



सत्यमेव जयते
Ministry of Agriculture &
Farmers Welfare

Report of the Committee on Doubling Farmers' Income

Volume XII

“Science for Doubling Farmers' Income”

**Focusing Scientific Development and Technological
Applications on Doubling Farmers' Income**

Document prepared by the Committee for Doubling Farmers' Income,
Department of Agriculture, Cooperation and Farmers' Welfare,
Ministry of Agriculture & Farmers' Welfare.

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Foreword

The country has witnessed a series of concerted discussions dealing with the subject of agriculture. In 1926, the Royal Commission of Agriculture was set up to examine and report the status of India's agricultural and rural economy. The Commission made comprehensive recommendations, in its report submitted in 1928, for the improvement of agrarian economy as the basis for the welfare and prosperity of India's rural population. The urban population was about 11 per cent of the whole, and demand from towns was small in comparison. The Commission notes, that communication and physical connectivity were sparse and most villages functioned as self-contained units. The Commission encompassed review of agriculture in areas which are now part of Pakistan, Bangladesh and Myanmar. The net sown area in erstwhile British India was reported as 91.85 million hectares and cattle including buffaloes numbered 151 million. Almost 75 per cent of the cultivated area was under cereals and pulses, with rice and wheat occupying 46 per cent of the net sown area. The area under fruits and vegetables was about 2.5 per cent and that under oilseeds and non-food crops was about 20 per cent. In the ensuing years, as well known, the country underwent vast changes in its political, economic and social spheres.

Almost 40 years later, free India appointed the National Commission on Agriculture in 1970, to review the progress of agriculture in the country and make recommendations for its improvement and modernisation. This Commission released its final report in 1976. It refers to agriculture as a comprehensive term, which includes crop production together with land and water management, animal husbandry, fishery and forestry. Agriculture, in 1970 provided employment to nearly 70 per cent of the working population. The role of agriculture in the country's economic development and the principle of growth with social justice, were core to the discussions. The country was then facing a high population growth rate. After impressive increase in agricultural production in the first two Five Year Plans, a period of stagnancy set in and the country suffered a food crisis in the mid-1960s. The report in fifteen parts, suggested ample focus on increased application of science and technology to enhance production.

Thirty years hence, the National Commission for Farmers was constituted in 2004 to suggest methods for faster and more inclusive growth for farmers. The Commission made comprehensive recommendations covering land reforms, soil testing, augmenting water availability, agriculture productivity, credit and insurance, food security and farmers competitiveness. In its final report of October 2006, the Commission noted upon ten major goals which included a minimum net income to farmers, mainstreaming the human and gender dimension, attention to sustainable livelihoods, fostering youth participation in farming and post-harvest activities, and brought focus on livelihood security of farmers. The need for a single market in India to promote farmer-friendly home markets was also emphasised.

The now constituted DFI (Doubling Farmers' Income) Committee besides all these broad sectoral aspects, invites farmers' income into the core of its deliberations and incorporates it as the fulcrum of its strategy. Agriculture in India today is described by a net sown area of 141 million hectares, with field crops continuing to dominate, as exemplified by 55 per cent of the area under cereals. However, agriculture has been diversifying over the decades. Horticulture now accounts for 16 per cent of net sown area. The nation's livestock population counts at more than 512 million. However, economic indicators do not show equitable and egalitarian growth in income of the farmers. The human factor behind agriculture, the farmers, remain in

frequent distress, despite higher productivity and production. The demand for income growth from farming activity, has also translated into demand for government to procure and provide suitable returns. In a reorientation of the approach, this Committee suggests self-sustainable models empowered with improved market linkage as the basis for income growth of farmers.

India today is not only self-sufficient in respect of demand for food, but is also a net exporter of agri-products occupying seventh position globally. It is one of the top producers of cereals (wheat & rice), pulses, fruits, vegetables, milk, meat and marine fish. However, there remain some chinks in the production armoury, when evaluated against nutritional security that is so important from the perspective of harvesting the demographic dividend of the country. The country faces deficit of pulses & oilseeds. The availability of fruits & vegetables and milk & meat & fish has increased, thanks to production gains over the decades, but affordability to a vast majority, including large number of farmers too, remains a question mark.

The impressive agricultural growth and gains since 1947 stand as a tribute to the farmers' resilience to multiple challenges and to their grit & determination to serve and secure the nation's demand for food and raw material for its agro-industries.

It is an irony, that the very same farmer is now caught in the vortex of more serious challenges. The average income of an agricultural household during July 2012 to June 2013 was as low as Rs.6,426, as against its average monthly consumption expenditure of Rs.6,223. As many as 22.50 per cent of the farmers live below official poverty line. Large tracts of arable land have turned problem soils, becoming acidic, alkaline & saline physico-chemically. Another primary factor of production, namely, water is also under stress. Climate change is beginning to challenge the farmer's ability to adopt coping and adaptation measures that are warranted. Technology fatigue is manifesting in the form of yield plateaus. India's yield averages for most crops at global level do not compare favourably. The costs of cultivation are rising. The magnitude of food loss and food waste is alarming. The markets do not assure the farmer of remunerative returns on his produce. In short, sustainability of agricultural growth faces serious doubt, and agrarian challenge even in the midst of surpluses has emerged as a core concern.

Farmers own land. Land is a powerful asset. And, that such an asset owning class of citizens has remained poor is a paradox. They face the twin vulnerabilities of risks & uncertainties of production environment and unpredictability of market forces. Low and fluctuating incomes are a natural corollary of a farmer under such debilitating circumstances. While cultivation is boundarised by the land, market need not have such bounds.

Agriculture is the largest enterprise in the country. An enterprise can survive only if it can grow consistently. And, growth is incumbent upon savings & investment, both of which are a function of positive net returns from the enterprise. The net returns determine the level of income of an entrepreneur, farmer in this case.

This explains the rationale behind adopting income enhancement approach to farmers' welfare. It is hoped, that the answer to agrarian challenges and realization of the aim of farmers' welfare lies in higher and steady incomes. It is in this context, that the Hon'ble Prime Minister shared the vision of doubling farmers' income with the nation at his Bareilly address on 28th February, 2016. Further, recognising the urgent need for a quick and time-bound transformation of the

vision into reality, a time frame of six years (2016-17 to 2022-23) was delineated as the period for implementation of a new strategy.

At the basic level, agriculture when defined as an enterprise comprises two segments – production and post-production. The success of production as of now amounts to half success, and is therefore not sustainable. Recent agitations of farmers (June-July 2017) in certain parts of the country demanding higher prices on their produce following record output or scenes of farmers dumping tractor loads of tomatoes & onions onto the roads or emptying canisters of milk into drains exemplify neglect of other half segment of agriculture.

No nation can afford to compromise with its farming and farmers. And much less India, wherein the absolute number of households engaged in agriculture in 2011 (119 million) outpaced those in 1951 (70 million). Then, there are the landless agricultural labour who numbered 144.30 million in 2011 as against 27.30 million in 1951. The welfare of this elephantine size of India's population is predicated upon a robust agricultural growth strategy, that is guided by an income enhancement approach.

This Committee on Doubling Farmers' Income (DFI) draws its official members from various Ministries / Departments of Government of India, representing the panoply of the complexities that impact the agricultural system. Members drawn from the civil society with interest in agriculture and concern for the farmers were appointed by the Government as non-official members. The DFI Committee has co-opted more than 100 resource persons from across the country to help it in drafting the Report. These members hail from the world of research, academics, non-government organisations, farmers' organisations, professional associations, trade, industry, commerce, consultancy bodies, policy makers at central & state levels and many more of various domain strengths. Such a vast canvas as expected has brought in a kaleidoscope of knowledge, information, wisdom, experience, analysis and unconventionality to the treatment of the subject. The Committee over the last more than a year since its constitution vide Government O.M. No. 15-3/2016-FW dated 13th April, 2016 has held countless number of internal meetings, multiple stakeholder meetings, several conferences & workshops across the country and benefitted from many such deliberations organised by others, as also field visits. The call of the Hon'ble Prime Minister to double farmers' income has generated so much of positive buzz around the subject, that no day goes without someone calling on to make a presentation and share views on income doubling strategy. The Committee has been, therefore, lucky to be fed pro-bono service and advice. To help collate, analyse and interpret such a cornucopia of inputs, the Committee has adopted three institutes, namely, NIAP, NCAER and NCCD. The Committee recognizes the services of all these individuals, institutions & organisations and places on record their service.

Following the declaration of his vision, the Hon'ble Prime Minister also shaped it by articulating 'Seven Point Agenda', and these have offered the much needed hand holding to the DFI Committee.

The Committee has adopted a basic equation of Economics to draw up its strategy, which says that net return is a function of gross return minus the cost of production. This throws up three (3) variables, namely, productivity gains, reduction in cost of cultivation and remunerative price, on which the Committee has worked its strategy. In doing so, it has drawn lessons from the past and been influenced by the challenges of the present & the future.

In consequence, the strategy platform is built by the following four (4) concerns:

- Sustainability of production
- Monetisation of farmers' produce
- Re-strengthening of extension services
- Recognising agriculture as an enterprise and enabling it to operate as such, by addressing various structural weaknesses.

Notwithstanding the many faces of challenges, India's agriculture has demonstrated remarkable progress. It has been principally a contribution of the biological scientists, supplemented by an incentivising policy framework. This Committee recognizes their valuable service in the cause of the farmers. It is now time, and brooks no further delay, for the new breed of researchers & policy makers with expertise in post-production technology, organisation and management to take over the baton from the biological scientists, and let the pressure off them. This will free the resources, as also time for the biological scientists to focus on new science and technology, that will shift production onto a higher trajectory - one that is defined by benchmark productivities & sustainability. However, henceforth both production & marketing shall march together hand in hand, unlike in the past when their role was thought to be sequential.

