arising at the retail, food service, and home stages of the food chain have grown dramatically in recent years for a variety of reasons. Therefore, different strategies are required to tackle two types of waste in two different worlds.

Figure 12: Makeup of total food waste in developed and developing countries.



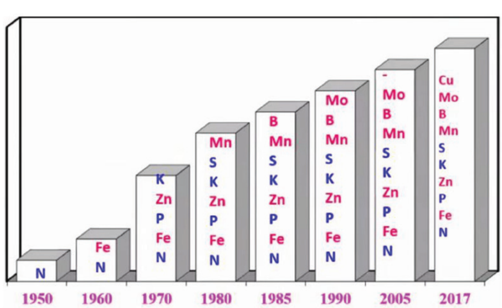
Natural Resources Status and Management:

Land and Soil:

The three basic resource inputs for food production are cultivable land, water, and energy. Some seem to believe that we have adequate land and water resources in India. As per the FAO assessment, the total cultivable land in India is 165.3 million hectares, which is about 50% of total geographical area (corresponding world average figure is 10.2%). Indian experts have however, considered that 266 million hectares or 80.9% of geographical area as having the potential for production of plant-based products of economic importance including food. Yet, of the 266 million hectares, around 175 million hectares (66%) are degraded to varying extents by water, wind, and soil erosion. Intensive cultivation methods involving excessive fertilizer application and water usage are also believed to have caused diminution of sub-surface aquifers and over all soil degradation.

Land areas have been under the use of human societies for many generations. It was only late in the last century that a tremendous degradation of farmlands, forest lands and common lands was witnessed. This was largely on account of a rapid growth in population, rapid changes in lifestyles, rapid expansion of human needs, and rapid spread of exploitative farming practices. With reduced forest cover and removal of vegetation on surrounding areas, farmlands have been subjected to erosion for years, now. As a result, soils have become shallow and sandy, with depleted soil fertility, and organic matter. Thus, the water holding capacity of these soils has been reduced, and their fertility level has been lowered. Large tracts of arable land have transformed into problem soils, becoming acidic, alkaline, and saline physico-chemically. These soils are generally shallow, low in plant available water capacity, very low sub-soil saturated hydraulic conductivity, sub-soil hard pans, imperfect drainage, sub-soil gravelliness, calcareousness, low soil organic carbon and have a multiple major and minor nutrient deficiencies (Figure 13).

Figure 13: Major and micronutrient deficiencies are widespread.



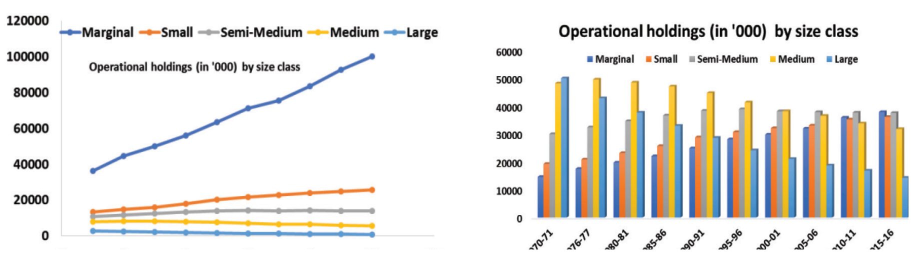
Source: Singh, 2008

- Rice, wheat, maize and other crops suffer with severe deficiency of Zn
- Analysis of a large number of soil and plant samples collected from various parts of country indicated 49%, 12%, 5%, 3% and 33% deficiencies of Zn, Fe, Mn, Cu, and B, respectively

The present land use pattern in the country shows that forestry and agriculture are the two major land uses, which occupy 71.8m ha (21.8%) and 140m ha (42.6%), respectively. The area under agriculture has increased from 119 m ha in 1950-51 to about 140 m ha in 1970-71 and since then has remained constant. During the same period, area under non-agricultural uses increased from 9.36 to 26.88 m ha. On the other hand, the area under barren and uncultivable lands, land under miscellaneous tree crops and groves, cultivable wastelands, and fallow lands other than current fallows has shown a significant decrease from 1950 onwards. This clearly shows that during this period, most of the barren, waste and fallow lands were either converted into agricultural lands or other uses or brought under forestry. However, there is hardly any scope now to bring additional area under agriculture.

The per capita availability of land has declined from 0.91 ha in 1951 to 0.32 ha in 2001 and is projected to slide down to 0.23 ha in 2025 and less than 0.19 ha in 2050. As far as agricultural land is concerned, the per capita availability of land has declined from 0.48 ha in 1951 to 0.16 ha in 1991, 0.13 ha in 2001 and it is likely to decline further to 0.11 ha in 2025 and less than 0.09 ha in 2050. This decline in per capita land availability in the country is mostly on account of increasing population and, therefore, it is important to examine the carrying capacity of the land under cultivation because there is no alternative other than intensifying agricultural activities to feed the huge population. Shrinking land resource and predominance of marginal and small farmers is a challenge (Figure 14).

Figure 14: Shrinking land holdings and predominance of marginal and small holders



Source: Agriculture census: 2015-16

- Declining holdings (Average size is 1.08 ha in 2015-16)
- Small and marginal farmers with less than 2 ha of land account for 86.2% of total operational land holdings in India
- Small and Marginal farmers account for 47% of the total area.
- Large (>10 ha) 0.83 m, Medium (4-10 ha) 5.5 m, Semi-medium (2-4 ha) 13.8 m, Small (1-2 ha) 25.8 m, Marginal (<1 ha) 99.8 m

Water:

Among different sectors requiring water, irrigation accounted for 78% in 2010 and is expected to account for 68% by 2050. Agriculture has been and will remain the largest consumer of freshwater resources. The focus will be on its efficient use. India has developed one of the largest irrigation infrastructures in the world, with more than 68 mha (48%) of net irrigated area, which is next only to China. Irrigation development played a crucial role in ensuring food security. However, the average productivity in the irrigated systems (~3 t/ha) is considerably lower than the potential. It is not only the demand–supply mismatch in the major and medium irrigation projects but also the fact that the gap between the irrigation potential created and utilized has been widening continuously, which stands at more than 25 mha. Top priority should be given to bridge this gap. The conclusions of a study carried out on 35 major/medium irrigation projects in the country by CWC (2016) have indicated that the overall water use efficiency was 36 per cent with the conveyance efficiency pegged at 69 per cent and on-farm application efficiency at 55 per cent indicating that the current level management practices offer a huge potential in improving water use efficiencies.

