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PRESIDENTIAL ADDRESS

Leveraging Science, Technology and Innovations for Transformation and Sustainability of Indian Agriculture*

Suresh Pal†

I

I consider it a great honour and privilege to deliver the presidential address at the 82nd annual conference of the Indian Society of Agricultural Economics. I am indeed grateful to esteemed members of the Society, its President, Professor D.K. Marothia, and past Presidents, particularly Dr.C.Ramasamy, Dr.Abhijit Sen and Dr.S.S. Johl for showing confidence in me. I am deeply humbled by this kind gesture and generosity. I have greatly benefited from the annual conferences of the Society since my student days and enriched my knowledge of Indian agriculture.

I began my research work on agricultural production systems and gradually moved to broader development issues. Several organisations notably the Indian Council of Agricultural Researchand individuals have shaped my thoughts on agricultural development, institutional change, science and technology policy, agri-input and service systems, and sustainable agriculture. I'vechosen to share with you some of my ideas on these issues. I acknowledge with deep respect thementorship provided by Prof. A.S Sirohi, Dr Dayanatha Jha and Dr Derek Byerlee during different stages of my career. Most of my work was done in collaboration with Mruthyunjaya, P.K. Joshi, Ramesh Chand, Philip G. Pardey and several other colleagues. The critiques of my work also deserve special acknowledgment for contributing tothe improvement of the policy content.

The development of Indian agriculture and the transformation of agri-food systems have received greater attention because of rapid growth and institutional changes in the recent past. The agricultural sector has shown strong resilience during the COVID-19 pandemic, and its contribution to the Sustainable Development Goals. The nature and sources of growth have also changed significantly. Technological and institutional innovations however shall continue to influence the growth, distribution of gains, and responsiveness of agri-food systems (Vaidyanathan, 2009, World Bank, 2008). I underscore the need for leveraging these innovations for accelerating the pace of development of Indian agriculture and allied sectors.

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† Former Director, ICAR-National Institute of Agricultural Economics and Policy Research, New Delhi-110 012.
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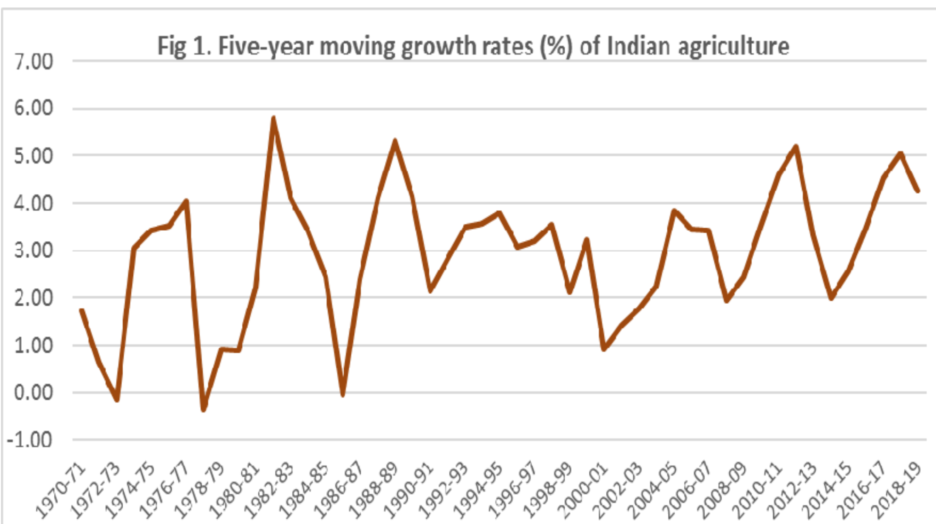
II

AGRICULTURAL GROWTH

2.1 Trends and Sources of Agricultural Growth

The growth of Indian agriculture during the last decade or so has shown a major departure fromthe past. There is an acceleration in the growth rate along with reduced fluctuations in the growth as compared to wider fluctuations during 1970s and 1980s in unfavorable weather years. Furthermore, both crop and livestock sectors contributed to agricultural growth until 2000s, but growth in livestock and fisheries sectors became much higher in the decade of 2010s and growth in crop sector remained moderate (Fig 1 and 2). The rise in the dominance of livestocksector could be attributed to commercial poultry and an increase in milch animals, mainly crossbred cows and buffaloes. The rise of commercial dairy has perhaps moderated the fluctuations in agricultural growth



The regional pattern of sectoral growth reveals the interesting pattern of high growth in the lowproductivity states like Madhya Pradesh, Andhra Pradesh, Assam and Rajasthan. It is interesting to note that the growth in livestock sectors was high in almost all the states, except in Kerala, with an exceptionally high growth rate (>6 per cent or more) in Andhra Pradesh, Assam, Bihar,Chhattisgarh, Haryana, Himachal Pradesh, Jammu & Kashmir, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu and Telangana (Table 1). The states of Odisha, Uttar Pradesh, Uttarakhand and West Bengal showed moderate growth (nearly 4 per cent) in livestock sector. The rising demand for milk and meat and infrastructure development perhaps explains this differential growth in livestock sector. In the states like Andhra Pradesh and Tamil Nadu, there is a rapid spread of aquaculture.