This Report is structured through 14 volumes and the layout, as the readers will appreciate, is a break from the past. It prioritizes post-production interventions inclusive of agri-logistics (Vol. III) and agricultural marketing (Vol-IV), as also sustainability issues (Vol-V & VI) over production strategy (Vol. VIII). The readers will, for sure value the layout format as they study the Report with keenness and diligence. And all other volumes including the one on Extension and ICT (Vol. XI), that connect the source and sink of technology and knowledge have been positioned along a particular logic.

The Committee benefited immensely from the DFI Strategy Report of NITI Aayog. Prof. Ramesh Chand identified seven sources of growth and estimated the desired rates of growth to achieve the target by 2022-23. The DFI Committee has relied upon these recommendations in its Report.

There is so much to explain, that not even the license of prose can capture adequately, all that needs to be said about the complexity & challenges of agriculture and the nuances of an appropriate strategy for realising the vision of doubling farmers' income by the year of India's 75th Independence Day celebrations.

The Committee remains grateful to the Government for trusting it with such an onerous responsibility. The Committee has been working as per the sound advice and counsel of the Hon'ble Minister for Agriculture and Farmers' Welfare, Shri Radha Mohan Singh and Dr. S.K. Pattanayak, IAS, Secretary of the Department of Agriculture, Cooperation and Farmers' Welfare. It also hopes, that the Report will serve the purpose for which it was constituted.

12th August, 2017

Ashok Dalwai
Chairman, Committee on
Doubling Farmers' Income

About Volume XII

The twelfth volume of the Report of the Committee on Doubling Farmers' Income (DFI) is discusses the status, role and approach desired from Science and Technology interventions. Various sciences include research and undertake development activities to support agriculture. This is necessary not only from perspective of food security but also needed to secure raw material for a vast multitude of industries that depend on agriculture. The technologies involved can be industrial in nature or modern day digital technologies, used across agricultural sectors.

The first part of this volume discusses how future scientific research and development can be prioritised to bring direct focus on areas that will have immediate impact on the agenda of doubling farmers' income. In the course of undertaking scientific studies in regards to agriculture, the efforts can tend become an exercise in academic pursuit, for enhancing agricultural knowledge and undertaking new discoveries. Such scientific direction is important for the general and long term development of scientific knowledge including new research. However, for the purpose of meeting the national agenda to double farmers' income, there is a need to direct scientific research in areas that can bring income gains in the comparatively shorter term for all agriculturists, especially for under developed and poorly resourced farmers.

The later chapters, discuss the availability of various existing digital technologies and associated applications, which can be utilised to enhance farmers' income. A systems approach, that promotes convergence within the technologies so as to develop farms and farmers as enterprises, is deliberated. All business enterprises need to optimise on inputs, both knowledge and materials, and linked the involved activities with market demand. The organisation in the production system with the aim to maximise on resource use efficiency is possible with modern day technologies. Similarly, the inputs and the output require to be guided by and directed to assured demand. Science that optimises on the inputs, helps to reduce costs, make the production more competitive and mitigates any inflationary pressure. Linking farmers with optimal demand and assisting the marketing system to develop optimised supply chain operations are critical areas where technologies can add great value to the farmer.

Ashok Dalwai

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Doubling Farmers' Income

Volume XII

“Science for Doubling Farmers' Income”

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Volume XII A

Research & Development for Agriculture

Chapter 1

Introduction

Science and Technology (S&T) and Innovation in Farm Management are critical inputs for economic development and poverty alleviation. The introductory chapter provides a broad overview of areas of operational concern deliberated in Volumes (III – XI) of DFI Report, as the basis for necessitating application of Research and Development (R&D) and Digital Technology in these areas for resulting in a relatively less vulnerable and enhanced income growth of farmers.

1.1 Setting the Context

The Doubling Farmers' Income (DFI) Committee recognises agriculture as a value led enterprise and suggests empowering farmers with “improved market linkages” and enabling “self-sustainable models” as the basis for continued income growth for farmers. This builds the basic strategy direction for four primary concerns: optimal monetisation of farmers' produce, sustainability of production, improved resource use efficiency and re-strengthening of extension and knowledge based services.

The Committee identifies and focuses on seven major sources of growth (Volume II), operating within and outside the agriculture sector. These are,

- Improvement in crop productivity.
- Improvement in livestock productivity.
- Resource use efficiency or saving in cost of production.
- Increase in cropping intensity.
- Diversification towards high value crops.
- Improvement in real prices received by farmers.
- Shift from farm to non-farm occupations.

In Volume-II of its Report, the DFI Committee tables the “growth targets” for doubling farmer's real income while improving the ratio between farm and non-farm income from 60:40 as of now, to 70:30 by 2022, by:

- a) Adopting a “demand-driven approach” for increased monetisation of farm produce to synchronise the production activities in Agriculture & Allied Sectors.
- b) Improving and optimising input delivery mechanism and overall input efficiency [technologies, irrigation methods, mechanisation, Integrated Pest Management (IPM), Integrated Nutrient Management (INM), farm extension services, adaptation to climate change, integrated agri-logistics systems, Integrated Farming Systems Approach, etc.].
- c) Offering credit support at the individual farmer and cluster levels.

- d) Strengthening linkages with MSMEs (micro, small and medium enterprises), so as to accelerate growth in both farm as well as non-farm incomes along with employment creation.

Farmers' income is directly related to cost of agricultural production (including input costs) and profitable monetisation of the agricultural produce, through effective market linkages. The DFI Committee Report, in Volumes III – XI and XIII, deliberates upon specific economic activities and topics that have a durable impact on farmers' income increase, some of which are categorised as follows:

- i. **Demand Driven Agricultural Logistics System** for post-production operations such as produce aggregation, transportation, warehousing, etc.
- ii. **Agricultural Value System (AVS)** as an integration of the supply chain and to drive market led value system – District level, State level and National Level Value-System Platforms to promote individual value chains to collaborate and integrate into a sector-wide supply chain.
- iii. **Farmer - Centric National Agricultural Marketing System** by restructuring of the marketing architecture and networking of Primary Rural Agriculture Markets (22,000) and wholesale markets to facilitate pan-India market access; as also integrating the domestic market with export market.
- iv. **Developing Hub and Spoke System** at back-end as well as front-end to facilitate and promote a AVCS (which includes input providers, farmers, transporters, warehousing, food and agro-processors, retailers).
- v. **Marketing Intelligence System** to provide demand led decision making support system - Forecasting system for agricultural produce, supply and demand, and crop area estimation to aid price stabilisation and risk management.
- vi. **Promoting Sustainable Agriculture** – Conservation Agriculture, Climate Resilient Agriculture, Rainfed Agriculture, Ecology Farming, Watershed Management System, Integrated Farming System, Agro-Climatic Regional Planning, Agricultural Resources Management and Micro-Level Planning, etc.
- vii. **Effective Input Management** achieving Resource-Use-Efficiency (RUE) and Total Factor Productivity (TFP) – Water, Soil, Fertilisers, Seeds, Labour-Farm mechanisation, Credit and Precision farming, so as to reduce farm losses.
- viii. **Enhancing Production through Productivity** – to achieve & sustain higher production out of less and release land and water resources to diversify into higher value farming for enhanced income.
- ix. **Farm Linked Activities** including secondary sector activities of MSME scale for promoting near-farm and off-farm income generating opportunities.

- x. **Agricultural Risk Assessment and Management** including drought management, demand & price forecast, weather forecast, management of biotic stress including vertebrate pests access to credit for farmers for farming operations; providing long term credit, post-production finance to preventing distress sale by farmers, and crop & animal risk management through insurance.
- xi. **Empowering Farmers** through Agricultural Extension, Knowledge Diffusion and Skill Development.
- xii. **Research & Development and ICT** for Doubling Farmers' Income.
- xiii. **Structural and Governance Reforms in Agriculture**, including building a database of farmers, facilitating farmer & produce mobilisation, institutional mechanism at district, state & national levels for coordination & convergence, utilising Panchayat Raj Institutions as key delivery channels for transparent and inclusive development.

The various interventions suggested in various volumes of the Report as above, will stand to benefit by close interface with science in agriculture, which is the subject dealt with in this Volume, namely Volume XII.

In order to bring the designed emphasis on different aspects of science, the issues have been delineated as Research and Development in Agriculture, and deployment of ICT in Agriculture. Accordingly, these two different issues are dealt with in Volume XII-A and XII-B.

This, Volume-XIIA, deals with the role of Research and Development (R&D) for delineating the needed science and developing appropriate technology to cater to the comprehensive mandate of agriculture and realise the objective of enhancing farmers' income.

1.2 Role of Research & Development (R&D) in Indian Agriculture

Agriculture is the backbone of the country with about 48 per cent of the population dependent upon it. It is the source of food, feed, fibre, fuel and the livelihood of Indian people. Increasing agricultural productivity is a key challenge for in realising higher output and farmers' income. The green revolution endowed India with a greater genetic diversity and supported by enhanced institutional capacity led to produce more crops.

The introduction of high yielding varieties, additional irrigation facilities, a great input flow through fertilizers and pesticides, farm mechanization, credit facilities, buttressed by price support, and other rural infrastructure facilities ushered in the green revolution. It stimulated infrastructure and rural development, increased prosperity of villages, and improved the quality of life. The radical change in land use and agricultural production transcended India from a food importing country to a self-sufficient and even to a food-exporting nation. There is lot of improvement in the agricultural production and productivity *per se* in India after the green revolution (Table 1.1).