Development of ground water resources which was a low-key affair in the earlier stages, is now contributing more than 60 per cent of the irrigation demand and playing a critical role in ensuring food security. However, over-exploitation of groundwater has become a very serious cause of concern in most of the areas except eastern part of the country. Out of the 6607 assessed blocks, 4530 are safe while the rest are in the semi-critical (697), critical (217) and over-exploited (1071) category. By 2025, an estimated 60 per cent of India's groundwater blocks will be in critical/semi critical/ over-exploited categories. Almost 54 per cent of the groundwater blocks in Gujarat, Haryana, Maharashtra, Punjab, Rajasthan, and Tamil Nadu are likely to fall in these categories if the present rate of declining trend continues. Although, overall ground water development in the country is only 62 per cent but in some of the states like Delhi, Haryana, Punjab, Rajasthan etc., it has already crossed 100 per cent. Considering the low groundwater development in the eastern

India and North-east, the Government of India has rightly decided to focus on this region under the programme aptly titled "Bringing Green Revolution to Eastern India". Average precipitation of 1160mm (rain fall+ snow fall) corresponds to 4000 billion m3 of water. Out of this 1869 bm3is annual run off and only 1123 bm3 is utilizable. The present water use, however, is only 634 bm^3 showing considerable potential for expansion of irrigation facilities. Emphasis needs to be given not only to sustainable development of potential resources of water but also to augment, conserve and manage available water through improvement in water storage, conveyance application, and crop water use efficiencies without detriment to environment and other natural resources of land, soil, plants and biodiversity.

Although cultivation of food crops by irrigation has been in vogue for a long time, notably rapid expansions in irrigated land have occurred only in the last century. However, owing to escalating costs of irrigation network, soil salination by inadequate drainage, and most importantly depletion of water sources themselves, the rate of this expansion has shown signs of slowing down. Estimates published by the National Institute of Hydrology, Roorkee, have shown that out of the total natural run-off of 1869 km3, the utilizable potential is 690km3 of water. In addition, there is also the ground water potential of 432km3 (rechargeable), which puts the total available water potential at 2301 km3. Assessment of water availability and usage for current agricultural practices may seem satisfactory, judged from self-sufficiency in food grains and good buffer stocks. But we need to also take cognizance of geophysical variations in water accessibility, perennial draught-and flood-prone areas, vagaries of monsoons, lack of well-designed irrigation net-work and wrong irrigation procedures (over-flooding or under-irrigation) etc. while considering future agriculture.

Strategies to Overcome the Challenges:

Modern agriculture has evolved to rely greatly on energy-intensive technology support both directly and indirectly. Land preparation, irrigation, production and application of fertilizers and pesticides, harvesting, post-harvest primary processing, transport and distribution etc. are all included in this. So far, the major energy source has been fossil fuels. This is now turning out to be a double-edged sword. Fossil fuel usage generates carbon dioxide as a major contributor to man-made greenhouse effect and climate change. However, it is impossible to turn away, at least for now, from fossil fuel as energy source. Concerns of greenhouse gas effect and the knowledge of physical limitation of the fossil fuels have driven governments to seek alternate sources of energy which are yet in their infantile stages of development. Jatropha and ethanol based biofuels and harnessing of wind and solar energy are being considered which are yet to be proven economically viable.

There is an apparent world-wide awareness of the issues of increased food production-resource conservation' paradox. The 'Scientists, technologists, industrialists and policy makers should brainstorm to evolve a tangible and workable action plan to accommodate the process of increased food production for long term food security assurance while ensuring optimized utilization of natural resources that is not only sustainable but also harmless to the wellness of our biosphere. We need to address, adopting crop patterning for food crops and cash crops to achieve a right balance of food production and income generation for sustained favourable agricultural practice, induce the Indian populace to adopt diversification in their dietary habits to enable stretching of food availability in millets and tubers, identify the prevailing misuse and abuse of natural resources (water, land, energy) and formulate remedial measures, consider highly efficient and cost-effective scientific and technological interventions-such as development of crop strains with improved water efficiency, improved photosynthetic efficiency, acquired nitrogen fixation capability, acquired protection against pests and pathogens and resilience to draught, salinity and harsh climate conditions, and plan for integrated processes of agriculture, post-harvest processing, by-product utilization, animal husbandry and aqua0culture and test their workability and plan for strengthening of rural economy to make rural life attractive and not abondonable.

The structural changes that are being witnessed by the agriculture sector in India necessitates re-orientation in policies towards this sector in terms of strengthening the agricultural value chain in agri-food system by focusing on allied activities like dairying and livestock development along with gender-specific interventions. To improve productivity in agriculture the focus has been on the critical inputs like irrigation, seeds, fertilisers, and mechanization. The dynamics of agricultural growth reflect a reduction in the share of crop sector and an increase in the share of agricultural sub-sectors. As agriculture entails risks related to production, weather, prices, and policy, capitalizing the structural changes in the agriculture sector by diversifying income generating activities can mitigate the risks and sustain growth of the economy.

Another primary factor of production, namely, water is also under stress. Emphasis needs to be given not only to sustainable development of potential resources of water but also to augment, conserve and manage available water through improvement in water storage, conveyance application, and crop water use efficiencies without detriment to environment and other natural resources of land, soil, plants and biodiversity. Enhancing water productivity in rain fed regions with rainfall ranging from 300-1500 mm, the imbalance between the rainwater input and the water withdrawals from surface and ground water needs to be balanced. Future projection of rainfall and temperature is likely to affect evapo-transpiration and irrigation demand which is to be answered by suitable technologies including crops and genotypes and policies on water use in such areas.

The rain-fed agriculture accounts to 55% per cent of total net sown area and is crucial to country's economy and food security since it contributes to about 40 per cent of the total food grains production, supports two-third of livestock and 40 per cent of human population. Further, it influences the livelihood of 80 per cent of small and marginal farmers and is most vulnerable to monsoon failures. Even if full irrigation potential is created, 40 per cent of the area will continue to rain dependent. The major challenge, therefore, is sustaining by addressing the issues of rain fed agriculture from technical, social and policy point of view.

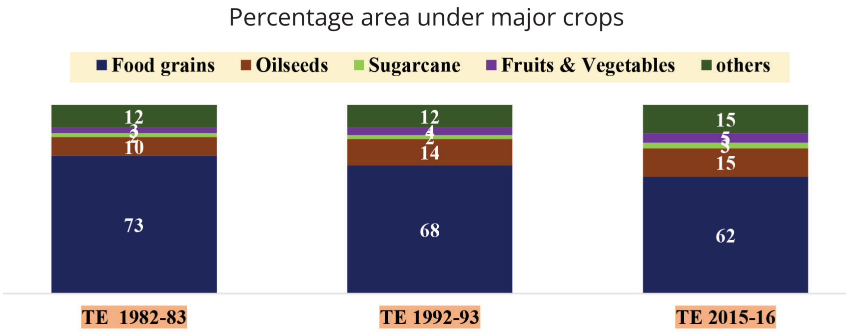
Evolving rain fed integrated farming system models by strengthening predominant traditional rain fed farming systems that enhances resource use efficiency and livelihood by providing risk resilience, food and nutritional security, staggered employment and income has a great promise for such situations. Promotion of agro-forestry and silvi-pasture systems, fodder trees, multiple tree-based systems have great opportunities in such lands. Promotion of dry land horticulture and animal husbandry especially sheep rearing, fisheries in water harvesting ponds, protected agriculture, fodder production, use of proper farm machinery for different operation, food processing and value addition are some potential areas for rain fed lands.