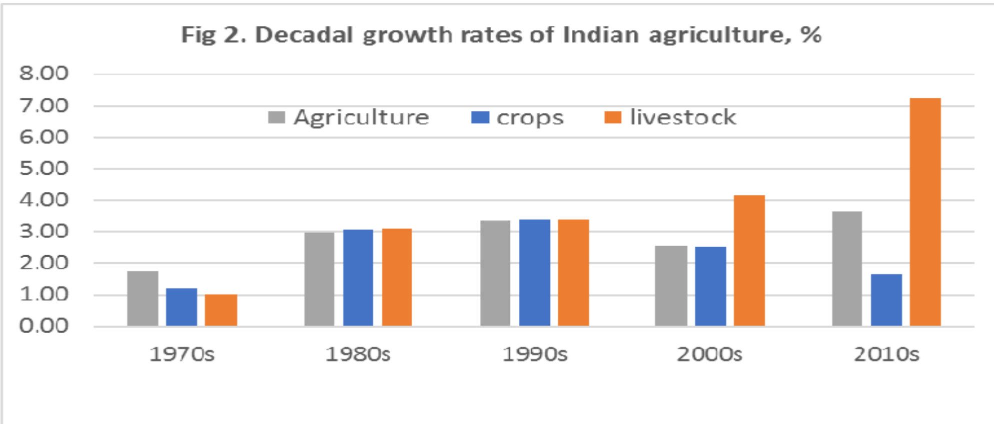


TABLE 1. AGRICULTURAL GROWTH, RURAL NON-FARM EMPLOYMENT AND FARM HOUSEHOLD INCOME

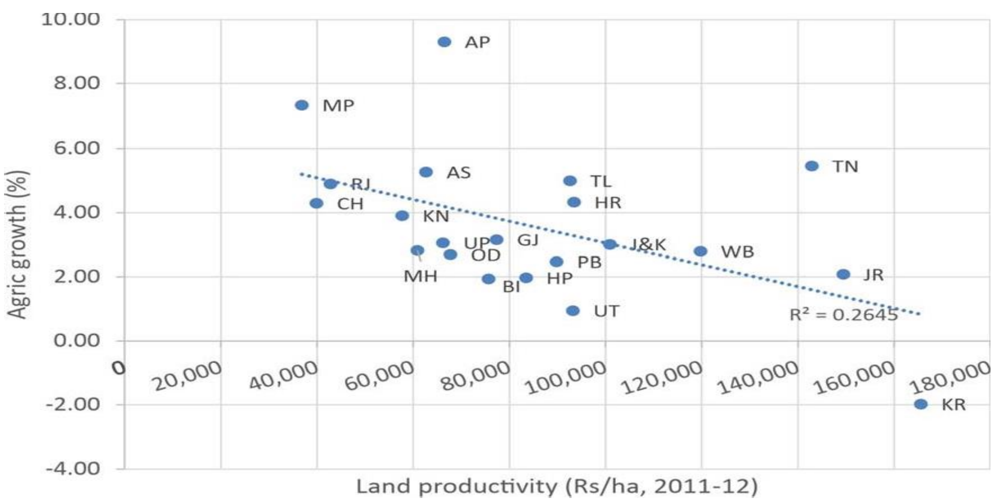
State (1)	GVA Growth (per cent)2012-2021 (2)	Crops share (per cent) in GVA (3)	Growth rate (per cent) of livestock GVA (4)	Average monthly income of farmers (Rs.) (2018-19) (5)	Share (per cent) of rural non-farm employment (2018-19) (6)
Andhra Pradesh	9.31	40.90	9.25	10,480 (46.26)	40.30
Assam	5.27	74.70	11.39	10,675 (52.28)	57.53
Bihar	1.94	52.90	8.64	7,542 (33.18)	46.88
Chhattisgarh	4.29	71.29	7.38	9,677 (45.92)	25.37
Gujarat	3.16	72.27	5.93	12,631 (34.95)	31.33
Haryana	4.33	54.09	8.55	22,841 (34.96)	61.19
Himachal Pradesh	1.97	75.27	9.60	12,153 (52.60)	39.27
Jammu & Kashmir	3.01	58.32	6.49	18,918 (64.33)	55.41
Jharkhand	2.08	63.37	5.57	4,895 (57.08)	48.77
Karnataka	3.91	69.52	8.20	13,441 (34.05)	38.43
Kerala	-1.97	58.76	-0.31	17,915 (56.94)	71.58
Madhya Pradesh	7.37	80.61	15.25	8,339 (29.83)	28.91
Maharashtra	2.82	72.18	6.46	11,491 (37.62)	29.74
Odisha	2.70	70.53	4.76	5,112 (51.82)	49.81
Punjab	2.47	61.51	5.62	26,701 (22.40)	61.26
Rajasthan	4.90	51.99	11.16	12,520 (42.78)	35.27
Tamil Nadu	5.46	41.82	12.29	11,924 (54.48)	56.90
Telangana	5.00	52.99	8.50	9,403 (31.49)	33.38
Uttar Pradesh	3.06	72.64	3.51	8,061 (35.97)	38.31
Uttarakhand	0.95	62.00	4.30	13,552 (27.51)	54.79
West Bengal	2.80	62.02	4.37	6,762 (55.02)	51.11
All India	3.64	59.90	7.25	10,218 (39.76)	42.16

Notes: (i) Figures in parentheses are share (per cent) of wage income in the total income of farm household for respective state.
(ii) Share of rural non-farm employment in workforce is based on the Primary Labour Force Survey 2018-19, NSSO.

The high agricultural growth could not be translated into higher farm income. The average monthly income of farm households in the country was Rs 10,218/- in 2018-19. The income was much below the national average in the states of Bihar, Jharkhand, Odisha, and West Bengal, primarily because of the smaller size of land holdings in these states. The share of wageincome was notably high in the states of Jammu & Kashmir, Jharkhand, Kerala, Odisha and West Bengal. The states with a higher share of wage income in the total farm income has also higher share of rural non-farm employment (Table 1). The exceptions are the states of Haryanaand Punjab with high crop productivity and Uttarakhand with a higher share of high-value crops.

2.2 Convergence and Inclusiveness of Agricultural Growth

Another important characteristic of agricultural growth in India is improved regional convergence. As noted above low productivity states like Madhya Pradesh have shown impressive growth in crop and livestock sectors. The available studies indicate a strong regionalconvergence in the productivity (Balaji and Pal, 2014). The recent estimates (Figure 3) also show a strong negative correlation between agricultural growth and land productivity. This convergence was much stronger when crop productivity alone is considered against its growth rate. This was possible by the spread of micro-irrigation in dryland states like Andhra Pradesh, Madhya Pradesh and Rajasthan. The preliminary evidence also indicates the positive impact ofbetter governance of agricultural programs on its growth.



The convergence of agricultural growth was further tested with the Beta convergence of land productivity. This was analysed both for the value of output and the gross state value added during 2011-12 to 2018-19. The results (Table 2) indicate a strong convergence for the agricultural sector as a whole as well as for the crop sector. However, the speed of convergence was rather faster for the crop sector. The speed was further high when the productivity was measured per hectare of gross cropped area. Besides the spread of micro-irrigation, stress tolerance cultivars, focus on pulses and oilseeds and climate-resilient practices have contributed to the growth convergence. These factors coupled with public investment in rural and agri-infrastructure can contribute to the development of the aspirational regions.

TABLE 2. BETA CONVERGENCE IN THE LAND PRODUCTIVITY

	β-coefficient (initial productivity)	
	Per ha NSA	Per ha GCA
(1)	(2)	(3)
Convergence in Value of Output (2011-12 to 2018-19)		
A. Crops	-2.52**	-3.67***
B. Crops + Livestock + Fisheries	-1.85*	-2.15*
Convergence in GSVA (2011-12 to 2020-21)		
A. Crops	-2.67**	-3.65***
B. Crops + Livestock + Fisheries	-2.06*	-2.30*

Note: GCA, NSA data are available only till 2018-19. In case of GSVA, GCA, NSA statistics for 2018-19 is used for both 2019-20 and 2020-21.

2.3 Sustainability of Agricultural Growth

The sustainability of agriculture is a major development challenge globally. The Sustainable Development Goals have accorded high property to the sustainability agenda, and in India, the concern is given attention in all the agricultural programmes. The concept of sustainability envisages meeting the needs of the present generation without compromising the productive capacity of agriculture to meet the need of future generations (FAO, 1989). The concept incorporates economic, social and environmental dimensions and implies the significant role oftechnology in promoting the sustainability. A study incorporating all the three dimensions of sustainability was conducted using 51 indicators for the north-west plains of India. The study indicated a moderate degree of sustainability with concerns about the depletion of groundwaterand agro-biodiversity (Pal *et al.*, 2021). In the present context, sustainability of the production systems of different states is measured using 14 indicators relating to soil (5), water (4) and environment (5). An index is computed for each of the dimensions for ease of understanding.

Usually, the index is computed with the min-max approach with equal weights to the indicators,which gives the relative position of a region in comparison to a most desirable region. In this exercise, deviation in actual value from the benchmark (scientifically optimum) value of the indicator was used to normalize the indicator and compute the sustainability index. The results given in Table 3, show low to moderate levels of sustainability of agriculture in different states.None of the states show a high index of sustainability with respect to all three dimensions of soil, water and environment. Karnataka and Tamil Nadu are the two states with a moderate degree of sustainability for all three dimensions.

The soil sustainability index was lower in the states of Assam, Jharkhand and Rajasthan with avalue of less than 0.50. Similarly, water sustainability index was poor in the states of Andhra Pradesh, Gujarat, Maharashtra, Odisha, Rajasthan and Telangana with an index of less than 0.40. The environmental index was lower in the states of Assam, Himachal Pradesh, Kerala, Punjab and West Bengal because of the lower system and varietal diversity and lower adoption of sustainability-enhancing practices like organic farming and cultivation of legume-based systems.