Table 1.1 Increase in productivity (kg/ha) of foodgrains in India

Year	Foodgrain production (million tonnes)	Foodgrain productivity (kg/ha)
1960-61	82.02	710
1970-71	108.42	872
1980-81	129.59	1023
1990-91	176.39	1380
2000-01	196.81	1626
2010-11	244.49	1930
2015-16	251.57	2042
2016-17	275.11	2129

There has been a quantum jump in production of various agricultural commodities. By 2017 foodgrains sector has increased by 5 times, horticultural crops by 9.5 times, fish by 12.5 times, milk 7.8 times and eggs 39 times since 1951. This has created a sizeable buffer stock, despite high increase in population. Grain crops registered about 127 m ha (59 per cent) of the gross cropped area (GCA) of the country. Rice and wheat occupied 22 per cent and 15 per cent of the net cultivable area in India respectively. Relative to cropping patterns, rice occupies the largest cultivable area during kharif (June to October) season, whereas wheat occupies largest cultivable area during rabi (November to March) season. Pearl millet (bajra), maize and sorghum occupied about 5 per cent, 4 per cent and 4 per cent of total cropland area in India respectively during 2009-10. Though the area under maize exhibited an increase from 3 per cent in 1990-91 to 4 per cent in 2009-10, the area under pearl millet and sorghum declined significantly during the same period, from 6 per cent to 5 per cent (sorghum) and 8 per cent to 4 per cent (pearl millet). The data for the year 2016-17 shows the status in terms of percentage of GCA and annual total output as: (pearl millet 3.84%; 9.73 million tonnes), maize (4.95%; 25.90 million tonnes), and sorghum (2.89%; 4.57 million tonnes).

India has clearly emerged as a leading horticultural country of the world with a total annual fruits & vegetable production of 300 million tonnes during 2016-17 (NHB, 2016-17). The area under horticulture has grown substantively over the last decade to about 25.1 million hectare which includes a wide variety of crops, vegetables, root and tuber crops, mushroom, floriculture, medicinal and aromatic plants, nuts, plantation crops including coconut and oil palm which are grown in different agro-climatic conditions. The positive change in production has been a result of gains in both productivity and area.

Livestock is an integral component of India's agricultural farming since time immemorial, providing consumable outputs like milk & meat, energy for crop production in terms of draught power and organic manure, in which in turn receive crop by-products and residues to meet their food energy requirements. This is a virtuous cycle of livestock farm sector that has been in existence over centuries. But now livestock are more valued as a source of food and contribute over one-fourth to the agricultural gross domestic product and engage about 9 per cent of the agricultural labour force. The livestock sector in India in recent times has been growing faster

than crop sector. The contribution of livestock output to the total output of the agriculture sector has significantly increased from 15 per cent in 1981-82 to 29 per cent in 2015-16. This not only provided a cushion to agriculture growth but also has set a pace for itself to emerge as an engine of agricultural growth.

This clearly depicts the impact of agriculture research system in imparting food security to the nation and benefitting the farmer with better output and income. The ICAR-SAU combination contributes to the coordinated research and education system for agriculture and allied sciences in the country. The Department of Agriculture, Cooperation and Farmers Welfare (DAC&FW), under the Ministry of Agriculture and Farmers Welfare, Government of India has been playing key role in extension and agricultural development system of the country.

1.3 Status of Research & Development

The R&D set up has made a visible impact on food and nutritional security of the country. It is engaged in cutting edge areas of science and technology development and its scientists are internationally recognized in respective domains of research.

The country has witnessed an impressive growth in rice production in the post-independence era due to the adoption of semi dwarf high yielding varieties coupled with the adoption of intensive input based management practices. Rice production has increased four times, productivity three times while the area increase has been only one and half times during this period. In order to keep pace with the growing population, the estimated rice requirement by 2025 is about 130 million tonnes. Plateauing trend in the yield of HYVs, declining and degrading natural resources like land and water and acute shortage of labour make the task of increasing rice production quite challenging. The current situation necessitates adoption of some innovative technologies to boost rice production. The country has become a leading exporter of the Basmati rice. Major export destinations (2016-17) were Saudi Arabia, Iran, United Arab Emirates, Iraq and Kuwait. The country exported 40,00,471.56 metric tons (Mts) of Basmati rice worth of Rs. 21,604.58 crore (or 3,230.24 US\$ Mill.) during the year 2016-17 to these countries.

Other area of work to enhance yield is popularization of rice hybrid. Efforts are being made to promote cultivation of hybrid rice through various crop development programmes such as National Food Security Mission (NFSM), Bringing Green Revolution to Eastern India (BGREI) under Rashtriya Krishi Vikas Yojana (RKVY).

From the initial level of 10,000 ha in 1995, area under hybrid reached one m ha in 2006, exceeded 2.5 m ha during 2014, which is about 5.6 per cent of the total rice area in the country. It has picked up during the last eleven years, mainly because of increasing popularity of hybrid rice in Uttar Pradesh, Bihar, Jharkhand, Madhya, Pradesh and Chhattisgarh and it is estimated that around 3 m ha plus was under hybrid rice cultivation in India in 2016 which is around 7 per cent of the total rice cropped area in India.

Maize (corn) is one of the most versatile emerging crops having wider adaptability under varied agro-climatic conditions and is valued as food, feed, fodder and industrial raw material. Globally, maize is known as the queen of cereals, because it has the highest genetic yield potential. In India, maize is the third most important food crop after rice and wheat. In view of its universal nature and adaptability under diverse ecology, development of high yielding hybrids with in-built resistance and tolerance to diseases, pests and various climatic stresses; and development and fine-tuning of production ecology deserve priority attention. During the last 10 years, more than 120 hybrids have been developed and released in addition to development of various production technologies. As of now (2017-18) more than 200 cultivators are available in the field.

While it is true that the growth rate of maize output over the last 5 years is more than that of USA & China, the country's output of 27 million tonnes (2016-17) pales before the output of 370 million tonnes of USA. Productivity in India is 2.6 tones/ha as against 12t/ha in USA and 5.5t/ha in China.

Considerable field scale understanding is available in India from empirical research on crop response to irrigation under varying soil, water use and environmental conditions, and efficient irrigation schedules have been developed for all the major crops. Similarly, technology improvements are being consistently addressed to application efficiencies of the commonly practised basin, flood, furrow and border methods of irrigation. Similarly, newer technologies are becoming increasingly available to help reduce the energy requirements of pressurized micro-irrigation systems like drip and sprinkler. Low pressure micro-irrigation technologies are being aggressively promoted in India by the central government, state governments and many non-governmental organizations (NGOs), to improve irrigation efficiencies and agricultural productivity.

The new technologies of micro-irrigation now include drip/trickle systems, surface and subsurface drip tapes, micro-sprinklers, sprayers, micro-jets, spinners, rotors, bubblers, etc. Despite wide promotion, only about 10 million ha of land is currently under micro-irrigation in India as against the total potential of 63 million ha. Maharashtra is the leading state under micro-irrigation followed by Karnataka, Andhra Pradesh and Tamil Nadu. Micro irrigation is popularly practised in about 30 crops, and is more popular in horticultural crops which allow relatively wide spacing. It is however critical that micro-irrigation is popularised and facilitated in field crops grown in rainfed cultivation systems. This will benefit the small and marginal farmers, who are predominant practioners of field crops and rainfed farming systems.

Studies have revealed that water savings ranging between 25 and 50 per cent are possible by drip irrigation compared with surface irrigation. Micro-irrigation also facilitates application of controlled quantity of water and nutrients in the vicinity of each plant, such that the crop, water and nutrient needs are almost matched with irrigation water supplies. Most current research in micro-irrigation is focused on simultaneous precision application of water, fertilizer and other

inputs to match the crop requirements on the field to increase the marginal productivities of water and inputs through impact on the quantity and quality of produce.

The practice of conservation tillage, agro-forestry, ley farming, mulching, nitrogen fixing legumes, crop diversification, integrated nutrient management etc has the potentiality to enhance C-sequestration in various locations.

Freshwater aquaculture is an integral part of the agriculture in India. It is one of the fastest growing subsectors in the country which has registered a growth rate of 5.1 per cent per annum over the last 60 years. During this period, the fish production in the country has increased from 0.75 million metric tonnes (mMT) in 1950-51 to 9.45 mMT in 2013-14, of which the major contribution has been from aquaculture as the sector has grown from 0.37 mMT in 1980 to 5.1 mMT at present. The consumption demand for fish is rising over a period of time, primarily due to the growing population, expanding urbanization and changing food habits. In future, freshwater aquaculture sector holds the key as around 85 per cent of the additional food fish demand could be met from the freshwater sector.

The dairy and livestock sector too has grown and both milk and meat production have registered impressive growth, so much so that India tops the global milk output at 164 million tonnes (2016-17).

1.3.1 Issues and challenges

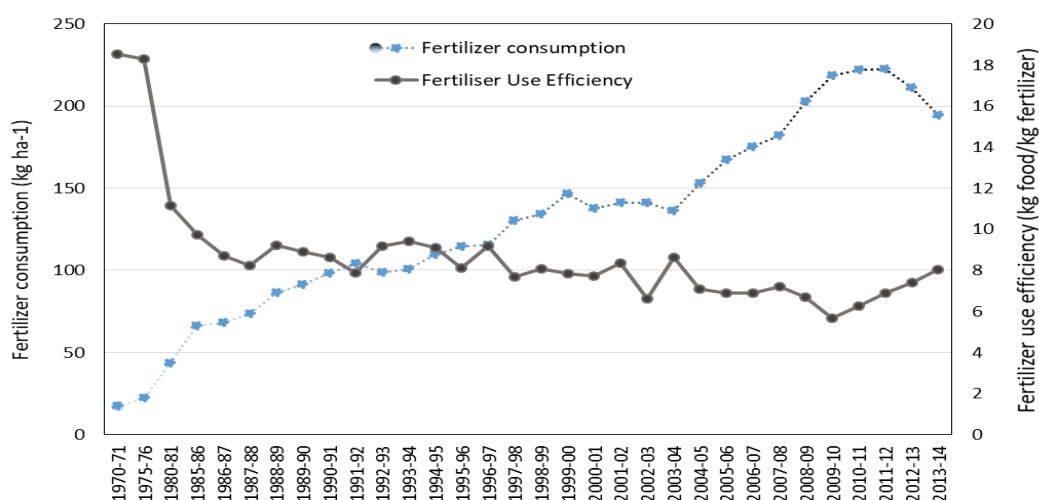
The national agricultural research and development system aided by several organizations and institutes has taken up many activities to develop and demonstrate new technologies for strengthening agricultural farming including dairy, livestock and fisheries in the country. The science and technology-led development in agricultural farming has resulted in manifold enhancement in productivity and production of different crops and commodities to match the pace of growth in food demand. But, at present the agricultural and allied sectors are facing new challenges like reducing availability of quality water, nutrient deficiency in soils, climate change, farm energy availability, loss of bio-diversity, emergence of new pests and diseases, fragmentation of farms, rural-urban migration, besides globalisation of agri-food markets and trade regulations and those need to be addressed during the years to come. The farm sector stress and non-realisation of the desired/accelerated growth rate are attributable to several factors, some of which are as follows:

- Stagnant yields in last 20 years except in cotton – importing edible oils and yet to reach pulse – self sufficiency.
- Depletion of critical resources – water & soil.
- Climate change – rising temperature and frequency of extreme weather events.
- Infrastructure constraints – power, roads, storage (cold & dry) and other agri-logistics.
- Low risk bearing capacity of farmers – poor farm returns.