The livestock sector has emerged as an important sector for ensuring a more inclusive and sustainable agriculture system. The livestock segment supplements farm income (almost 30-40%) by providing employment, draught animals, milk, manure etc. There is evidence to show that farming households with some cattle head are better able to withstand distress due to extreme weather conditions. Fishery is one of the most promising sectors of agriculture and allied activities in India, with a projected overall growth rate of 6 per cent for the 12th Five Year Plan. Fisheries sector supports the livelihood of almost 1.5 million people in the country.

Crop diversification needs to be encouraged to improve soil health, productivity and thereby, profitability of cultivation. There is a need to diversify into high value crops and horticulture crops for which Government has taken several measures. Crops Diversification Programme is being implemented by the government in original green revolution states viz. Punjab, Haryana and in Western UP to diversify paddy area towards less water requiring crops like oilseeds, pulses, coarse cereal, agro-forestry and shifting of tobacco farmers to alternative crops/cropping system in tobacco growing States (Figure 15).

There is a gradual shift to commercial and cash crops from traditional subsistence crops

Figure 15: Diversification towards high value crops



Land Use Statistics at a Glance, (DES, 2017)

In India, where still about two-third of the population depends on agriculture and nearly half of the cultivated land is rain dependent makes livelihoods highly vulnerable to climate change. This poses a serious threat to the food security. Climate sensitive sectors like agriculture, forestry, water resources, human and animal health and so on, highly vulnerable to climate, will face serious consequences and will have the future effects through: continued change through this century and beyond; continuous temperature rise; longer frost free season (and growing season); changes in precipitation pattern; air will become more and more polluted; more drought and heat waves; more stronger and more intense hurricanes; sea level rise by 1-4 feet by 2100; arctic likely to become ice-free and so on and so forth. Latest WHO study shows that 92% of the world population breaths polluted air. India accounts for 75% of 0. 8 million air pollution related deaths in Southeast Asia region, over 0.6 million people die every year in India of ailments caused from air pollution such as acute lower respiratory infection, chronic obstructive pulmonary disorder, ischemic, heart diseases and lung cancer. Solution exists with sustainable transport in cities, solid waste management, access to clean household fuel and cook-stoves, as well as renewable energies and industrial emission reductions (TOI, Sept. 28, 2016).

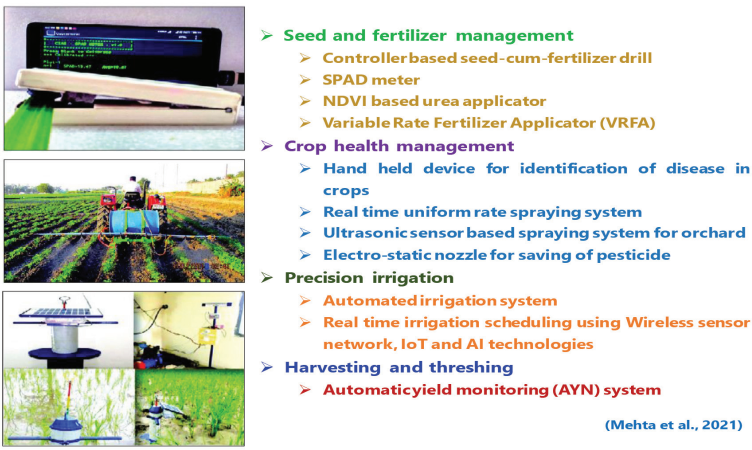
Climate change has become a serious global negative externality with its multiple, far-reaching and persistent effects. Its adverse impact on food production systems, due to rising temperatures and extreme weather events, is at the centre stage of discussion worldwide. Developing countries with their large agrarian base, are more prone to threats due to climate change. With India's large size, its numerous agro-ecological zones, preponderance of small, fragmented holdings and persistent dependence on the vagaries of the monsoon, the issue of climate change becomes even more challenging. Recently acknowledged by the world community that the Climate change caused by excessive emission of Green House Gases (GHGs) is one of the greatest challenges facing our planet today. The atmosphere carries out critical function of maintaining life sustaining conditions on earth. GHGs [for example carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), water vapour] re-emit some of the heat to the earth surface. If they did not perform this useful function, most of the heat energy would escape, leaving the earth cold (about -17^{o}C) and unfit to support life. Increase in the level of GHGs could lead to greater warming, which, in turn could have an impact on the world climate-the phenomenon known as "Climate Change". Ever since industrial revolution began 150 years ago, manmade activities have added significant quantities of GHGs to the atmosphere. A portfolio of measures on various sectors of economy like energy, agriculture, urban and rural habitat, and all measures related to environmental protection and ecological sustenance are needed to combat this grave problem.

Slow infusion of new technologies, lack of timely availability of information and communication, lack of marketing facilities and cold chain and food processing and product development systems are issues of concern today. Extension services need to be strengthened by scaling-up investment levels and by improving their quality. The government spending on agricultural extension has been fluctuating, though has moved on a rising trend. The share of agricultural GDP spent on agricultural extension has not shown any specific trend. In recent years, the government has spent about 0.14% of agricultural GDP on extension services (NIAP Policy paper: 25).

Biggest challenge remains in terms of increasing access to credit, particularly for the poor farmers. The structural changes that are being witnessed by the agriculture sector in India necessitates re-orientation in policies towards this sector in terms of strengthening the agricultural value chain by focusing on allied activities like dairying and livestock development along with gender-specific interventions.

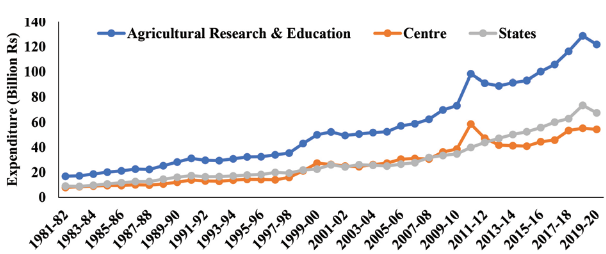
There is predominance of small operational holdings in Indian agriculture. It is, therefore, needed to consolidate the land holdings to reap the benefits of agricultural mechanization (Figure 16). There is a need to innovate custom service or a rental model by institutionalization for high-cost farm machinery such as combine harvester, sugarcane harvester, potato combine, paddy transplanter, laser guided land leveller, rotavator etc. to reduce the cost of operation and it can be adopted by private players or state or central organizations in major production hubs.