TABLE 3. SUSTAINABILITY INDICES RELATING TO SOIL, WATER AND ENVIRONMENT (0 LOWEST, 1 HIGHEST)

State	Soil	Water	Environment	Investment response of state	
				Research and education intensity (per cent, 2019-20)	Capital expenditure (Rs./ha, 2018-19 TE)
(1)	(2)	(3)	(4)	(5)	(6)
Andhra Pradesh	0.68	0.33	0.58	0.19	11,423
Assam	0.36	0.56	0.35	0.79	9,635
Bihar	0.60	0.44	0.49	0.39	5,562
Chhattisgarh	0.55	0.42	0.44	0.26	23,925
Gujarat	0.67	0.28	0.57	0.38	6,972
Haryana	0.59	0.54	0.40	0.38	10,530
Himachal Pradesh	0.79	0.46	0.28	1.59	31,364
Jharkhand	0.36	0.40	0.52	0.32	16,678
Karnataka	0.52	0.50	0.61	0.45	15,351
Kerala	0.59	0.54	0.28	0.78	30,039
Madhya Pradesh	0.61	0.44	0.62	0.04	8,830
Maharashtra	0.54	0.39	0.68	0.40	13,634
Odisha	0.51	0.29	0.47	0.20	9,635
Punjab	0.70	0.46	0.35	0.29	16,686
Rajasthan	0.42	0.38	0.57	0.12	19,880
Tamil Nadu	0.54	0.52	0.56	0.59	3,540
Telangana	0.60	0.29	0.54	0.25	24,957
Uttar Pradesh	0.50	0.50	0.45	0.07	19,026
Uttarakhand	0.69	0.41	0.44	1.08	10,640
West Bengal	0.53	0.53	0.36	0.07	41,209

Notes: *Soil sustainability indicators:* degraded area, area with unfavourable pH, nutrient deficient samples,organic carbon and FYM application; *Water sustainability indicators*: water productivity, potential utilization, investment in soil and water conservation,rate of groundwater depletion; *Environmental sustainability indicators*: agro-forestry, organic farming, area under legumes, cropping/productionand varietal diversity (crops, livestock, fish).

Although there is a lower index of sustainability in some states, none of the states has poor sustainability with respect to all the indicators. Therefore, there is a need to focus on the relevant indicator to promote sustainability. These efforts could be assessed by examination ofthe measures taken by the government. Here two such factors are considered; one is public investment in promoting the sustainable use of natural resources, and the second is the investment in the development and dissemination of sustainable farm practices and technology.As seen from Table 3 last two columns, there is a need to step up public expenditure in the states of Assam, Bihar, Gujarat, Madhya Pradesh, Odisha, Tamil Nadu and Uttarakhand, which have low per hectare public investment. The response is grossly inadequate when agricultural research and education intensity of state funds is considered. The intensity is very low in the states of Andhra Pradesh, Madhya Pradesh, Odisha, Rajasthan, Uttar Pradesh and West Bengal.The intensity must be at least doubled in these states. Any compromise on this investment shall deplete the productive capacity of the states and slow down the flow of technology to farmers.The cost of correcting these unsustainable trends shall be much higher in the future, certainly much beyond the reach of farmers and local rural communities.

2.4 Development of Rural Non-Farm Sector

The past evidence and recent data given in Table 1 show that the growth of the rural non-farm sector is extremely important for increasing rural income and generating rural employment. This has also contributed to a significant reduction in rural poverty. It is also found that there is a bidirectional causality between agricultural growth and the development of rural non-farm sector (Chadha, 2008). An increase in agricultural productivity increases the demand for other goods and services, while the growth in the non-farm sector increases employment and wage income in rural areas. This was particularly visible during the COVID-19 pandemic when the agriculture and rural non-farm sector contributed to the resilience and recovery of the economy(NIAP, 2020).

Within the rural non-farm sector, manufacturing, construction, trade, transport and services arethe major sectors generating employment and income for rural workers in India. Systematic data are generated by the National Sample Survey Organisation for the organised manufacturing sector through the Annual Survey of Industries in the country. Most of these industries are micro, small and medium enterprises. In addition, there are unorganized industries in rural andurban areas. The NSSO data provide useful information about the performance of the rural industries to assess the potential of this sector. As seen from Table 4, there are 2,46,503 industries in the country and nearly half of these industries are located in rural areas. The number of rural industries has risen moderately during 2011 to 2020 and the increase was lowerfor food processing industries. Important among the food processing industries are grain milling, sugar, edible oil and dairy. This implies that the growth in the number of rural industries was rather moderate, certainly lower than that needed to absorb the increasing labour force. The workers employed per industry remained 33-36 for food processing industries and 54-56 for all the rural industries. The performance in terms of output-input ratio and net valueadded-output ratio remained constant or declined both for food processing and all the rural industries. This means that new investment to increase the labour productivity is inadequate andtherefore the ratio of productive capital to wages declined for rural and other industries as well. A study of the food processing industries for a longer period (1980-2018) shows a decline in capital productivity and the workforce was employed in contract mode (Nithyashree and Pal, 2020). Much of the investment usually comes along with improved technology to raise capitaland labour productivity. This trend was not seen for rural industries and therefore this sector remained unchanged during the last decade. It is, therefore, necessary that the manufacturing sector in rural areas must grow to enhance employment and income-generating opportunities and for this, higher investment, improved technology and education of rural workers are necessary. In addition, the development of rural infrastructure like roads, digital connectivity, electrification and institutions should be given high priority. The impact of the Agri-Infrastructure Fund, Skill India and Startup India should be examined for necessary mid-course correction, if needed. The manpower requirement may be even more challenging in the case ofthe service sector and in the absence of investment in human capital, the employability of ruralyouth may be abysmally low.

TABLE 4. TRENDS IN THE FOOD PROCESSING AND RURAL INDUSTRIES

(1)	2010-11 (2)	2015-16 (3)	2019-20 (4)
Food Products			
Number of factories	34,023	37,098	39,149
Number of workers per factory	35.26	33.39	36.06
Productive capital-wages ratio	22.26	19 .16	16.30
Output-input ratio	1.11	1.11	1.10
Net value added-output ratio	0.09	0.08	0.08
Rural industries			
Number of factories	78,040	92,080	1,03,286
Number of workers per factory	54.40	54.02	55.95
Productive capital-wagesratio	36.10	32.96	26.92
Output-input ratio	1.24	1.24	1.20
Net value added-output ratio	0.16	0.16	0.13
All Industries			
Number of factories	211,660	233,116	246,503
Number of workers per factory	46.78	47.77	52.97
Productive capital-wages ratio	26.01	22.76	19.68
Output-input ratio	1.21	1.23	1.20
Net value added-output ratio	0.15	0.16	0.13

Source: Based on *Annual Survey of Industries* data.

III

TECHNOLOGY AND INNOVATIONS

Science, technology and innovation (STI) are being used interchangeably but these are differentconcepts and differ greatly in terms of their ability to provide a solution to economic and technical constraints. Science is for the creation of new knowledge with potential applications inthe future, while technology provides an immediate solution to a binding constraint and usually,it is supplied by a formal research process. Innovation is a broader connotation relating to process, product, technology and institution, and its source could be formal or informal researchor any other source to improve efficiency (World Bank, 2012). Therefore, both technology andinnovation are used interchangeably. Given rising resource constraints and the applied nature of agricultural research, technology and innovations are given high priority. Recently, G20 has identified STI as a key instrument to help achieve the sustainable development goals.