- Low profitability in many crops / due to high vulnerability geographies – high cost of production; and less than remunerative returns.
- High market risks – information asymmetry and market inefficiency.
- Inadequate financial services – credit and insurance.
- Increasing labour shortage and cost.
- Lack of data capture from field making price & demand forecasts (useful in decision making) difficult.
- Poor use of technology and modern science – as reflected in wide yield gaps between FLDs (frontline demonstrations) and farmers' fields.

In India, subsidies and increased awareness about fertilizers have led to a significant increase in fertilizer consumption. Importantly, while fertilizer consumption has continued to rise substantially, the elasticity of output with respect to fertilizer use has dropped sharply (Figure 1.1). During the period of 1970-71 to 2010-11, while foodgrain production grew by about 2.3 times, the increase in fertilizer (NPK) consumption was about 13 times (GoI, 2014). In the year 2013-14 food production was 264.8 million ton with use of 24.5 million tonnes of NPK fertilizers. The average crop response which was about 50 kg of foodgrain per kg of NPK fertilizer during the year 1970-71, fell to about 18.70 kg during 2010-11 and further down to about 10.8 during 2013-14. It also needs to be noted, that the increase in fertilizer use has come at significant cost. The fiscal burden of fertilizer subsidy which was just Rs 60 crore in 1976-77, shot up to over Rs 70,000 crore in 2012-13. It was as high as Rs. 72,437.58 crore in the year 2016-17). There are other important costs in the form of long-term soil degradation, degradation of water resources (in both quantity and quality), and general stagnation of yields due to application of sub-optimal nutrient ratios. Thus, disproportionate NPK fertilizer application, multi-nutrient deficiencies, and lack of organic manure application has led to reduction in the carbon content of the soil and contributed to stagnating agricultural productivity. This in turn has been getting reflected in high cost of production over the years.

Figure 1.1 Fertilizer consumption and use efficiency in India from 1970-71 to 2013-14



1.4 Restructuring of R & D for Science-led Impacts

Addressing the new challenge in Indian agriculture requires systematic application of science-based agro-ecological principles to enable an agro-ecological intensification for more precise farming in both small and large farms. The sustainable agro-ecological intensification may lead to increased productivity and profitability, enhanced use of local resources, maximized returns from external inputs, improved stability and diversity of yields, reduced greenhouse gas emissions, enhanced ecological resilience and environmental service provision. There exist large yield gaps in different regions of the country, that can be bridged through simple interventions such as better seed, nutrients, and water management. However, it is generally necessary to move towards more knowledge-intensive forms of agriculture – embellished further with technologies and incentives that make it viable for farmers to adopt and adapt them. In crop production, agro-ecological intensification primarily implies adoption of good agronomic management principles in a local context, which includes the following:

- Profitable and sustainable crop rotations
- Quality seed of a well-adapted high-yielding variety or hybrid that also meets market demands
- Planting at the right time to maximize the attainable yield by capturing water and nutrients
- Maximization of water harvesting and efficient utilization of available water
- Integrated soil and nutrient management, including conservation agriculture, balanced and more efficient use of fertilizers
- Integrated pest management, including biological control and the judicious use of pesticides
- Optimized recycling and use of bio-mass and agricultural bi-products
- Enhancing suitable crop-tree-livestock interactions

The doubling/enhancing of farmer's income can be achieved through various means, of which scaling up production via productivity of the crops/dairy etc. units is one of the important factors. As on date, there is lot of scope for improvement in Indian average yield levels vis-a-vis that of the world, as well as neighbouring countries.

Table 1.2 Productivity of some important crops in India and world

Crop	India (kg/ha)	World (kg/ha)	Highest productivity in kg/ha (country)
Paddy	3576	4546	6832 (China)
Wheat	3144	3314	8634 (Germany)
Maize	2560	5622	10744 (USA)
Pulses	659	909	2031 (Canada)
Groundnut	1400	1657	4397 (USA)

Several factors are responsible for lower productivity in India. (Table 1.2). Of these the research and strategic gaps which requires policy support and research prioritization are discussed.

In terms of population, India has the distinction of being the most populous country in the world after China. Increasing food production and ensuring food & nutrition security for such a huge population is a difficult task. The challenge can be addressed only if improvement in other sectors as well as increased investment in R&D, upgrading research infrastructure, better management of agricultural resources and creating more income generation opportunities are ensured.

- An important option is increasing investments in agricultural R&D and rolling out efficient institutional reforms in order to contribute more effectively to tackling the emerging challenges in agriculture including food & nutrition security both at national and regional levels. Investment in agricultural R&D, must accompany institutional reforms to create an environment that facilitates adoption of new technologies. Otherwise the existing gap in adoption of new technologies will continue.
- The emerging concept of agricultural innovation systems involves a wide range of stakeholders and a dynamic process. For efficient outcomes, the innovation system should allow an effective linkage between farmers and local communities with research institutions and markets.
- Importantly, preparation of research agendas/plans are still missing or there is little involvement of farmers, producers, and policy makers for agriculture development to be effective. Agricultural research needs to be more demand driven rather than supply driven, which calls for responsive changes in organizational culture, structure and systems. Assisting national agricultural research systems (NARS) to implement such changes is a major development challenge.
- Agricultural research systems need to be integrated with appropriately designed and sustainable agricultural extension/advisory systems that are able to support farmer innovation & experimentation; facilitate learning between farmers and researchers; and provide farmers with the information they need to make choices about production processes.
- With a view to cater to the needs of farmers in a changing climate, public extension agencies and development departments need to change their orientation from purely varieties and inputs to other areas like resource-conserving technologies, farm mechanization, post-harvest management, marketing and deployment of technologies for early warning & risk management.
- Innovative agricultural development should require research to be integrated and follow multi-disciplinary approach.
- Participatory research and development could be a practical approach through which scientists, extension agents, NGOs and farmers are engaged to address low productivity

and poor resource use efficiency in an integrated approach. This approach, which has been known for long, needs now to be scaled-up.

- Past experience indicates that public sector alone cannot meet current & future challenges; and private sector has huge potential in meeting various requirements of agriculture. Therefore, there is a need to create favourable environment for private sector participation in agricultural research and technology development.
- Given the Indian agricultural structure dominated by small and marginal farmers and who technologically are advised to practise integrated farming system (IFS), the NARs of the country should adopt package approach in preference to mono-cropping / mono-activity; as also income basis as an alternate to productivity/production basis.

In this context, the agenda of research and development needs to be changed to marshal efforts for its integrating through active partnership. The convergence issue needs to be dealt with proper infrastructure development, institutional building and policy guidelines.

The partnership should also provide scope for private sector participation in R&D.

1.5 Digital Technology in Agriculture

Agriculture is the world's first solar powered factory. It organises human effort to capture the life force hidden in seed and sunlight, to process the elements in the soil, air and water, into produce. Agriculture converts hard natural elements into useful material for use of mankind. Agriculture, in itself, is not digital but a very material physical process.

Like in all other parts of one's life, there is increasing use of electronic devices, tools and a fusion of digitised systems, to manage agricultural processes. Hence, the phrase “**Digital Agriculture**”, a recently coined catch-phrase seems a misnomer - it actually refers to the use of digital technologies in managing the business of agriculture. ‘**Digital Technologies in Agriculture**’ is probably the more accurate narrative.

Advanced technologies are not uncommon to agriculture. Gene mapping under the electron microscope, bio-technology and the information services have regularly brought into use available digital technologies. Satellites & weather scanning radars and digital temperature & humidity sensors have been around for a few decades. However, of late, the digitisation of agricultural information and its analytics is increasingly changing the way farming is done. Gone are the days of second guessing the next monsoon, or of watering the field at set schedules. Embedded sensors in the soil can tell when and how much water to feed, and digital analysis of wind patterns and upper jet streams has reduced the guess work of rain dancers. Digital photography allows for near-instant spectrographic analysis of soil and plant health. In minutes, patterns not visible to the eye, are compared with a large database to diagnose the INM and IPM needs on a farm. These possibilities are already in use in pockets, and need to find more universal application.

Digitisation of everyday data, helps to analyse trends, forecast events in advance and quickly share knowledge across geographies. Already, in the communications arena, digital technologies have made a huge impact on agricultural communities. Alerts and remote advice are frequently sent to farm across the digital ether helping in intelligent decision making.

Digital technologies can help counter many of the inherent vagaries in farming and optimise upon the resources that are deployed. Given, that there is increasing concern from climate change, land depletion, water shortage and wasteful use of agro-chemicals, making sure that farms remain environmentally relevant and sustainable will require more use of digital devices and the associated analytics in agriculture.

A farm itself is no longer a large field, but can now be addressed by aid of technology at the scale of a few feet and even at a granular level. Geo-informatics is not merely the cartography of large tracts of land, but can be used for precisely targeted treatment on a field, without affecting the adjoining tract of land. This precision can even happen at the level of individual plants, opening up opportunities for efficiency, hitherto unimaginable. While one is used to seeing growing use of protected cultivation, using physical plastic and glass to envelope and safeguard the plants from inclement happenings, the future may yet see another envelope, invisible and digital, that is superior to the current day protected cultivation practices.