Fig.16. Small Farm/Smart Mechanization for Precision Application



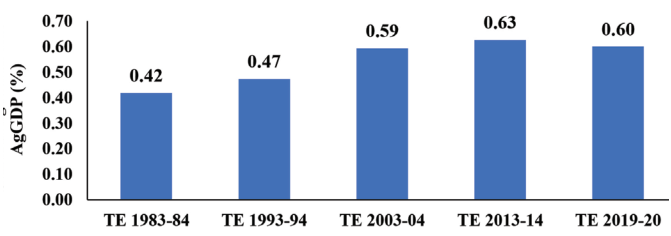
In India, public spending on agricultural research and education increased from Rs. 16.86 billion in 1981-82 to Rs. 121.18 billion in 2019-20 with a compound annual growth rate of 5.45% (Figure 17). Significant change was also seen in the share of central and state allocations in agricultural research and education investment over years. During 1980s and 1990s, the share of states in total research and education was higher as compared to central share (43-46%), but a reverse trend was seen during 2000 to 2010; when central share in total allocations increased to as high as 55%. The growth rate of agricultural research and education expenditure in the centre and in the states was about 5.61 and 5.28% respectively, during 1981-82 to 2019-20.

Figure 17: Public spending in agricultural research and education in India



During the last four decades, the share of the agricultural research and education in agricultural GDP had increased consistently from 0.42% during TE (triennium ending) 1983-84 to 0.63% during TE 2013-14, which slightly declined to 0.60% owing to a fall in central sector investment in research and education in agriculture (Figure 18). Compared to other developing economies like China, Brazil and South Africa, India is lagging behind in terms of investment in agricultural research and education and is still far behind its targeted rate of 1% R&D intensity in agriculture Investment in the agriculture sector as a whole and research, extension and education in particular need to be enhanced. Investments and technology development are two major drivers of growth. A major cause of present agrarian crisis is inadequate investment in agriculture. Of the total Plan outlay the share of agriculture as 4.90% in 9th Plan; 3.90 in 10 the Plan and further reduced to 3.70% in the 11th plan. In the 12th Plan (2012-17) the annual share of agriculture that was 5.40 % in 2012-13 reduced to 1.88 % in 2015-16. These include the infrastructure development as irrigation facilities, roads, markets, cold storage, rapid transportation especially of perishables etc. and simultaneously new technologies development to improve the resource use efficiency. Unfortunately, the investment in agriculture R&D has never gone more than 0.7 per cent of total agriculture GDP. Considering there is a resource crunch and will continue to be, so we need to make serious prioritization efforts to ensure optimum allocation and use of resources.

Figure 18: Share of agricultural research and education expenditure in AgGDP



Innovative Tools and Technologies:

i.Precision Agriculture: Precision agriculture merges the new technologies borne out of the information technology era with a mature agricultural industry. It is an integrated crop management system that attempts to match the kind and number of inputs with the actual crop needs for small areas within a farm field. It recognizes site-specific differences within fields and adjusts management actions accordingly. Precision agriculture can address both economic and environmental issues that surround production agriculture today. The concept of "doing the right thing in the right place at the right time in right amount" has a strong intuitive appeal. The potential of precision agriculture for economic and environmental benefits could be visualized through reduced use of water, fertilizers, herbicides, and pesticides besides the farm equipment.

It is also advisable for farmers to consider the availability of custom services when making decisions about adopting site-specific crop management. The most common custom services that precision agriculture service providers offer are intensive soil sampling, mapping and variable rate applications of fertilizer and lime. Equipment required for these operations include a vehicle equipped with a GPS receiver and a field computer for soil sampling, a computer with mapping software and a variable rate applicator for fertilizers and lime. Purchasing this equipment and learning the necessary skills is a significant up-front cost that can be prohibitive for many farmers. Agricultural service providers must identify a group of committed customers (Self Help Groups or Co-operatives) to justify purchasing the equipment and allocating human resources to offer these services. Once a service provider is established, precision agriculture activities in that region tend to center around the service providers. For this reason, adopters of precision agriculture practices often are found in clusters surrounding the service provider.

The Government is promoting the use of modern tools and technologies in agriculture and one such step is the use of drones. Drones could replace $127 billion worth of human labor globally. Infrastructure and agriculture make up the largest chunks of the potential value-some $77.6 billion between them-including services like completing the last mile of delivery routes and spraying crops with laser like precision. Drones can be used for several tasks. Some of which are listed below:

Identify pests, disease, and weeds and optimize pesticide usage and crop sprays through early detection.

- Provide data on soil fertility and refine fertilization by detecting nutrient deficiencies localized nutrient foliar spray e.g. nano-urea.
- Control crop irrigation by identifying areas where water stress is suspected. Make land improvements such as installing drainage systems and waterways based on multispectral data.
- Estimate crop yield. PMFBV— Crop Insurance
- View damage to crops from farm machinery and make necessary repairs or replace problematic machinery.
- Help with land management and whether to take ground in or out of

production or rotate crops etc.

- Survey fencing and farm buildings.
- Monitor livestock.

ii. Sensor Technologies: With the fast-paced development in technology, wireless sensors are now becoming affordable and available for a wide range of parameters. Their inputs can help in quantifying variability of the field in a finer resolution.

iii. Bio-technological Tools: It is obvious that the agricultural production system is going to face greater intensities and occurrences of multiple abiotic and biotic stresses with new strains coming up more frequently. Conventional tools may not be successful in coming up with new products in a short time. All modern tools, be it genetic engineering, gene pyramiding, marker aided selection or Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) etc. are to be used for generating new varieties (field and horticultural crops) and breeds (livestock including fisheries). The treasure house of genes that the rich biodiversity of the country possesses must be scientifically utilized to come up with products that will impart resilience to the production system. These tools must be utilized fully to enhance the genetic potential of all agricultural commodities.

iv. Water Smart Technologies: Today, water is being used very inefficiently and the availability of the resources is now becoming a key issue. It is possible to meet the water requirement of agriculture if the efficiency of surface water use is enhanced to 60 per cent and that of ground water by 75 per cent. It is certainly not because of lack technologies. The NARES have a plethora of technologies available that can lead to increase in water use efficiency at the field level. Water savings associated with the various interventions are:

Proper scheduling of canals (matching supply with demand)	:	40-60%
Precision leveling through laser levelers	:	15-20%
Scientifically designed check basins/border strips	:	10-30%
Zero tillage	:	20-30%
Adoption of pressurized irrigation systems	:	40-70%
Land configuration -ridge/furrow or raised/sunken beds	:	20-25%

Precision leveling followed by adoption of scientifically designed check basins/ border strips and land configuration-ridge/furrow or raised/sunken beds can significantly enhance water and nutrient use efficiency. The focus should be on the land configuration approach where all crops can be grown. Use of micro-irrigation systems where no land leveling is required offers enormous potential for undulating and dry lands.