The organised application of agricultural science has been quite old but it grew more rapidly in terms of funding, structure and regulation in developed countries like USA, Europe and Australia. However, the progress was quite slow in developing countries and now three countries, namely India, China and Brazil have well-established agricultural science systems. InIndia, the system has a history of more than one hundred years old, but now it is far behind China and Brazil in terms of funding. Institutionally, the structure has moved from the national institutions to the research system to the innovation system, comprising diversity and interdependence of the organizations. However, the Indian Council of Agricultural Research (ICAR) and State Agricultural Universities (SAUs) remained the major components, and ICAR- SAU system developed a close partnership with the Consultative Group for International Agricultural Research (CGIAR). Here it may be important to mention that the council system ofresearch is adopted by many developing countries and only Brazil has a corporation-type research establishment.

3.1 Has STI Contributed?

The contributions of STI in the field of agriculture are well-known and documented. It began with the green revolution and subsequently spread to all other sectors like livestock, poultry, fisheries and horticulture. Simultaneously, there have been developments in the areas of naturalresource management, nutrition and post-harvest management (Pathak and Mohapatra, 2022). Agricultural exports are rising rapidly in the recent past and soon the country shall be a leadingproducer and exporter of many agricultural commodities. Recent success stories are of pulses,floriculture, horticulture and fisheries. Have these impacts been examined econometrically?

The impact of agricultural research has been examined at the sector, system and programme levels.The ICAR-SAU system has been subjected to performance assessment periodically. Recently,external reviews of ICAR were conducted by high-power committees and these indicated progress in terms of research output like technology, products and publications and their impressive outcomes in terms of commercialisation of technology and linkages with farmers. The human resource contributions are equally impressive (ICAR, 2017 and ICAR 2020). A large system like ICAR-SAU can't be free from limitations and the most important constraintsare funding patterns with a higher share of salary and overhead cost, and weakening research capacity in SAUs. The system should be open to ideas and the proliferation of programs shouldbe subjected to review and change. This has been done globally and some programs in Europewere even transferred to the private sector. The CGIAR system has been subjected to drastic review and change for enhancing its performance and linking funding to economic, social and environmental outcomes.

The impact of STI has been studied extensively and most of the early studies focused on the impact of technology on the productivity of a commodity using decomposition analysis. New crop varieties and animal breeds in a production function were the focus of most of these studies. However, a large body of literature on the topic estimated the cost advantages of new technology using the economic surplus approach. The series of benefits was compared with thecost series for estimating the rates of returns to research investment. A meta-analysis of the studies for India indicated that the median rate of return was 57.5 percent. The inclusion of recent studies may further improve the median rate of return (Pal, 2017).

Some studies have examined the impact of agricultural research on the total factor productivity(TFP). The analysis was further extended to examine the impact of public research investmentand other infrastructure like irrigation, rural roads etc. and a multi-equation econometric modelwas employed. The TFP and other growth impacts were also used for calculating the poverty impacts of agricultural growth. The ERS estimate shows significant improvement in the TFP index in India, from 100 in 2015 to 117 in 2020. The impact of public research investment on the TFP growth and poverty reduction was much higher than that for irrigation and rural roads.A recent study by Rada (2016) for the period 1980-2008 estimated the internal rates of return toinvestment in agricultural research from 34.96 percent for eastern India to 80.51 percent for northern India. For every million Rupees invested in agricultural R&D moved 436 people abovethe poverty line, whereas it was 193 and 881 for irrigation and rural roads, respectively, during1990s. The return per Rupee invested was Rs 9.5 for agricultural R&D and Rs 7.66 for roads (Fan et al, 2008).

3.2 Trends in the Public Funding

The rates of return are high enough to justify a higher allocation of public funds to agriculturalresearch. Although the trend in the public funds in India has been positive, except in a few recent years, agricultural research remained underfunded in India like in developing countries. As seen from Fig 4 and Table 5, annual public expenditure on agricultural research has grown in real terms (2011 prices) and it stands at 4,722.89 million PPP dollars during 2019-21. There has been some correction during the Pandemic period because of a general cut in the budget. These public funds are contributed by both the central and state governments, but most of the state funds are for education and are used by SAUs.

Another way of estimating the funding is the ratio of the expenditure to agricultural gross domestic product (AgGDP). This indicator is often known as research intensity and can be directly used for international comparison. Table 5 shows that the research intensity more than doubled during the 1970s and 1980s over the 1960s, which further rose to 0.40 during 2001-03 and 0.44 during 2011-13. But it reduced to 0.34 during 2019-21, coinciding with a budget cut during the pandemic period. India is one of the countries maintaining an uptrend in the real expenditure and the research intensity, but its absolute level was much lower than the developed countries like the US and the economies in transition, China (Beintema *et al.*, 2012, Pal, 2017).

Under-investment in agricultural research is a global issue and the allocations are usually influenced by the availability of government funds, rising demand from different sectors, and development priorities. Agriculture is a priority sector in developing countries because of food security and poverty reduction objectives, major constraint arises from the limited availability of public funds. Furthermore, the allocation process is influenced by historical trends and therefore, a major shift of funds in favour of agriculture is unlikely, except for welfare programs. This is despite the fact a broad consensus has emerged to raise the research intensity to one percent of AgGDP.

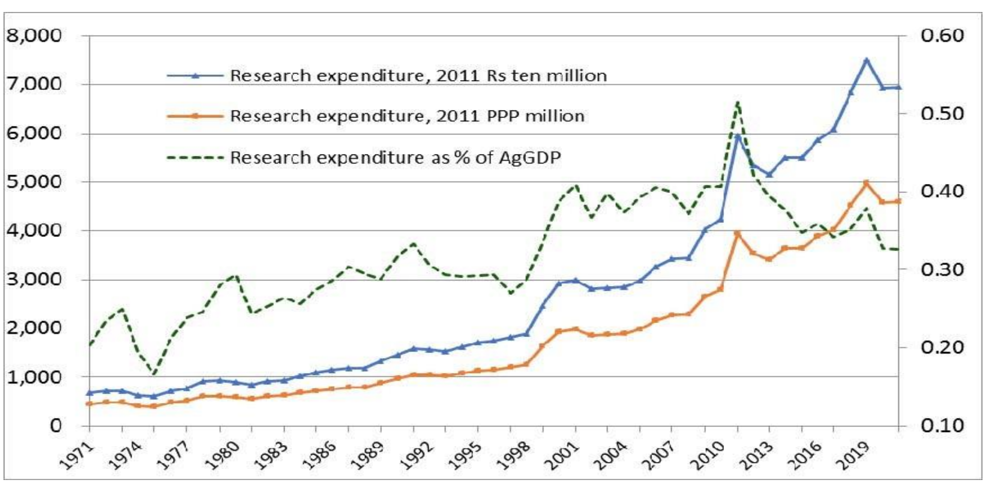


Figure 4. Trends in Real Public Expenditure on Agricultural Research and Research (Secondary Axis)

TABLE 5. TRENDS IN REAL PUBLIC EXPENDITURE (2011-12 PRICES) ON AGRICULTURAL RESEARCH AND EDUCATION

(1)	1961-63 (2)	1971-73 (3)	1981-83 (4)	1991-93 (5)	2001-03 (6)	2011-13 (7)	2019-21 (8)
Research and education expenditure, Rs. million	5,011.97	11,441.60	14,003.34	24,696.59	44,669.45	86,382.64	118,811.04
Expenditure decadal Growth rate (per cent)	10.64	3.17	6.07	5.94	4.85	3.94	-
Research expenditure, Rs.million	2,808.42	7,050.33	8,973.53	15,623.96	28,778.09	54,880.39	71,358.22
Research expenditure, 2011PPP million	185.88	466.63	593.92	1,034.08	1,904.70	3,632.29	4,722.89
Research expenditure as percentage of AgGDP	0.12	0.23	0.27	0.32	0.40	0.44	0.34
Research & education expenditure as percentage of AgGDP	0.22	0.38	0.43	0.51	0.62	0.68	0.57

Source: Based on data compiled by the author, figures are triennium averages.