In agriculture linked governance, a fusion of digital technologies are playing an important role. The direct benefit transfer (DBT) system for a multitude of support schemes, linked with Aadhaar (the 12 digit unique identity number based on biometrics) is a notable example. Digital head count of livestock and analysis of their health through RFID (radio frequency identification) and micro-chips based ear tags and the traceability of a vegetable to its farm plot through digital barcodes are examples of applications. The electronic National Agricultural Market (eNAM) is yet another example, where digital technologies are aimed to link farmers seamlessly with a national level market.

Secondary agricultural activities, involving the post-production management phase of produce, is another area seeing increasing use of digital technologies. Big data analytics that can forecast consumer demand, not just a week in advance, but even before the farmer plans to sow her field, will redefine crop planning, harvest scheduling and market linkages. There is need to ensure that the output from farms will find a market, across place, time and form. Digital data collation and analytics will be a big boon in this area, especially in India where though producing surpluses, yet many still remain hungry.

Not too far into the future, any citizen could order a flower or a fruit while still on the bush, thanks to use of digital technologies in agriculture. Emergent Artificial Intelligence (AI) may replace the shepherd dog, or take self-contained decisions to robotically prune leaves and manage the canopy in orchards. Maybe, farmers will have a robot repair workshop, with 3-D printers in their barns, in a few more decades.

1.6 Science & Technology in Farm Management

Science and Technology (S&T) are critical in managing economic activities in modern farms. Digital Technology applications in Agriculture have emerged in developed countries, through the use of Information Technology, Space Technology, Geo-Informatics, Internet of Things (IoTs), Web of Things (WoTs), Block Chain Technology, Artificial Intelligence & Big Data Analytics, etc., and their first-mile connectivity to farmers. Farm Management includes, among other things, farm production, farm planning, agro-business planning, and farm produce marketing and trade. With continuing advances in agricultural machinery, the role of the farmer is becoming increasingly specialised. Furthermore, the farmers' market range has to expand beyond their immediate horizon; and fortuitously, consumers are increasingly demanding more secure and safe nutrition. All of this adds to a complicated set of data, from selection of planting material, input management, weather and risk management, ecology management, market management, as well as traceability of the output all the way to the consumer, living in and outside India.

The on-going massive digitalisation of Agricultural Input System, Production System and Output System has already shown positive and influential impact on productivity increase and effective input management. Output management in the markets is also showing positive changes. The achievements in all these domains can be scaled up and also needs to be developed to provide for a demand driven agricultural value system that is inclusive and equitable towards farmer producers. Reduction in cost of cultivation, produce losses and predictable risk management are important aspects that help to overcome distress sale, and this will rely on effective access to technology and will help to promote a sustainable farming system among others.

1.6.1 Paradigm shift needed in applying science & technology

Science and Technology are mandatory for executing and innovating in management of natural resources to promote sustainable agricultural development, developing agricultural supply chains and promoting markets. The technology can also support alert mechanisms on natural disasters, food crisis and in institution building. Innovation depends on the access to information and knowledge and requires continuous learning. Digital technologies provide such access on demand. Many different industrial technologies and scientific systems have been evolved and are evolving, both in public and private sectors, some of which are listed below:

- a. Irrigated Agriculture Technologies
- b. Rainfed and Dryland Agriculture technologies
- c. High Yielding Seed Technologies
- d. Resource Conserving Technologies
- e. Resource Use Efficient (RUE) technologies
- f. Climate Resilient Technologies

- g. Agricultural Mechanisation Technologies
- h. Post-Harvest Technologies
- i. Traditional Knowledge Systems and Technologies
- j. Fusion of Technologies: Bio-technology, Nano-technology, Environment technology, Space technology & GIS technology, Sensor technology, Information technology, Web technology, Internet, Drones, Block chain technology etc.

Various technologies would require to be integrated for the purpose of enhancing income of farmers. To sustain economic growth, each intervention would require to be market linked. Integration is possible by deploying digital technologies, to provide the necessary control triggers, for monitoring and assessment. An ecosystem based on R&D, ICT and data that supports the delivery of timely, targeted information and services will hasten the process of making farming profitable and sustainable while securing safe, nutritious and affordable food for all.

Fusion of technologies such as digitised information, GIS (Geographic Information System), GPS (Global Positioning System), remote sensing technology, image processing technology, data warehousing, data mining, etc., is essential to convert traditional agricultural practices into ICT (Information and Communication Technology) enabled operations. This will make for a digitally enabled and smart form of agriculture.

1.7 Prioritising Science & Technology for Farmers

India's farm sector has adopted a shift in how farmers are approached. They are now not merely actors with primary function to achieve growth in production, but are the key economic stakeholders in the agricultural value system. The success in agricultural operations is not merely a measure of value of the marketable surplus, but a measure of the value captured by the farmer.

The new mandate of agriculture (from the farmer income perspective) is to produce more from less, to capture value from every grain, ounce & drop produced, and to ensure that this value is monetised in equitable manner, to bring sustainable economic growth to farmers. As such, from the perspective of doubling farmers' income, there is a need to prioritise efforts in science and technology (S&T) along these lines. A broad categorisation is possible in reference to target areas for S&T:

- i. Extension services: that strengthen knowledge dissemination. This includes targeted information sharing systems, expanding outreach of extension services, building capacity and skills, standard operating procedures, protocols and good agricultural practices, providing knowledge to take up secondary agricultural activities, etc.;
- ii. Risks: that mitigate the inherent risks in agriculture. These include a range of systems such as weather forecasting, insurance coverage, market forecasting, animal and plant health, pest mitigation, etc.;

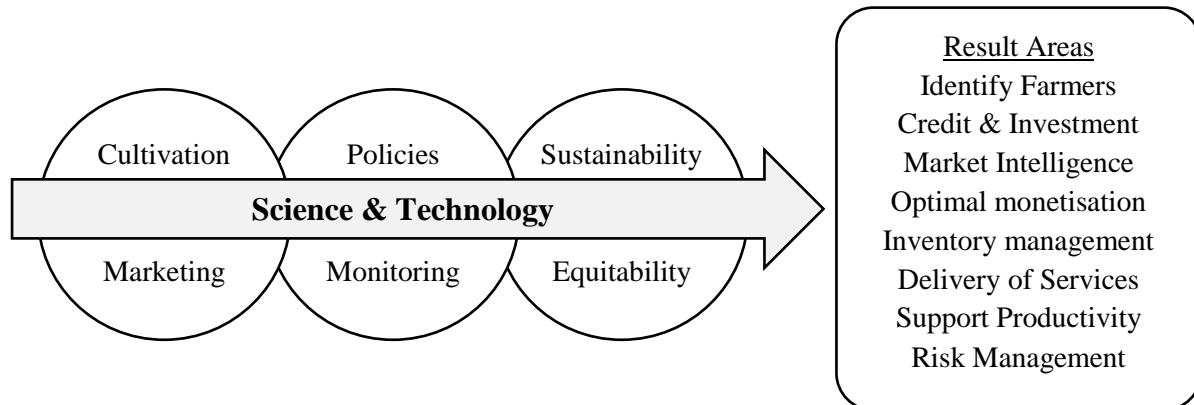
- iii. Post-production: that safeguards the produce and enables efficient marketing. These include modern warehousing and inventory management systems, traceability for food safety purposes, transparency in price discovery and exchange process, packaging and transportation systems, minimising of produce losses, value assaying technologies, technologies that convert waste into usable commodities, value-addition where form of produce is changed, and similar;
- iv. Resource use: that optimises the use of natural resources at each level of the agricultural eco-system. These include initiatives taken for soil health, water health, quality of planting material, and similar inputs;
- v. Energy use: that brings energy use efficiency in agricultural activities. These include those that bring efficiencies in use of fuel and electricity, automation that minimises indiscriminate energy use, systems that enhance the output from labour, etc.;
- vi. New developments: that generate new technologies and associated knowledge, such as developing of new varieties, breeds, climate resilience, etc.;
- vii. Agricultural governance: that identifies and builds a database of farmers, links identified farmers to their specific requirements, ensures that delivery systems are transparent and effective, monitors cropping and yields, facilitates access to a unified national market, etc.

The application of modern day technologies, especially digital technologies are all pervading, and this Committee does not intend to list all the options and applications. The options available include innovations, which also change with every new development. However, there is a need to prioritise efforts, and the localised need assessment of farming clusters at state and district level, and should be fully considered. This will make the S&T system more effective and efficient.

At the national level, the priority areas to target doubling of farmers' income, though Science and Technology could be:

- a. Farmers database – as recommended in Volume-XIII, to build a dynamic database and ensure targeted and efficient delivery of support to farmers, and to assist specialised extension services.
- b. Credit availability – to provide greater coverage under Kisan Credit Cards including crops, fishers and livestock farmers, and universal access to post-harvest pledge loans.
- c. Market efficiency – to provide market intelligence through demand & price forecasting.
- d. Extension system – to standardise the information, integration of effort among stakeholders and to maximise coverage to reach all farmers.
- e. Resource use efficiency – specifically to improve soil and water management.
- f. Sustainability and productivity gains – to improve yields and broad base the production while suiting regional ecological strengths.

- g. Risk management – information and insurance systems that improve farmers' capacity to handle the vagaries of weather, pests, disaster and markets,
- h. Convergence in efforts by public and private sectors.



There are various schemes and programmes of both Public Sector (Ministry of Agriculture & Farmers' Welfare, Ministry of Water Resources, Ministry of Rural Development, Ministry of Fertilizers, Ministry of Forests, Environment and Climate Change, Ministry of Science & Technology, Department of Space, Ministry of Earth Sciences, Ministry of Electronics and Information Technology, Ministry of Communications, Ministry of Commerce and Industry, Ministry of AYUSH, Ministry of Micro, Small and Medium Industries etc.) and Private Sector at village level, and digital technologies that can help bring convergence at ground level.