Strategies for adoption of modern water management technologies focus at:

- Speedy transfer of improved technologies.
- Multiple use of water–focus on water productivity.
- Fine tuning of furrow-based irrigation systems (raised bed) for different crops and soils.
- Use of agrochemicals which enhance water (and nutrient) use efficiency.
- Use of modern tools for developing cultivars of higher water productivity.
- Planned wastewater reuse with emphasis on peri-urban water use.
- Focus on bioremediation of waste waters.
- Use of renewable energy e.g., solar energy for water use in agricultural purposes.
- Development of user-friendly Decision Support Systems (DSS) for real time decision making.
- Regulatory mechanism for ground water resource development and utilization.

v. Nanotechnology Applications: Nanotechnology applications have the huge potential to change agricultural production by allowing better scientific management and conservation efforts to plan production. Nanotechnology provides a much better effective way of environment detection, sensing and bioremediation. It can enhance agricultural productivity by using:

i. Nanoporouszeolotes for controlled release and efficient use of water, fertilizer etc.

ii. Nanocapsules for delivering of herbicide, vector and managing of pests.

iii. Nanosensors for detecting aquatic toxins and pests.

iv. Nanoscale biopolymers, (proteins and carbohydrates) based nanoparticles with few properties such as low impact on human health and the environment may be used in disinfection and recycling of heavy metals.

v. Nanostructured metals can be explored in decomposition of harmful organics at room temperature.

vi. Smart particles can be useful in effective environmental monitoring and purification processes.

vii. Nanoparticles as a novel photocatalyst.

viii. Wastewater treatment.

vi. Remote Sensing: India has made tremendous progress in the field of remote sensing and the potential for its application in agriculture is immense both in terms of assessment, monitoring and real time collection of data. Data sensors can simply be hand-held devices or drones mounted on aircraft or satellite based. Remotely sensed data provide a tool for evaluating crop health e.g., plant stress related to moisture, nutrients, compaction, crop diseases and other plant health concerns are often easily detected in overhead images. Electronic cameras can also record near infrared images that are highly correlated with healthy plant tissue. New image sensors with high spectral resolution are increasing the information collected from satellites. Remote sensing can reveal in-season variability that affects crop yield and can be timely enough to make management decisions that improve profitability for the current crop. Remotely sensed images can help determine the location and extent of crop stress. Analysis of such images used in tandem with scouting can help determine the cause of certain components of crop stress. The images can then be used to develop and implement a spot treatment plan that optimizes the use of agricultural chemicals.

Unmanned Aerial Vehicles (UAV) can be used to monitor and observe important data like multispectral imagery, visual and thermal imagery, humidity, the weather condition at a resolution of up to 1 cm/pixel and air pressure. This data can help the farmer make an informed decision.

vii. Crop Scouting: In-season observations of crop conditions may include weed patches (weed type and intensity), insect or fungal infestation (species and intensity), crop tissue nutrient status; flooded and eroded areas using a GPS receiver on an all-terrain vehicle or in a backpack, a location can be associated with observations, making it easier to return to the same location for treatment. These observations also can be helpful later when explaining variations in yield maps. Every farm presents a unique management puzzle. Not all the tools described above will help determine the causes of variability in a field, and it would be cost-prohibitive to implement all of them immediately. An incremental approach is a wiser strategy, using one or two of the tools at a time and carefully evaluating the results.

viii. Decision Support System (DSS): The adoption of precision / smart agriculture requires the joint development of management skills and pertinent information databases for real time decision making. Effectively using information requires a farmer to have a clear idea of the business objectives and crucial information necessary to make decisions. Effective information management requires more than record-keeping analysis tools or a GIS. It requires an entrepreneurial attitude toward education and experimentation. If one examines the basic data that is being generated by the National Agricultural Research, Education and Extension system on field crops and horticultural crops, livestock including fisheries and associated disciplines through the huge network of ICAR institutes including the All India Coordinated Research Projects, Agricultural Universities, Krishi Vigyan Kendras (KVKs) in conjunction with the IMD, Ministry of Water Resources, Ministry of Rural Development and Ministry of Agriculture and Farmers Welfare etc., there is a lot of scope to use modern tools of artificial intelligence, internet of things, cloud computing, data mining and processing algorithms to come up with cost-effective solutions in real time to the problems being faced by farmers on a day to day basis. A dedicated unit should be set up with professionals having the necessary competence.

ix. Artificial Intelligence (AI): AI is perhaps one disruptive technology which has the potential of impacting all aspects of our day-to-day existence. AI, however, is not a new technology. Its development was initiated more than 70 years ago and has been in use in many sectors particularly the industrial sector. But now because of almost unlimited computing power and lowering of data storage cost, AI based applications are on the fast track. It is a combination of technologies which enable machines to act with higher levels of intelligence and emulate the human behavior. Globally, digital and AI technologies are helping solve pressing issues across the agriculture value chain. The relative role of each technology in creating impact is dependent on the nature of the work, and the issues at hand. India has ~30 million farmers who own smart phones, which is expected to grow 3 times and about 315 million rural Indians are using internet. An Accenture study reported that digital farming and connected farm services can impact 70 million Indian farmers in 2020, adding USD 9 billion to farmer incomes. These are not futuristic scenarios, they are already on ground today, enabled by a vast digital ecosystem which includes traditional original equipment manufacturers, software and services companies, cloud providers, open-source platforms, startups, R&D institutions and others. Future growth is interdependent on the close partnership among these players.

Blue River Technology has designed and integrated computer vision and machine learning technology that enables farmers to reduce the use of herbicides by spraying only where weeds are present, optimizing the use of inputs in farming–a key objective of precision agriculture. Crop diseases or pest infestation in the crops can be accessed by an image on a farmer's phone and determine the product quality in real time, without any manual intervention. Farmers just need to know the operation of app in their phone. This will help farmers in their product grading.

x. Predictive Agricultural Analytics: Farming practices advisories are limited due to lack of access to scientific understanding of crop lifecycle, pests, quality metrics and the latest micro-fertilizers use. Supply chain efficiencies–real-time data analysis can be used for efficient and smart supply chain. These modern techniques are the future of the Indian agriculture. They capture complete information about the commodities (growing information, pre- and post-harvest, transportation, warehousing etc.) and proactively advice farmers on sowing, pest control, harvesting etc.