3.3 The Regional Congruence

Given the resource constraints for agricultural research, it would be useful to utilize the available funds judiciously by linking with regional, sectoral and program priorities. There are formal approaches and economic methods to assess research priorities and allocate the resources accordingly (Alston *et al*., 1995). Given the diversity of production environments in India, it would be useful to promote regional congruence in the allocation of research resources. In particular, marginal production environments should get adequate research resources. The basic assumption in such macro-priorities is that potential research benefits shall in proportionate tothe economic and ecological importance of the region. One simple criterion could be that the resources should be allocated in proportion to their share in AgGDP. As seen from Table 6, the country has allocated more funds to the dryland, hill and northeast region. The share of southern SAT has risen from 27.47 per cent in 2001-02 to 39.36 per cent in 2019-20, whereas its share in the national AgGDP was only 27.34 per cent only. The share of the northern irrigated region has come down significantly, even lower than its share in AgGDP. The share of the eastern region remained around 9 per cent against 15.28 per cent share in AgGDP. These imbalances in the resource allocation should be corrected and allowance for sustainability and equity concerns should also be made in allocating the resources.

Another important consideration in the efficient use of research resources is to balance the factor shares, particularly overhead and operational expenses. However, as noted by the reviewteam (ICAR, 2017), most of the resources of ICAR are cornered by salary and overhead administrative expenses and little resources flowed down to research programmes. The problem isfar more serious for SAUs and hardly there is any effort to address this problem. There were funds available with ICAR for competitive mode, which were effectively used for funding priority research problems and augment research funds of SAUs and other organizations. The problem could also be addressed by rationalization of the system expansion and the number ofscientific to non-scientific staff. Uncontrolled organisational expansion and splitting of SAUs based on faculty shall likely distort the factor shares and adversely affect organisational efficiency because of less focus on multi-faculty research.

TABLE 6. REGIONAL CONGRUENCE IN THE ALLOCATION OF THE STATE FUNDS

Region	Share (per cent) in the total expenditure of states			Share in national AgGDP (per cent)	Expenditure intensity (per cent)
	TE 2001-02	TE 2011-12	TE 2019-20		
(1)	(2)	(3)	(4)	(5)	(6)
Southern SAT	27.47	32.99	39.36	27.34	0.38
Eastern States	9.99	9.04	9.63	15.28	0.19
Northern States	17.37	11.88	11.56	19.37	0.18
Drylands states	33.20	30.74	25.59	33.31	0.21
Northeastern States	4.59	5.06	5.38	2.85	0.72
Hill states	7.34	8.37	8.33	1.85	1.41

3.4 Outscaling the Innovations

There is a scope for outscaling of the current stock of knowledge and innovations to enhance their impacts and improve farmers and social welfare. Some of the innovations could not spreadfurther due to a lack of necessary inputs, policy support and absorption capacity of farmers andrural communities. The frontline extension system of ICAR-SAU is intensifying its outreach activities for technology demonstration, skill development of farmers and rural youth and enhancing the production of critical inputs like planting material. The system is also working onthe commercialization of technology through licensing, and promoting agri-business incubators and agri-startups. Both the approaches are distinct in nature and need considerable resources and the latter needs greater participation of the private sector, the establishment of venture fundsto support the innovations. This is particularly true for technology like farm machines,hatcheries, vaccines, etc. which need resources for the production of these technologies.

The state technology delivery system needs organisational identity and strategy and it should work in line with ICAR-SAU system. Efforts should be made for promoting convergence and coordination of the programs, mobilization of funding by charging for services and managing the programs and partnerships in a decentralized manner. The idea of information and innovation platforms in rural areas should be explored on a pilot basis for outscaling the research innovations, and scouting, revalidating and outscaling of farmers' innovations. There has been advancement in the theory of learning behavior and decision-making of individuals and groups and the decisions are different when the outcomes are uncertain or decision makerscan incur some loss (Kahneman, 2011). These insights should be used for developing the strategy for outscaling of innovations.

Public-private partnerships can serve social objectives with the efficiency of the private sector in the delivery of a service. A partnership could be very productive for upscaling and out scaling of innovations, particularly when resources are limited, asset specificity is high andinnovation is risky in terms of its acceptance by end users (Williamson, 2000). Participation of the private sector in the innovation process and fostering partnership with public research programs shall depend upon scientific infrastructure, funding by producer organisations, the scope for the appropriation of research benefits, i.e. IPRs, and regulatory policy (Byerlee and Echeverria, 2002). Some countries have enacted regulations to encourage private investment and bring the innovation process closer to end-user farmers. For example, the US enacted the Bayh-Dole Act (1980) to encourage research organizations to protect and commercialize patents for resource generation. Similarly, China allowed state-owned enterprises to collaborate with foreign companies to engage in the innovation process. Brazil in a major reform process allowed *EMBRAPA* to work in corporate mode and generate resources through technology commercialisation. All these reforms made an impact in terms of diversification of theinnovation system and bring it close to farmers' needs. In addition, some countries like India have fiscal incentives to attract private investment. As a step in the direction of appropriation of research benefits, most developing countries adopted a stronger intellectual property rights (IPRs) regime. This is discussed in the next section.

IV

INTELLECTUAL PROPERTY RIGHTS

IPRs were strengthened in developing countries as a follow-up of the agreement under the World Trade Organization. India also adopted a stronger IPR regime, allowing product and process patents in all fields of science. In the case of agriculture, the protection of plant varietieswas also permitted under the *sui generis* system and the Protection of Plant Varieties and Farmers Rights Act (2001) was enacted and an authority was established in the Ministry of Agriculture and Farmers Welfare to administer the Act. The Biological Diversity Act (2002) was also passed to establish sovereign rights over biological resources and an authority was established to administer the Act. Efforts were also made to harmonize these acts withinternational agreements. How these reforms have affected the innovation process? This is discussed in the context of the Indian seed industry.

4.1 IPRs and Diversification of the Innovation Systems

The impact of a stronger IPR regime can be seen in terms of diversification of the seed system, plant breeding priorities, access to improved material and relationships among plant breeding programs. Not many studies have examined these impacts, or even how the structure of the seed industry and markets have changed after the introduction of plant variety rights. Early work indicated that there is not much change in the structure of the industry and plant breeding priorities, but the seed-to-grain price ratio has increased for hybrid seed because of the rising share of the private sector (Pal *et al.*, 2007). Table 7 also shows that both public and private plant breeding programs seek the protection of their material, but private seed companies are more active in crops with hybrid seeds like maize, pearl millet, cotton, etc. The private companies supply most of the hybrid seeds (more than 90 per cent) and an increasing share of seeds of open-pollinated crops like paddy, wheat, pulses and oilseeds. Most of potato seed (78.91 percent) is now supplied by the private sector. This is because of the introduction of processing grade varieties and the use of improved technology for rapid seed multiplication. Some of this is being produced under contract farming for the processing industry.