1.8 Ongoing Focus on Science & Technology (S&T) for Agricultural Development

The Government of India has been very proactive in developing new technologies, applications and systems for use in agriculture, on a continuous basis. It has actively been formulating required policies and establishing institutions in promoting S&T in agricultural development. There have been a commendable number of programs and efforts that target growth for farmers and the production system. With the advent of digitised sciences, various interventions and recommendations have been acted upon by the government of India and many state governments. It is appropriate to revisit the recommendations detailed in the ICAR, 2025, Vision document; National Mission on Sustainable Agriculture (NMSA), 2009 Report; and National Statistical Commission Sub-Group V Report 2011 in the following sections.

1.8.1 ICAR 2025 - Vision Document

The Indian Council of Agricultural Research (ICAR) 2025 Vision Document outlines following Technology Drivers of Food and Agriculture Systems in India, and suggests the need to integrate the research agenda of both ICAR and National Agriculture Research and Education System (NARES):

- i. Convergence across Bio-Technology (BT), Nano-Technology (NT) and Information technology (IT) for technology advancement in Agriculture and Food sector
- ii. Innovations in Industrial sector - Advanced Technology in Agriculture and Food Processing, Robotics and Automation in Agriculture and Food sector
- iii. Energy-Efficient and Environment-Friendly (EEEF) Devices for farm operations to compensate for the growing shortage of farm labour
- iv. Developments in Bio-Technology and other Frontier Sciences
- v. Genetic improvement, through conventional techniques and frontier scientific techniques, of agricultural commodities by using huge in-situ and ex-situ collections of genetic stocks of crops, animals, fishes, insects and microbes, collected and available with ICAR
- vi. Information technology (IT) systems - the core component in the transition from breakthroughs in labs to field-scale implementation
- vii. Precision farming : A combination Systems-Research Tools relating to Information Technology, Geographic Information Systems (GIS), Global Positioning Systems (GPS), Remote Sensing (RS), and climate smart resource management technologies
- viii. Smart sensors and new delivery systems to help combat viruses and pathogens
- ix. High Performance Computing (HPC) for manipulation of very large data sets, particularly those related to agricultural genomics, proteomics, geo-informatics and climate change
- x. Smart Knowledge Agriculture Corridor (SKAC)
- xi. An effective regulatory approval process for new technologies, which allow farmers to gain access to the latest technological advancements, to be put in place.

This Vision Document clearly perceives the need for a regulatory process for new technologies so as to allow farmers to gain access to latest technological advancements, and also the fusion of technologies for achieving higher level productivity in food and agriculture systems.

This Document has also identified “Information Technology (IT) Systems as the Core Component in the transition from breakthroughs in a Labs to field-scale implementation”, besides giving due importance to High Performance Computing (HPC), Precision farming, Fusion of Technologies – Bio-Technology, Nano-Technology and Information Technology, in ICAR’s endeavour to adopt as “technology drivers”. This requires establishment of GRIN Centres of Excellence (COEs) in Genomics, Robotics, Informatics and Nano-Technology, in each of the ICAR Institutes and Agricultural Universities (State and Central).

1.8.2 National Mission on Sustainable Agriculture (NMSA), 2009

To strengthen “informatics led agricultural development”, the recommendations of the Mission Document of National Mission on Sustainable Agriculture (NMSA, 2009)¹, as given below, were focused and required to be adopted:

- (i) Creation of detailed Soil Data base to develop micro level agricultural land use plan and Space technology enabled spatial database for Village Resource Centres
- (ii) Development of a National Portal on agriculture statistics and soil resource and its spatial decision support systems
- (iii) Extension of Land Use statistics data, under nine fold classifications, to Village / Panchayat level in pilot districts
- (iv) Development of a prototype of ICT based information dissemination system for stakeholders for various agro-climate zones
- (v) Appropriate decision support system (DSS) for assessing risk and risk profiling at farm level, regional level as well as at national level including appropriate advisories for risk mitigation
- (vi) Need to convert relevant information to knowledge before it is transferred to the grass-root for wider impact and dissemination
- (vii) Installation of about 20,000 Automatic Weather Stations (AWSs) for collating weather data from Gram Panchayat level, assuming that a weather station can be representative in about 5 K.M. radius
- (viii) Development of GIS and Remote-Sensing methodologies for detailed soil resource mapping and land use planning at the level of a Watershed or a River basin
- (ix) Implementation of Agricultural Resources Information System (AgRIS) Project (<http://agris.nic.in>) and DISNIC-PLAN (IT for Micro-level Planning) (www.disnic.nic.in) in every district.

All these recommendations are required to be acted upon through an institutionalised approach.

The Agricultural Resources Information System (AgRIS), as conceived, facilitates building up databases, both spatial and non-spatial, on farm as an economic unit, farm household as social unit, and land as the environment unit (Moni, 2004)². There were attempts to operationalise AgRIS on a pilot basis in two districts (a) Banasakatha (Gujarat) and Rohtak (Haryana) under the NNRMS Project during 2005-2010. Earlier attempts to operationalise the DISNIC-PLAN

¹ NMSA (2009) : Mission Document of National Mission on Sustainable Agriculture (NMSA) 2009, one of eight Missions announced under the National Action Plan on Climate Change (NAPCC), Government of India;

² Moni.M (2004): Designing e-Government for the Poor – “Agricultural Resources Information System (AgRIS): An e-Government Programme for fostering agricultural growth, poverty reduction and sustainable resource use in India”, presented in the Regional Workshop on Implementing e-Government”, organised by Asian development Bank Institute (ADBI) and Information, Communication and Space Technology Division of UNESCAP.

project, on pilot basis, in 28 districts (one district per state) categorized into 14 Typologies were undertaken during 2002-10. This dataset is essential for undertaking agro and socio-economic analysis of a village, facilitating micro-level planning.

Such a comprehensive database based on these parameters is yet to be established in India. The database is to be linked with farmer database and farm database. Both the AgRIS and DISNIC-PLAN Projects had faced both inter-and intra-institutional problems, as they were conceived well ahead of time. Whereas, e-Governance projects (top-down) were undertaken but operational projects (bottom-up) for developmental sector were not given required importance. In view of their relevance, the NMSA 2009 Report had recommended for operationalisation.

The NMSA 2009 Report has also recommended “installation of about 20,000 AWSs” to strengthen agricultural risk management system, which requires “site specific” real time weather and biological data. Weather Stations are the source for all weather data for agricultural uses viz., Agro-Meteorological Planning, Forecasting, Research and Agro-Meteorological Advisory services etc. Such agro-met advisory services empower farmers to take the right decisions viz. What to grow, when to sow/plant, when to irrigate, how much to irrigate, when to plant, what pest to scout for, when and what to spray, when and how much to fertilize, when will harvest be, and about expected yield.

The way forward is to establish a Comprehensive Agricultural Resources Information System at Village level. This will facilitate sustainable agricultural and rural development in an integrated manner, both farm and non-farm activities.

1.8.3 National Statistical Commission Sub-Group V, Report 2011

The Directorate of Economics and Statistics (DES) of the Ministry of Agriculture and Farmers' Welfare is the custodian of Agricultural Statistics, which gets collected periodically (not real time) and maintains a time-series (Non-spatial) database, among others, in respect of (a) Socio-Economic Indicators (b) Outlays, Expenditure and Capital Formation in Agriculture (c) Area, Production and Yield of Principal Crops (d) Area, Production and Yield of Horticulture & Plantation Crops (e) All India Index Numbers of Area, Production, Yield and Terms of Trade (f) Minimum Support Prices/ Marketed Surplus ratios (g) Stock, Consumption and Storage Capacity (h) Land Use Statistics (i) Inputs (j) Agricultural Census and Input Survey (k) Situation of Agricultural Households in India (l) Livestock and Fisheries (m) Rainfall. However, the DES is yet to deploy Big Data Analytics on its datasets.

The National Statistical Commission Sub-Group-V Report 2011 has recommended for overhauling the existing Indian Agricultural Statistical System through ICT enabled process from “Farm-Household” and “Farm-level” to Panchayat, Block, District, State and Centre, by bringing the National Agricultural Research System (NARS) Institutions and about 500 Departments of life sciences (Botany and Zoology) and about 250 Departments of Geography and Spatial Informatics in to the System, to facilitate implementation of the World Bank-FAO's Global Strategy to improve agricultural and rural statistics.

This Report 2011 stated, “restructuring of the Directorate of Economics and Statistics (DES) by inducting ICT Professionals and Big Data Analysts, at appropriate level is essential to make the Directorate ICT-enabled and to build Decision Support Systems (DSSs) based on Database systems, Experts systems and Knowledge bases, by applying Big Data Analytics”. **The DES is expected to be Decision Support System (DSS) enabler based on Big Data Analytics.**

1.9 Ministry of Agriculture & Farmers' Welfare –Sustainable Development Goals (SDGs)

The Development Monitoring and Evaluation Office (DMEO) of NITI Aayog has carried out a draft mapping of the Sustainable Development Goals (SDG) against nodal ministries, with information on related interventions and targets.

The nodal Ministry in respect of SDG number two (2) is the Ministry of Agriculture and Farmers' Welfare (MoAFW), Government of India. This SDG states: “*End hunger, achieve food security and improve nutrition and promote sustainable agriculture*”. In this target setting exercise, target number 2.3 states: “*By 2030, double the agricultural productivity and the incomes of small scale producers, particularly women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets, and opportunities for value addition and non-farm employment*”.

The related interventions & targets are presented in the Table below based on extractions from mapping by NITI Aayog.