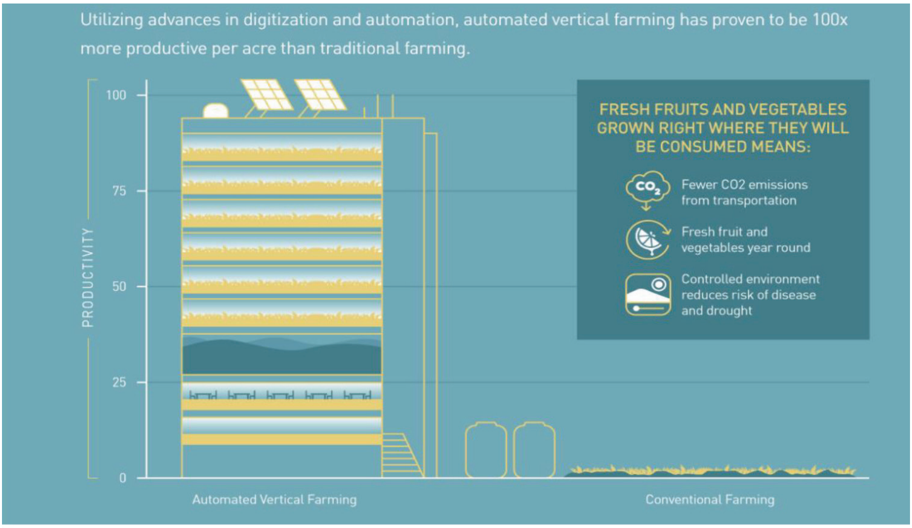
xi. Biosecurity and Safety: Bio-security and safety has become a very vital issue in today's world from threats like gene-piracy, cross-border movement of vector-borne diseases, alien invasive weed species and pests. Environmental and safety aspects of nano-technology derived products, GM crops are issues which need to be addressed before large scale use can be recommended.

xii. Robotics in Agriculture: There are real problems in modern agriculture. Traditional farming methods struggle to keep up with the efficiencies required by the market. Farmers in developed countries are suffering from a lack of workforce. The rise of automated farming is an attempt to solve these problems by using robotics and advanced sensing. Robots also have an advantage as they can access areas where other machines cannot. For example, Maize growers face a problem that the plants grow too quickly to reliably fertilize them. "Rowbot" aims to solve this problem as it easily drives between the rows of corn and targets nitrogen fertilizer directly at the base of each plant. Some drone companies offer farmers combined packages which include robotic hardware and analysis software. The farmer can then move the drone to the field, initiate the software via a tablet or smart phone, and view the collected crop data in real time. Ground based robots can provide even more detailed monitoring as they are able to get closer to the crops. Some can also be used for other tasks like weeding and fertilizing. Some weeding robots don't even need to use chemicals. "Robocop", for example, uses computer vision to detect plants as it is pushed by a tractor. It then automatically hoes the spaces between plants to uproot the weeds. Other weeding robots use lasers to kill the weeds.

xiii. Urban Agriculture, Automated Vertical Farming, and Hydro-and-Aquaponics: The urban population is expanding globally, and yesteryear's food system will soon be suboptimal for many of the mega-cities swelling with people. The future of food depends on technology that enables us to get more food out of fewer resources. The next generation food production system will include urban agriculture, automated vertical farms, aquaponics / hydroponics, in vitro meats, and artificial animal products. With new technology, the future agriculture could change drastically. Many products will flop, but others will take a firm hold in our supply chain and become culturally acceptable and economically viable.

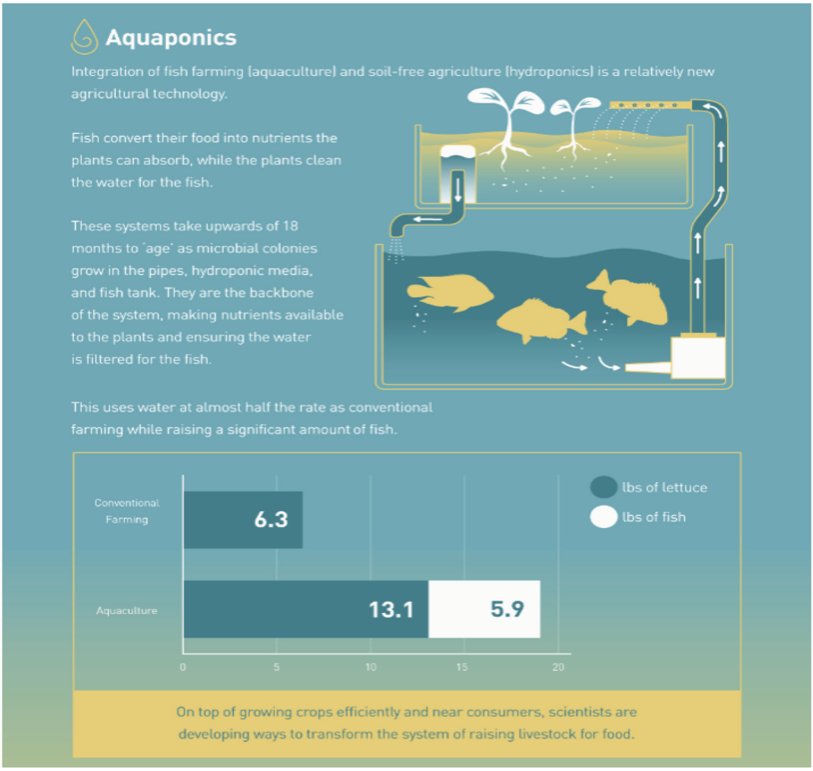
Urban agriculture will allow moving food production from rural to urban areas, reduce transportation costs and allow fresher food to be delivered to the growing urban population. In 2015 alone, some 9.9% of the world population was engaged in some level of urban agriculture, producing about 17% of the world's food. Most of this activity, is small scale and often sustenance farming. This is changing as technology is allowing more compact agricultural infrastructure. Using **automated vertical farms** advances in digitations and automation; automated vertical farming has proven to be 100 times more productive per acre than traditional farming (Figure 19), (Sonali, 2018).