TABLE 7. ROLES OF PUBLIC AND PRIVATE SECTORS IN THE INDIAN SEED INDUSTRY

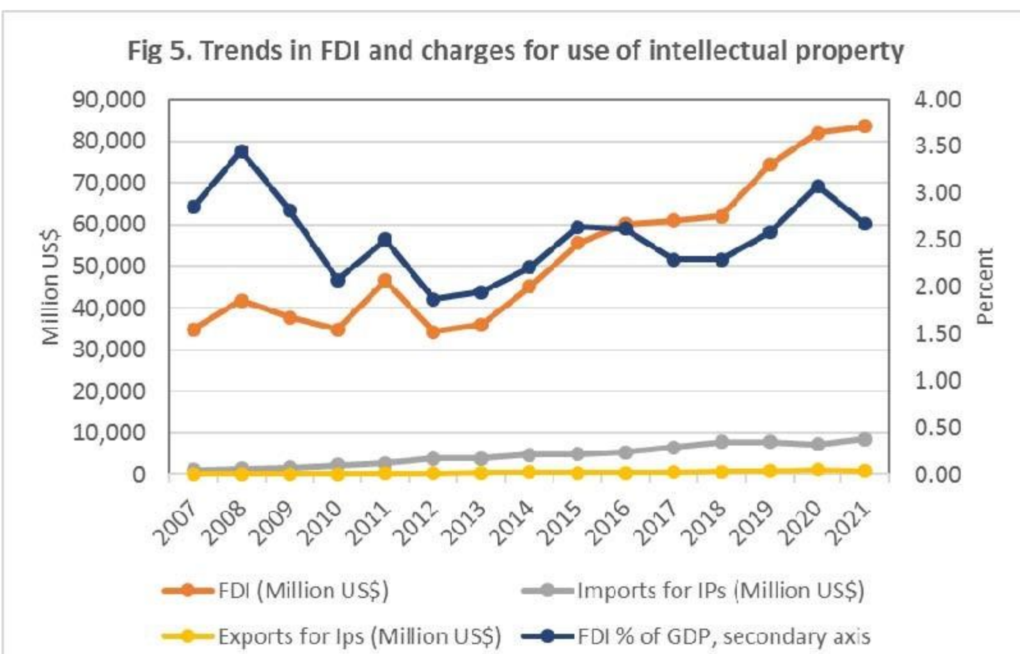
Crop	Availability of quality seeds and shares of public and private sectors						Registration certificates issued for new varieties under PPV&FRA (2009-2021)[b]		
	TE 2014-15			TE 2020-21					
	Quantity (lakh qtls)	Public share (per cent)	Private share (per cent)	Quantity (lakh qtls)	Public share (per cent)	Private share (per cent)	Private sector	Public sector	Total certificates issued
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Paddy	87.73	52.84	47.16	98.93	51.31	48.69	137	25	162
Wheat	112.48	43.67	56.33	143.32	34.48	65.52	12	22	34
Maize	11.41	11.39	88.61	15.12	8.38	91.61	128	37	165
Sorghum	3.17	27.97	72.03	2.88	28.73	71.27	38	30	68
Pearl millet	3.05	12.25	87.75	2.72	9.82	90.18	67	0	67
Chickpea	16.99	65.36	34.64	24.24	67.66	32.33	0	2	2
Pigeon pea	2.52	47.42	52.58	3.06	42.89	57.00	14	1	15
Black gram	3.48	61.24	38.76	3.77	63.78	36.23	0	0	0
Groundnut	28.65	61.07	38.93	27.16	49.73	50.27	1	0	1
Rapeseed& mustard	2.70	53.03	46.97	2.97	57.19	42.81	3	1	4
Soybean	34.18	50.59	49.41	28.54	43.23	56.76	2	0	2
Sesame	0.33	39.80	60.20	0.50	28.93	71.67	0	0	0
Sunflower	0.58	6.32	93.68	0.34	7.54	92.46	39	0	39
Potato	20.37	28.53	71.47	66.60	21.09	78.91	17	2	19
Cotton	2.60	6.28	93.72	2.56	4.60	95.42	143	7	150

Source: a) *Agricultural Statistics at a Glance*, MoA&FW; b) Protection of Plant Varieties and Farmers' RightsAuthority

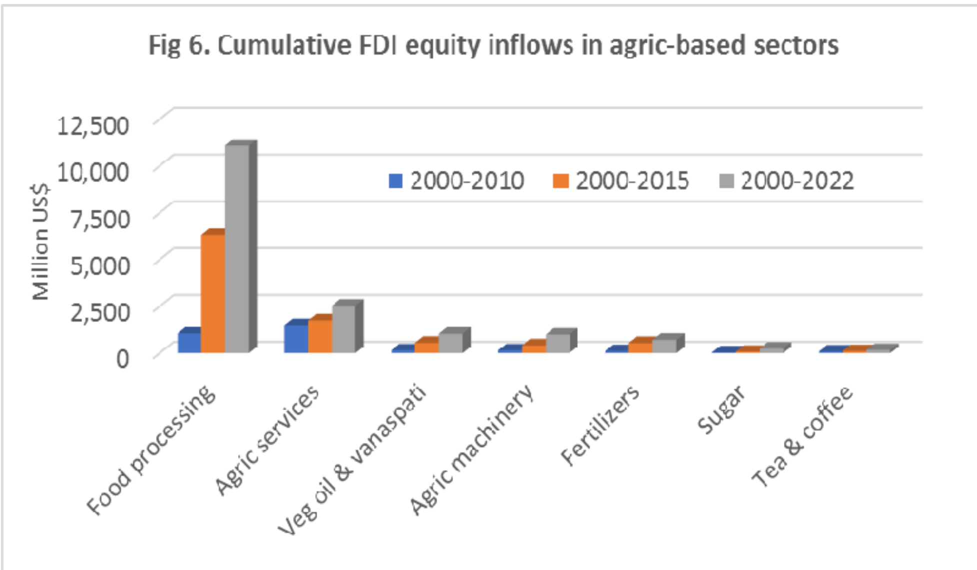
Private seed companies have been working in India, but now their participation has increased because of the rising demand for commercial seed and additional protection of material under IPR regime. For example, Bt cotton was introduced in India before the new IPR regime. The protection was done through the biological protection of parental lines and contract agreements.However, there was no change in breeding priorities but some varieties developed abroad wereintroduced in India. This was happening more so in maize, vegetables, and flowers. The licensing of varieties among the seed companies was common and various market operations like multiplication, processing and distribution are managed under contract agreements.

4.2 IPRs, Access to Technology and Market Concentration

Has IPRs improved access to technology? The evidence is positive but the impact can't exclusively be attributed to IPRs; rising market demand and a better policy environment also contributed to the flow of material to farmers from national as well as international R&D organizations. The growth of the flower industry and exotic vegetables can be attributed to these developments in the industry. Another example of technology access is the number of patents granted to foreign companies in India. WIPO data show that total 1531 patents were granted in the field of agriculture in India during 2007-2021 and more than 70 per cent of these were granted to private foreign companies. It means that there is a flow of foreign technology to India either through licensing and local production of technology or imports of technology-based inputs. There has been an upward trend in foreign direct investment in India during the last or so, but trade in the use of intellectual property remained almost nominal (Figure 5). In the field ofagriculture, the trade in intellectual property was almost negligible and it was in the food processing sector (Figure 6). This implies that there is not much overseas or national private investment in R&D and the industry is becoming better organised through consolidation andmerger of private companies.



Note: FDI data are for financial year, source DPIIT, and import & export data are for calendar year,source DGCI&S



Source: Based on DPIIT data.

Has technology ownership and consolidation of the industry increased market concentration? The evidence from developed countries like the US shows an increase in market share and inputprices (Fuglie *et al.*, 2011). In India, there is an increase in market concentration but not to the extent of monopolisation. For instance, the market share of the top four companies was 32.24 per cent for seed, 19.95 per cent for pesticides and 35.02 per cent for farm machinery (Table 8).Thus, there is no market concentration but an increase in input prices is obvious for cost recovery reasons. Another example is Bt cotton—the gene is owned by Monsanto (now Bayercrop science) but Bt seed was sold by many seed companies. Only recently, the government introduced a cap on the royalty and Bt cotton seed prices. Therefore, one may infer that marketconditions have managed the competitiveness and input prices. This feature should also be exploited for input quality concerns and unhealthy market practices.