Table 1.3 SDG number 2, related interventions and targets set by NITI Aayog

Centrally Sponsored Schemes/Central Sector Schemes (CSS)	Related Interventions	Targets	Other concerned Ministries/ Departments
Green Revolution, the umbrella scheme, includes: <i>Rashtriya Krishi Vikas Yojana (RKVY); and Krishi Unnati Schemes</i> {Mission for Integrated Development of Horticulture (MIDH), Integrated Scheme on Agriculture Census & Statistics, Integrated Scheme on Agriculture Cooperation, Integrated Scheme on Agricultural Marketing, National Food Security Mission, National Mission on Oilseeds & Oil Palm (NMOOP), National Mission for Sustainable Agriculture (NMSA), and National	1) Targeted Public Distribution System (TPDS)	2.1 By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round.	Consumer Affairs Food & Public Distribution, Tribal Affairs
	2) National Food Security Act (NFSA), passed in 2013	2.2 By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons	Health & FW, Ayush, WCD
	3) Antyodaya Anna Yojana	2.3 By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women,	Agriculture & Cooperation,

Centrally Sponsored Schemes/Central Sector Schemes (CSS)	Related Interventions	Targets	Other concerned Ministries/ Departments
<p>Mission on Agriculture Extension & Technology (NMAET)} (<i>Core</i>)</p> <p>2. Pradhan Mantri Fasal Bima Yojana (PMFBY)</p> <p>3. Rasthriya Pashudhan Vikas Yojana (White Revolution), the umbrella scheme, includes National Livestock Mission (NLM), National Programme for Bovine Breeding and Dairy Development, and Livestock Health and Disease Control Programme. (Core)</p> <p>4. Interest subsidy for short term credit of farmers</p> <p>5. National Programme of Mid-Day Meal in Schools (MDM) (Core)</p> <p>6. Price Stabilisation Fund</p>		<p>indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment</p>	<p>Chemicals & Fertilisers, Tribal Affairs</p>
		<p>2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality</p>	<p>Agriculture & Cooperation</p>
		<p>2.5 By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed</p>	<p>Agriculture & Cooperation Tribal Affairs</p>
		<p>2.a Increase investment, including through enhanced international cooperation, in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks in order to enhance agricultural productive capacity in developing countries, in particular least developed countries</p>	<p>Commerce External Affairs</p>
		<p>2.b Correct and prevent trade restrictions and distortions in world agricultural markets, including through the parallel elimination of all forms of agricultural export subsidies and all export measures with equivalent effect, in accordance with the mandate of the Doha Development Round.</p>	<p>Commerce Agriculture & Cooperation</p>

Centrally Sponsored Schemes/Central Sector Schemes (CSS)	Related Interventions	Targets	Other concerned Ministries/ Departments
		2.c Adopt measures to ensure the proper functioning of food commodity markets and their derivatives and facilitate timely access to market information, including on food reserves, in order to help limit extreme food price volatility	

Source: NITI Aayog

The target mapping indicates the need for greater coordination between among various departments and ministries and as recommended in the DFI Report, various areas of convergence are necessary. As such, a multi-tier coordination between the implementing agencies of the ministries and departments, including state governments have been proposed in the DFI Report. The coordination and monitoring is obviously optimised through use of digital technologies. However, the accountability and monitoring needs to be structured under the responsibility of a nodal body or Commission charged with doubling of farmers' income. This assumes critical importance, considering that Government of India targets to double the farmers' income by 2022, that is, 8 years ahead of the SDG targeted year of 2030.

1.10 Annotation

India has/is witnessed/witnessing several revolutions in agriculture viz., the Green Revolution, Blue Revolution, White Revolution, Sweet Revolution, Rainbow (Pulses) Revolution, Bio-Technology Revolution, etc. India continues on its mission to develop capacities in health and agricultural technologies, information and communication technologies, bio-technology and nano-technology as a priority. India has also achieved great advancements in satellite based technologies in the last 40-50 years. The need is evident, to converge technological expertise on making farming practices a sustainable and profitable enterprise.

Achievement of the recommended growth targets for doubling farmers' real income and for improving the ratio between farm and non-farm income from 60:40 as of now to 70:30 by 2022, necessitates application of Science & Technology in farm management, to effectively impacting "farm to profits". Self-sustainable models empowered with improved market linkages are expected to be the next generation agricultural models with built-in digitalisation. This means digitalised data and application will be the accepted norm for farm management.

Research and development projects, covering various technology needs such as in plant biology, soil management, water use efficiency, industrial machines, robotics, genetics, industrial use of agricultural raw outputs, etc., are all ongoing and necessary. These help to develop agriculture in keeping with the changed dynamics, and to keep agriculture future ready. However, there is need to also prioritise such efforts, to meet an already changed dynamic, of

farmers not achieving an income growth rate, synonymous with that achieved by the users of farm produce.

Modern scientific knowledge keeps upgrading and extends the users' horizon. Boundaries are frequently redrawn and this is happening at ever increasing speeds. It is obvious that research and development programs are kept equally nimble and adequately paced with such advances, though not in isolation but with determined focus on a holistic systems approach to agriculture.

The Constitution of India through Article 48, requires that the country endeavours to organise agriculture and animal husbandry on modern and scientific lines. This makes it mandatory to explore and apply modern scientific knowledge. Science is an evolving subject and the modern learnings as they apply to agriculture will inherently require to shift as and when scientific knowledge progresses. Holistic application of scientific learning is also indispensable for sustainable development and for the welfare of farmers.

Key Extracts

- India's achievements show up gaps, when compared to global yield levels; breaking these stagnant yields is the scope that exists through research and development.
- Priority attention is needed in respect of millets, pulses and oilseeds, on enhancing yield per unit area or per unit time.
- New science & technology needs to facilitate the income-centric transformation of agriculture. Simultaneous to growth of farmers' income, the ratio of farm:non-farm income will have to change from the present level of 60:40 to 70:30.
- Creation of detailed soil data base to develop micro-level agricultural land use plan, and space technology enabled spatial database for Village Resource Centres will promote efficient utilisation of natural resources.
- Use of organic manure or bio-fertilisers be promoted to reduce burden on inorganic fertiliser. This will improve soil health and also reduce spend on fertilizer linked subsidy.
- Facilitate fusion of various technologies encompassing bio-technology, nano-technology, space-technology, information-technology, GIS technology, sensor technology, drones, web based technology etc.
- Deployment of ICT at various stages in the agricultural value system will impart greater efficiency and effectiveness.

Chapter 2

Research & Development for Doubling Farmers' Income

Scientific research is an important driver for new discovery. Such scientific discoveries are made pragmatic when used to develop solutions for grass root level problems. Science, when delivered to meet pre-determined outcomes, is normally driven by economic considerations and doubling of farmers' income is a key outcome proposed for the Research & Development community.

2.1 From Science of Discovery to Science of Delivery

Science and technology with the support of pragmatic policies, outcome oriented budgetary allocations and convergence of schemes based on agro-ecologically focused growth engines will be key to realizing the vision of doubling farmers' incomes (DFI) by 2022. This calls for a change in the mindset on how the research is undertaken – an approach that is holistic and enabled by cloud computing and mobile phones to support rapid cycle innovation, agri-entrepreneurs and farmer organizations to translate effectively the 'Science of Discovery to the Science of Delivery'.

Indian farmers are presently vulnerable to impacts of climate change, water scarcity and land degradation. In addition, increasing fragmentation of holdings, extreme weather events, rising input costs and post-harvest losses pose an enormous challenge to sustaining agricultural growth. Modernisation of research systems draws strongly on Spatial Data Integration (SDI), especially cloud computing capabilities to integrate data assets across organizations. This will help support modern breeding programs, model priorities and track progress using geo-spatial analytics and apply machine-learning to distil complex data into actionable and relevant recommendations for farmers.

There has been considerable expansion and change in the research and extension system, but the key questions remain: 'Is this sufficient to double farmers' incomes by 2022? Is there a need for a different mindset to ensure that agriculture science empowers farmers to reach their full economic potential? Can this be achieved while delivering nutrition to the nation as well as within the ecological boundaries of India's natural resources?' It is important to note, that 'Demand-Driven Innovation', that leverages participatory research to engage farmers and key value chain actors to design, develop and deliver relevant income centric solutions, takes on a sense of urgency. The core to this modern approach is compressing the time to deliver technology and knowledge at scale.

2.2 WHY is a Change in Research Mindset Needed?

Although the Indian agricultural Research & Development (R&D) system has been one of the pioneering systems among developing countries, there are many complexities restricting it from realizing its full potential. Though there has been considerable change in the research and extension system in India, many issues persist. Farming is not generating sufficient income opportunities, with 48 per cent of the population generating only 15 per cent of the nation's Gross value added (GVA). This situation does not support welfare of agriculture dependent

population. This requires innovation to reduce production costs and market systems to increase unit prices of farm produce, with both integrating appropriate technology and services to reduce production and market risks. Only if these issues are addressed, will farmers have an opportunity to double their incomes and youth (future farmers) see agriculture as a viable commercial enterprise.

Indian agricultural research needs to compress the time for demand-driven innovation to reach farmers' fields to increase rural incomes resilience and nutrition to the nation

2.3 HOW a Mind-set Change Facilitates DFI

To bridge the gap from research to scaling, there is a need for a research-for-development mindset that is focused on demand-driven innovation (key pillar of the Science of Discovery) and engages a wide range of development actors in the public and private sectors and consults with farmers and consumers in the design, development and delivery of farmer- and consumer-preferred solutions.

Science of Delivery is a new and potentially disruptive concept that will motivate scientists and development practitioners to collaborate beyond their own disciplines and institutions. Popularizing innovative technologies and achieving larger impacts on the ground requires the involvement of all stakeholders. Science of Delivery will require focused funding, institutional incentives, behaviour change, and rethinking on the role of public extension systems.

Farming is a complex and risky business in the wake of increasing water scarcity, land degradation and climate change as also market unpredictability. Its success heavily depends on the size and quality of the land, weather, markets, knowledge, access to inputs, support services and capital and infrastructure. Hence, solutions need to be flexible as one tailors them to local needs and production and market situations and scale them through “trust networks” and market signals that leverage ICT. Science of Delivery for agriculture development requires strengthened farmer organizations, better functioning service providers and an enabling institutional framework. Demand for agricultural advisory services will likely emerge from market players who want to compress supply chains to increase quality, integrate traceability, ensure supply and be competitive in the marketplace.