Figure 19: Automated vertical farms



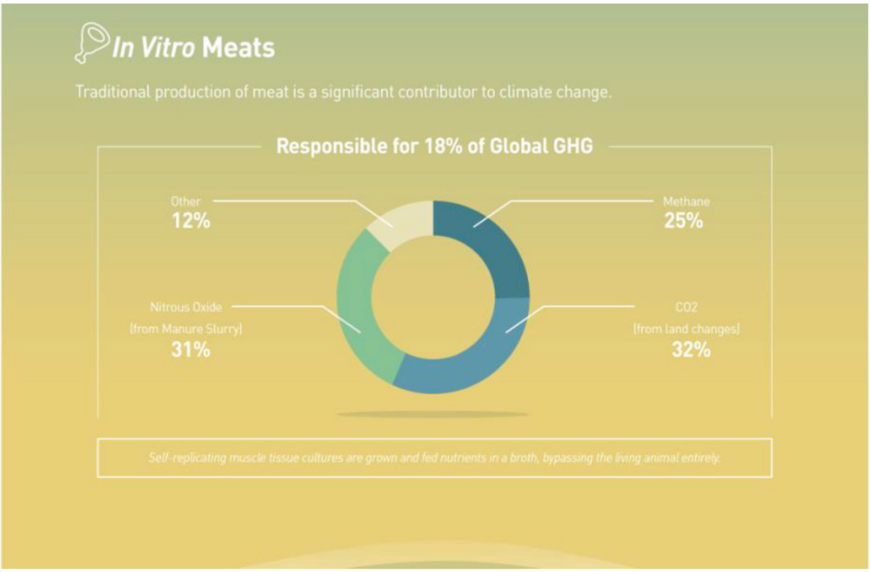
Aquaponics: Under aquaponics, integration of fish farming (aqua-culture) and hydroponics (soil-free agriculture) is convenient and producing much more than conventional farming. Integration of fish farming (aquaculture) and soil free agriculture (hydroponics) is relatively new technology. Fish converts into nutrients the plants can absorb, while the plants clean the water for the fish. The system takes upward of 18 months to age as microbial colonies grow in the pipes, hydroponic media, and fish tank. They are the backbone of the system, making nutrients available to the plants and ensuring the water is filtered for the fish. This uses water at almost half the rate as conventional farming while raising a significant number of fish. In conventional farming, the production has been 6.3 lbs of lettuce, whereas in aquaponics it produced 13.1 lbs of lettuce plus 5.9 lbs. of fish (Figure 20).

Figure 20: Aquaponics



xiv. Molecular Food Technology: Under in vitro meat production technology, traditional production of meat is a significant contributor to climate change. Meat production is responsible for contributing to 18 % of the global greenhouse gas emissions, which includes 25 per cent methane, 32 per cent carbon dioxide, 31 per cent nitrous oxide, and 12 per cent others (Figure 21). The first proof-of-concept meatball was produced in 2016 by Memphis Meats. A year later the start-up can produce 450 gm of beef for $2,400. As the process is scaled up for planned market entry in 2021, the cost will drop.

Figure 21: In vitro meats



Artificial animal product is the other route to get artificial meat—is to use machine learning to grasp the complex chemistry and texture behind these products and to find ways to replicate them. This has already been done for mayonnaise and it is in work for eggs, milk, and cheese, as well. The option for lab grown meat are limited only by how fast they can be developed, with biotech start-ups working on these already (Mandelbaum, 2017).

xv.Space Agriculture: This is first time humans have done biological growth experiments on lunar surface. A small green shoot is growing on the moon in an out-of-this-world first after a cotton seed germinated on board a Chinese lunar lander. The sprout has emerged from a lattice-like structure inside a canister, according to a series of photos released by the Advanced Technology Research Institute at Chongqing University, China. Scientists who designed the "mini lunar biosphere" experiment–sent an 18 centimeter bucket-like container holding air, water and soil. Inside are cotton, potato, and Arabidopsis seeds–a plant of the mustard family as well as fruit fly eggs and yeast. Images sent back by the probe show a cotton sprout has grown well (Xie Gengxin, 2019).

xvi. Genome based Green Technologies: Simply inherited traits such as disease resistance, submergence tolerance, QPM, etc. have been successfully transferred into elite genotypes through marker assisted backcross breeding. For example, Swarna Sub1, Vivek QPM 9, HHB67, Pusa Basmati 1637 (blast resistance gene Pi9) etc. However, genomic assisted breeding for improving complex quantitative traits has largely been unsuccessful due to the difficulty in finding the major QTLs stable across environments and genetic backgrounds. Several other advanced strategies such as forward breeding, marker assisted recurrent selection, genomic selection is being utilized to improve complex traits. To improve the abiotic stress tolerance such as drought, salinity, submergence etc., and to improve the nutrient use efficiency such as nitrogen and phosphorus etc. in crop plants, genomic resources and tools would be indispensable. South and East Asia, including India, put together consumes 58% of nitrogen and 57% of global phosphorus fertilizers and, therefore, managing fertilizer requirement of Indian agriculture remains a major challenge.

Strategies to Cope with Changing Climate:

Plant breeding strategies include, exploitation of alien genetic variation, enhanced input use efficiency, breeding for earliness and varieties for fragile ecosystems. The genomic tools include, marker assisted breeding, transgenic/cisgenics, proteomics, tilling/eco-tilling (search for new genes) and next generation sequencing technologies etc. In breeding varieties for no-till agriculture, adoption of Resource Conservation Technologies (RCTs) like direct seeding of rice saves water up to 30%, fuel and labor up to 25%, production cost up to 22%, reduces CH4 emission by 19%, and resolves weed problems. Identifying traits and genes for minimum till agriculture through use of genomics for developing varieties with better adaptation, breeding for submergence tolerance have resulted in ten Sub1 rice varieties developed in backgrounds of popular varieties are commercialized with yield advantage of 1- >3 t/ha after 7-18 days of flooding with no penalty on yield or quality in absence of floods.fertilizers and, therefore, managing fertilizer requirement of Indian agriculture remains a major challenge.

Losses due to Drought:

About 86% of the global cultivated land is under rain-fed cultivation (Kumar, 2005) and about 50% of world rice production is affected by drought (Bouman et al., 2005) and 160 million ha of maize grown globally is rain-fed (Edmeades, 2008). Loss in wheat production during 2009 was 22% less than in 2008 due drought (de Carbonneel, 2009) and reproductive stage drought leads to 50% yield loss in pearl millet (Mahalakshmi et al., 1987).

Deep Rooting 1 (DRO1) QTL confers deeper roots that can access moisture reserves, an avoidance strategy and deep-rooting phenotype also enhances nutrient uptake and yield under non-drought conditions.