4.3 Entrepreneurships and Industry Transformation

Besides the diversification of the input industry in the IPRs regime, there have been some major changes to transform the industry and markets. Some major changes in seed, pesticide and farmmachinery are summarized in Table 8. As seen from this table, the scale of operation and globalization have made the industry more competitive. Technology and business strategy are being employed to integrate and consolidate biological and chemical innovations. The main example of this is herbicide tolerant maize, cotton and soybean. Most companies understand theimportance of innovations to increase their market share and therefore have

TABLE 8. TRANSFORMATION OF AGRICULTURAL INPUT INDUSTRIES

(1)	Seed industry (2)	Pesticide industry (3)	Farm machinery industry (4)
Structure of theindustry	• Diversified but dominated by the public sector • Concentration ratio: C4 32.24, C8 47.55	• Diversified but dominated by theprivate sector • Concentration ratio: C419.95, C8 29.38	• Largely private, including smallscale • Concentration ratio: C4 35.02, C8 58.06
Direction of change	Vertical integration for R&D, globalization, useof hybrids, contracts among the agencies, including farmers	Globalization and consolidation, chemical and biological technologyintegration, environmental safety	Globalization for technology transferand production
Sources of technology	Largely NARS, but spillovers common for hybrids, flowers, Bt	Largely international spillovers	Domestic clusters and international spillovers in heavy machinery
Property rights	Plant variety protection, trade secret	Product and process patent, trade secret, including data protection	Product design andpatent
Nature of contracts	Licensing of technology, contract for seed multiplication and distribution	Licensing of molecules,contract for distribution	Access to machines throughcustom hiring
Key challenges	Seed quality assurance, regulation of GMOs	Registration and deregistration of pesticides, Pesticide quality assurance, market competitiveness	Finance for technology, industry competitiveness, post-sale services
Key regulations ofthe industry	Seed Act (1966, new bill under review), PVP Act (2001), Biodiversity Act (2002), harmonization of standards, recently price control	Insecticide Act 1968 (Pesticide Management Bill under review), Environmental Protection Act (2002), Patent Act (1970), Food Safety and Standard Act (2006)	Company and trade regulations asapplicable to all industries
Fiscal incentives	Tax exemption for R&D, support to public seeds corporations	Tax exemption for R&D	Tax and duty concession, financing farm mechanisation
Linkages with farmers	Through contract seed growers and retail dealers, CSR	Through retail dealers,CSR	Through localdealers, CSR
Conflict resolution	Court of law for IPR infringement, consumer forum for seed quality, out of court settlement	Court of law for IPR infringement and product safely, consumer forum for pesticide quality, out of court settlement	Mostly through direct negotiationsfor manufacturing defects

operated in contract mode to reduce the transaction cost, while technology is accessed through licensing (Tripp and Pal, 2001). There are clusters of companies that enable mutual learning, and sharing of resources like seed processing units, and help the growth of startups and entrepreneurs to support small operations and commercialise innovations in the public sector.

Although there are some instances of a dispute relating to the infringement of rights, these aresettled through the court of law. This is a common practice and in fact, it determines the strength of enforcement of IPRs. However, there are issues relating to product quality (seed, pesticides) and the production of deregistered, old unsafe pesticides. Farmers are at a disadvantage to protect themselves against the purchase of substandard, spurious inputs. The best way to protect farmers is to strengthen consumer forums for compensation againstsubstandard inputs. The industry association can also play an important role to address qualityconcerns. There is scope for educating farmers about input purchase decisions and small entrepreneurs can take this responsibility of providing market information and advising them about grievance redressal mechanisms. As seen subsequently input dealers and entrepreneurs are a reliable source of information for farmers. Thus, multiple mechanisms can be used to protect the interest of farmer users and capacity-building activity can be done under the corporate social responsibility.

V

TOWARDS SUSTAINABLE AGRICULTURE

Will market transactions and institutions shall shift the incentives in favour of commercial R&D and neglect sustainability-enhancing natural resource management (NRM) research? It looks quite feasible in the context of private research, but the importance of NRM research can't be neglected in the public research system. The focus on climate change and sustainability under SDGs has shifted priority to NRM research for developing sustainability-enhancing farm practices. Therefore, increasing resources shall be available for natural resource conservation and environmental protection. A few developments in this context are discussed below.

5.1 Sustainability Matrix and Practices

There is increasing realisation both at the international and national levels to protect the environment and promote green technology. The international treaties to reduce carbon emissions, achieve SDGs, adapt to climate change etc are universal development objectives. Forcoastal ecologies, the Ramsar Convention (1971) on Wetlands and follow-up activities are notable development for the sustainable management of wetlands and coastal ecosystems (Marothia, 2022). In the context of agriculture, conservation agriculture, carbon sequestration, reclamation of degraded lands, and waste recycling are accorded top priority. However, a uniform approach may not serve the purpose and it would be useful to develop a sustainabilitymatrix by identification of key indicators for different production systems or environments. Soil, water and biodiversity are important areas of focus, but a detailed analysis of different sustainability indicators showed that water conservation and carbon sequestration are two important indicators, which are strongly correlated with other sustainability indicators. It is therefore useful to monitor these indicators for different environments and target to improve them with the application of technology and other farm practices.

Carbon sequestration is also important to mitigate the impact of climate change and build the resilience of agricultural systems. Climate change is manifested through erratic weather events, causing wide yield fluctuations. Sustainable farm practices, cultivars tolerant to extreme weather and biotic stresses, conservation agriculture, crop residue management etc. are found tomanage climate change and put more carbon in soil (Kumara *et al.*, 2020). This shall be feasibleif adequate incentives and the right institutions are in place to influence farm practices. The spread of micro-irrigation has proved this and contributed to recent growth in Indian agriculture.

5.2 Policy Imperatives

The Government has announced new policy objectives but policy instruments and incentives are not aligned with the objectives. For example, the role of ecosystem services is well accepted in the promotion of sustainable agriculture and the environment, but hardly there is any incentive to reward those who are generating them. The problem is that there is no understanding of the value of these services like carbon sequestration and institutional mechanism to channel part ofthe value to the creators. To begin with, the value of major ecosystem services could be assessed and see how much society values these services and how much it is willing to pay for them. There is a significant advancement in the behavioural economics to make such an assessment and design a suitable policy and mechanism to promote the payment of ecosystem services. Similarly, suitable policy measures could be designed for water conservation, crop residue management, biodiversity conservation, green energy, and arresting desertification. These are high-priority programs and therefore need immediate attention.

5.3 Balancing the Roles of State and Markets

Changing role of the state, markets and civil society organizations has been well understood, but not adequately applied. Since the government has vacated some space, the markets have a greater role in the delivery of private goods and services, and most agri-inputs and agri-productsfall in this category. The government should set the regulations right and intervene when thereis a market failure. The state can also empower farmers and build their capacity to participate inthe market with greater bargaining power. In the case of local markets, e.g., millets, minor forest produce, etc., farmers or community organizations can help develop the market and link it with the value chains.

In agriculture, there are infrastructure and other services which generate larger benefits. Theseare primarily managed by the state, but in order to improve equity in the use of service and its maintenance, farmer user associations are encouraged. Notable examples are surface irrigation,watershed development and forest management. Gandhi (2021) showed that technical, economic, political and governance rationalities govern the success of these associations and smaller groups managing scarce resources like water were found to be successful.

In the New Institutional Economics, the state assumes greater responsibility for providing a stable and facilitating institutional environment. This role becomes clear in market economieswhere property rights and contracts form the basis of market transactions and a cost-effective dispute resolution mechanism is useful in the enforcement of the contracts. In the field of agriculture, property rights for land and water should be properly defined and documented anddispute resolution should be fast and within reach of farmers. This is a must to address the problems of informal tenancy and develop confidence among the contracting parties.

5.4 Addressing Information Asymmetry

Farmers need information on technology, inputs, weather, and markets and benefit from publicextension services (Nikam *et al*., 2022). In the absence of reliable and timely information, the wrong choice of the purchase of a sub-standard input or selling a product at a lower price is made. Table 9 shows that nearly half

TABLE 9. ACCESS OF FARM HOUSEHOLDS TO TECHNICAL ADVICE FROM DIFFERENT SOURCES

State	Households accessed technical advice (per cent)	Distribution of per thousand households by source of advice					
		Public extension	Livestock Deptt and dairy cooperative	Farmers, FPOs, NGOs	Input dealers, private agents	Mass media	Smart phones, call centres
Andhra Pradesh	73.5	99	248	253	423	309	20
Assam	26.3	4	76	142	55	142	32
Bihar*	41.5	15	23	242	185	42	15
Gujarat*	45.2	29	155	219	148	178	31
Haryana*	63	18	340	314	386	57	18
HimachalPradesh	65	89	268	94	239	508	71
Jharkhand	33.3	36	22	90	178	92	11
Karnataka	47.7	57	157	241	232	276	68
Kerala	71.1	157	206	316	200	728	65
Madhya Pradesh*	48.5	20	42	252	266	212	16
Maharashtra	64.1	58	65	400	327	274	45
Odisha	65.1	168	125	302	267	462	69
Punjab*	44.7	23	308	120	203	189	107
Rajasthan	34.5	33	34	196	194	42	9
Tamil Nadu	78.6	39	390	346	168	319	20
Telangana	63	69	52	233	516	158	25
Uttarakhand	29	98	35	146	94	22	4
Uttar Pradesh	50.6	7	64	285	293	92	8
West Bengal*	40.7	13	3	172	283	73	4
NE states	28.8	101	59	105	37	118	11
All India	48.7	47	93	239	237	185	27

Source: Based on NSS 77th Round.

Note: *, data pertain to Jan-June 2019 and for other states, data pertain to July-Dec 2018.

of farm households in India get technical advice. However, the proportion of farmers seeking technical advice is much higher (more than 70 per cent) in the states growing commercial crops, viz., Andhra Pradesh, Kerala, Tamil Nadu. The target should be that all farmers should get advice from either formal sources or fellow farmersto make a correct choice. Direct contact of public extension for crops and livestock is rather less, and fellow farmers and NGOs further spread information. It is important to note that inputdealers and private agents provide information, mostly related to inputs (seeds, pesticides) to a high proportion of farmers. However, this information is ‘controlled’ and there is information asymmetry to push market sales at the cost of farmers. In such cases, the public extension has the responsibility of providing generic information to farmers.

Information asymmetry is much higher in the case of product markets and crop insurance (Nabli and Nugent, 1989), leading to the non-participation of farmers. For example, the insurance company has all the information about the incidence of risk, insurance product, premium and compensation in case of crop loss. On the other hand, farmers are not aware of these attributes and therefore prefer non-participation. The same holds true for market prices for agri-products which are linked to quality attributes. This information asymmetry should be addressed to reduce the transaction cost and make a correct choice in markets.

There is a digital divide in the country despite the digital revolution. The cost may be slightly high because of low tele-density in rural areas or low willingness to pay. But considering socialand economic benefits, the entire farming community should be connected to information platforms. These platforms can provide “value-added information” on technology, weather, commodity prices and government welfare programs. Once farmers realise the value of information, their participation shall increase and they may be willing to pay for some of the ‘specialized information for livestock and horticulture.

VI

FOURTH INDUSTRIAL REVOLUTION

The fourth industrial revolution is happening globally, which involves the fusion of digital, mechanical and biological technology for higher economic efficiency and precision. India hasnot been able to fully utilize the digital revolution for the masses and this may delay the fourth revolution unless the necessary infrastructure and human capital are developed (Lele and Goswami, 2017). The situation may be far more serious in agriculture, where participation of the private sector is rather low. The country needs three things in this context. First, there is adequate investment in science and technology and establish a partnership with the private sector. This is true for all fields of science and collaboration across fields of science and organizations is a must. Secondly, there should be substantial investment in human capital development, beginning with science and technology, industry and farmers to understand the process of innovations and change. The efforts should entail education, skills and digital literacy. The task is even far more challenging in the field of agriculture where the applicationof artificial intelligence, use of sensors and internet of things (IoT) and cloud computing are confined to pilot experimentation. Robotics and automation of operations shall need more resources, time and skills.

Since the fourth industrial revolution shall be led by innovations in the private sector, the regulations should focus on "ease of doing business," protection of property rights andenforcement of contracts. The private sector should be seen as an ally in the development process and regulations should help establish public-private partnerships. This shall help establish global value chains, attract private investment, and facilitate market transactions and contractual arrangements to reduce the transaction cost.

VII

CONCLUDING REMARKS

Indian agriculture has shown appreciable growth and sectoral diversification. Land productivityhas also shown a stronger regional convergence. The growth in some of the low-productivity states like Madhya Pradesh is unprecedented. The focus given to the aspirational districts shallfurther improve regional convergence. There are some concerns relating to sustainability as some of the states have shown low to moderate levels of sustainability index, particularly waterand environment. The government should invest adequately in sustainability-enhancing activities and farmers should be incentivized to adopt sustainability-enhancing technology. One option could be payment for ecosystem services like carbon sequestration and resourceconservation.

STI shall continue to drive agricultural growth which should also be applied to the rural non- farm sector, particularly manufacturing. The productivity and investment must grow in this sector to absorb surplus labour from agriculture. Most of the industries in this sector are relatedto agriculture, and the modernisation of the food processing sector has the potential tocontribute to employment and income generation in rural areas. Technology for food processingcan be accessed from developed countries and MSME character of the industry can be transformed.

STI should be given a major boost in terms of investment, manpower and technology management. The public investment should be at least doubled and private investment should maintain pace with it. India's STI ecosystem has reached a stage where it needs to consolidatethe gains and leverage the presence of private R&D to bring STI closer to farmers and other end-users. CGIAR system has been a useful ally during the green revolution and after, the public system should develop a partnership with CG centers to emerge as a leader of the southin the provision of R&D services. Any further delay in reforming the public system for research and technology transfer shall slow down the process of agricultural transformation. The system must reform to prepare for the next generation of technology under the fourth industrial revolution.

The roles of the state, markets and CSOs are changing rapidly and the nature of government interventions is also under change. A uniform approach shall not work in the provision of all goods and services. This roadmap should be developed and implemented with suitable incentives and regulatory policies. There is information asymmetry in agricultural markets, leading to incorrect purchasing choices and non-participation in the programs like cropinsurance. This must be corrected by developing suitable market, weather and technical information systems or digital networks. Gradually, input, product and technology systems shall involve more market-based transactions and therefore enforcement of property rights, includingintellectual property rights and contracts shall be critical for the rapid transformation and efficient functioning of these systems.

Finally, agricultural policy-making should include the preferences and opinions of farmers and other stakeholders. The advancement in behavioural economics should be used to design better policy instruments and their implementation.

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