The Way Forward:

The agri-food system of the future will be technology based and a paradigm shift is needed in our R&D approach towards intensified sustainable and resilient agricultural production system. To achieve this, we need to focus on the followings:

- Systems approach in addition to breeding of low-water footprint crop varieties, and on innovations in irrigation management that can potentially improve water-use efficiency in crop production. Emphasis of the agricultural research should be on breeding to produce high-nutrient staple food crops, a low-cost option to combat malnutrition.
- Innovative bio-based fertilizers (vermi-compost, and plant-based bio fertilizers) and crop breeding for improved nutrient-use efficiency and higher nitrogen-fixation capacity of crops to improve soil fertility. A holistic approach for organic farming with emphasis on organic inputs for pests, disease and weed control and adequate processing and value addition system for organic produce.
- In livestock sector more attention to refinement of sexed semen technology that provides farmers a choice of sex of the offspring suited to different animal species. Besides, more research is warranted on improving quality of feeds and fodders and animal health.
- Machines and equipment suited for labour-intensive crop production. Also developing post-harvest technologies aimed at reducing agricultural wastage, and recycling of waste into biological products and green energy including establish agro-processing centers with warehouse/storage facilities and decentralize storage of grains, fruits, and vegetables with private and government partnership.
- To reduce the GHGs emission intensity by 33-35% of 2005 level by 2030 as well as achieving land degradation neutrality by 2030, our focus must shift on breeding crop varieties and animal breeds and on evolving innovative husbandry practices to enhance resilience of agriculture to climate change and to insect-pests and diseases induced by it.
- Field tested IFS Models relevant to the average farm holdings, focusing on small and marginal farmers for different agro-ecosystem must be up-scaled in a mission mode with assured market linkages and MSP.

- The two vital natural resources, soil (land) and water provide a host of ecosystem services in addition to the provisioning services like food production. An institutional mechanism needs to be put in place for Payment of Ecosystem Services (PES) so that their sustainable management is guaranteed.
- A national mission on precision agriculture needs to be set up, which focuses on utilization of modern tools and technologies like remote sensing, drones, sensors, decision support systems, robotics, artificial intelligence, internet of things (IoT), biotechnology (CRISPER, gene editing. genome based green technologies) etc. encompassing all sectors so that "More from Less for More" is ensured for the 1.7 billion Indian by 2050.
- Opening entrepreneurship development training and incubation centers in each district for rural youth and launching a dedicated campaign for educating all stakeholders involved from farm to fork to minimize the loses in the supply chain.
- Use of renewable/alternative forms of energy like solar and wind-based application instead of fossil fuels need to be pushed in a big way as the energy use in agriculture in India is still low compared to other developing countries.
- Mechanization, custom hiring centers, gender friendly small farm implements that can cater to resource poor farmers must be promoted by the government for bringing in efficiency, reducing drudgery and cost of cultivation.
- Adequate and dedicated funding should be provided for high end research on futuristic technologies like genome based green technologies, nanotechnology, climate adaptation and mitigation options, enhancing soil and water use efficiency, robotic, AI, etc.

Finally-

Towards a New Development Path

The dominant path to industrialization has been characterized by high concurrent GHG emissions

Committing to alternative development paths requires major changes in a wide range of areas:

- Economic structure
- Urban design
- Transport infrastructure
- Consumption patterns
- Demography

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Dr A.B. Joshi Memorial Lecture Award

Prof. Panjab Singh

Prof. Panjab Singh was born in Anantpur, District Mirzapur, Uttar Pradesh on 10 December 1942. Educated at Agra University, B.Sc. 1962, M.Sc. 1964 and Indian Institute of Technology, Kharagpur, Ph.D. 1969. In his 40 long years of service in different capacities as teacher and researcher, research manager and administrator starting his career from Assistant Professor in a University and rising up to the post of Secretary, Department of Agriculture Research and Education (DARE), Govt. of India and Director General (DG), Indian Council of Agricultural Research (ICAR) and Vice-Chancellor of three premier Universities/Institutes, viz. Banaras Hindu University, Varanasi, Country's premier Indian Agricultural Research Institute (A Deemed University), New Delhi and Jawaharlal Nehru Agriculture University, Jabalpur. He is currently the Chancellor of Rani Lakshmi Bai Central Agricultural University, Jhansi. Prof. Singh contributed significantly in promoting research and higher education in the country by creating an enabling environment through establishing institutions, strengthening of research, education and extension infrastructure and producing qualified man power in different sectors. All these efforts resulted in generation and dissemination of innovative agricultural technologies, and breeding of qualified and trained human resource which moved the nation towards self-sufficiency in food grains and significant rise in production of fruits and vegetables, milk, fish, and poultry products. His contributions in areas of feed and forages for livestock and agro forestry systems for sustainable agriculture, environment and livestock development are very significant. All this was possible because of proper planning, able governance and their effective implementation over years, of which Prof. Singh has been an active partner while being in senior positions in the government systems at the state and central levels.

Prof. Singh's contribution in establishing a second campus (South Campus) of Banaras Hindu University (BHU) at Barkachha, Mirzapur during his tenure as its Vice-Chancellor is a land mark contribution in promoting higher education in tribal, backward and naxal affected region of the country bordering U.P., M.P., Bihar and Jharkhand. As a visionary Vice-Chancellor of BHU Prof. Singh also felt the need and initiated the process to raise the status of Institute of Medical Sciences to that of AIIMS and that of Institute of Technology, BHU to IIT.

As Regional Plant Production and Protection Officer of the Food and Agricultural Organization (FAO) of the United Nations at Bangkok, he promoted and coordinated research and development programmes in crop sector in countries of South and South East Asia. Even today in his capacity as Chancellor and Advisor to universities/ industries and state development departments and also as founder President/CMD of Foundation for Advancement of Agriculture and Rural Development (FAARD) and a Farmers Producer Organization (FPO), he is playing a significant role in promoting education and agricultural growth and development by empowering farmers and people through education and capacity building.

Prof. Singh has more than 350 publications in the form of research papers in scientific journals and national and international seminars and symposia, books and book chapters, policy papers/ reports etc. in different sectors. In recognition of his scientific contributions, five scientific societies honored him with life time achievement awards. Prof. Singh has been President and Vice-President of eleven scientific societies, and Fellow of ten national societies/ academies including the National Academy of Agricultural Sciences (NAAS). Indian Institute of Technology, Kharagpur has honored Prof. Singh as its distinguished alumnus and Eleven universities with Doctor of Science (h.c.) besides other honors, awards and recognitions from India and abroad. Prof. Singh has been consultant to the FAO, World Bank, ADB and advisor (Agriculture and Plantations), ETA, Dubai and RKDF group of institutions, besides several others, and continues to contribute for the benefit of the society, in general and the farming community in particular.

The National Academy of Agricultural Sciences (NAAS), while acknowledging his contributions, feels honored to invite Prof. Singh to deliver the prestigious Dr. A.B. Joshi Memorial Lecture at the occasion of the XVI Agricultural Science Congress.