2.3.1 Science of delivery – some key areas

- **Accelerating the innovation cycle** will require agricultural research to compress the long research-into-use pathway into a shorter and more impactful pathway that leverages participatory research approaches coupled with ICT to provide real-time feedback on farmer and consumer acceptance of new products and services, so that they can be adapted and then adopted quickly by farmers.
- **Modernizing agriculture** will draw on the rapid evolution of molecular biology and information technology to integrate across disciplines to develop new varieties with multiple production and market traits integrated. In a similar manner, modern tools

(cloud computing, artificial intelligence, mobile, remote sensing, and systems research) are driving transformation of agriculture in advanced economies that incentivize youth to return to agriculture as a commercially attractive and sustainable enterprise.

- **Convergence** of data (agriculture, nutrition, environment, hydrology, soil health, weather, farm diversification, markets, socio-economics and government schemes/policies) is critical to the implementation of a modern agri-food system to optimize resources, ultimately accelerating equitable and sustainable rural economic growth. Spatial Data Integration (SDI) offered through commercial cloud services will be a key component as Artificial Intelligence is used to distil complex data into actionable recommendations for farmers/FPOs. It will also provide real-time M&E (monitoring & evaluation) to policy makers to identify bottlenecks and accelerate DFI schemes. Additionally, it will give visibility to the opportunities for multi-disciplinary research efforts to work in concert so as to increase farmers' incomes, safeguard the environment, and deliver better nutrition to farmers and consumers.

- **Partnership with the private sector and supporting agri-entrepreneurs** will provide modern value addition, delivery of inputs and provision of extension services by bringing together agriculture sciences, Information and Communication Technology (ICT), and allied sectors to deliver sustainable and scalable solutions.

- **Backward integration of supply chains** ensures that farmers' surpluses will enjoy market opportunities. Agri-entrepreneurs are recognizing their rapidly emerging role to compress supply chains and provide primary processing services closer to rural communities to reduce losses, increase convenience to diversify diets, and shift the value capture process closer to farmers.

- **A consortium** of research organizations, government ministries, public and private sector organizations and non-governmental organizations needs to work in a coordinated and accountable manner with the appropriate cloud-enabled databases and dashboards to **scale-up science-backed solutions for farmers**.

Achieving tangible economic benefits for farmers will require research systems to adopt and operationalize a holistic approach through convergence and collective action. To achieve the goal of sustainable intensification, backward and forward linkages in terms of providing necessary inputs (seeds, fertilizers, pesticides, machineries, credit and insurance), local value addition and preservation (primary processing and storage) and market integration. This will require modern grades and standards, policies and private sector partners in the agrifood sector.

With the support of Aadhaar India Stack coupled to Spatial Data Integration (SDI) (Agri Stack or KisanStack), the vision for doubling farmers' incomes can be translated into

reality with the commitment from leadership at all levels to work as a consortium of public and private sector partners to implement state rural development plans – with speed and at scale.

2.4 WHAT Needs to be Done?

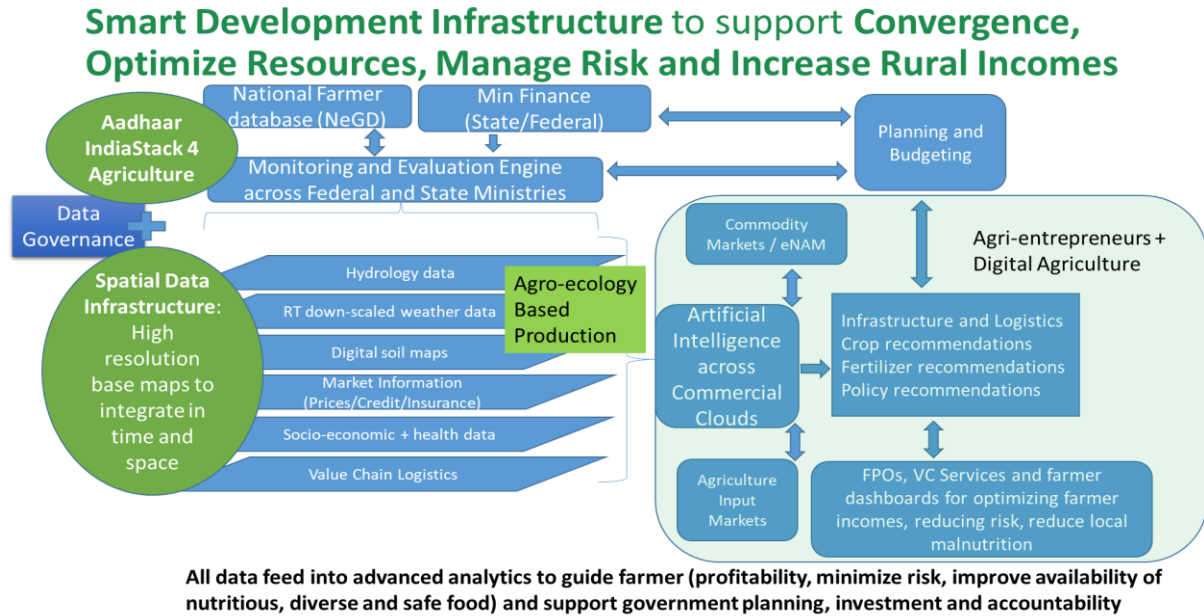
The National e-Governance Programme (NeGP) needs to pivot its focus to DFI by working with State e-Mission Teams along with SAUs, ICAR, CGIAR, private sector and FPOs to define state (district-level) growth engines for each agro-ecological zone. It would be good to focus on 5-10 states that have the full support of the respective governments that designate a direct report embedded in the State e-Mission Team with a license to work across Ministries/Departments within the state. SAUs and KVKs need to respond to the gaps identified by district-level analysis of the farmers' value chain and on how these can integrate with others, such that the integration of value chains can function as a larger demand-led supply chain network, led by the State Ministry of Agriculture. The key steps that need to be actioned before the next production season are:

- **Spatial Data Integration** to be supported by government and commercial cloud services to integrate data assets (starting with digital soil maps, hydrology and weather) to drive agro-ecological-based convergence and stimulate private sector investment, especially agri-entrepreneurs. This data would also serve financial institutions to better serve farmers through a range of financial services (e.g. credit, microfinance, insurance) to stabilize markets, manage risk and support farmers as viable businesses.
- Modern **grades and standards** to be set for all major commodities (including horticulture, livestock and fisheries) that can be graded based on mobile devices. This will support traceability to realize higher prices for farmers and support the vision to triple agri-exports by 2022.
- **National Nutrition Mission should integrate with DFI** strategy for creating consumer awareness to diversify diets and farms. Farmers should be incentivized to produce better nutrition to fuel the development of children and expecting mothers in particular, and general population at large.
- **Primary processing should shift closer to farmers** farm gates for value addition, reducing post-harvest losses and providing convenience to rural consumers.

Leverage Aadhaar India Stack and Spatial Data Integration (KisanStack) to converge schemes with progressive states to deliver targeted and timely subsidies for farmers based on the ecology, soil requirements and market requirements to dampen price volatility and prioritize local investments in processing and storage. Within a year, lead farmers in participating states would have a mobile dashboard to optimize farm resources, access service providers and connect to e-NAM clusters, processors or consumers to compress the supply chains and to consolidate logistics. Based on

learnings in these lead states, the systems can be replicated in other states and union territories across the country.

Figure 2.1 Smart Infrastructure to Support Convergence



Given the complexity of convergence and the data-intense nature of agriculture, DFI's strong recommendation is to put in place incentives to drive Spatial Data Integration across research organizations, government ministries and progressive private sector partners that will enable the delivery of timely, targeted and tailored solutions for farmers to double their incomes by 2022.

2.5 Emerging Issues

As already stated earlier, it is worth reiterating that, "Although the Indian agricultural R&D system has been one of the pioneering systems among developing countries, there are many complexities restricting the system from realizing its full potential (Ramasamy, 2013)". The R&D system needs to address multiple development challenges such as efficient and inclusive growth, sustainable natural resource management and environmental safety, food safety, monitoring and management of emerging nutritional security threats – among others. To manage this complexity, it requires efforts and skill development within the line departments and a move towards modern data management to prioritize and target research (state and federal), coordinate with allied ministries and the private sector.

Difficulty in transitioning from an intensive pilot level (hundreds) to large scale (millions) adoption of technology by farmers is a concern and has been referred to as the "Death Valley of Development". To bridge this gap, there is a need for a research for development mindset that is focused on demand-driven innovation, that engages a wide range of development actors in the public and private sectors and one that consults with farmers and consumers in the design, development and delivery of farmer- and consumer-preferred solutions.

International research organisations, such as CGIAR (Consultative Group on International Agricultural Research) institutes, have contributed significantly in terms of crop improvement and natural resource management in India. Overall, 65 per cent of the area of the 10 major food crops (including sorghum and millets) is planted with improved varieties, and of this total area approximately 60 per cent is being sown to varieties having CGIAR ancestry, and half of these are derived from crosses made at a CGIAR Centre (i.e., direct releases by national systems). Among regions, impacts have been highest in Asia (both in relative and absolute terms) and lowest in Africa (Renkow and Byerlee, 2010). However, what has been tapped into is approximately 1 per cent of the genetic diversity in the development of new varieties (Upadhyaya et al., 2006). As Climate Smart Crops are developed, there will be need to apply modern genomic tools, crop improvement databases and breeding tools to accelerate the integration of diverse production (pest and disease resistance, drought and flooding tolerance), profitability (machine planting and harvesting, processing quality) and nutritional (amino acid and lipid profiles, micronutrient dense) traits to support modern agri-food systems and economic opportunity for farmers. ICAR institutions are working to migrate breeding programs into the Breeding Management System (BMS). This work is being done with International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and supported with high throughput genotyping and phenol typing to accelerate genetic gains.

Seed systems research is the next important issue to accelerate replacement of the old with new varieties. Innovative models on seed systems that leverage participatory variety selection with farmer producer organizations (FPOs) and state seed corporations (SSCs) have proven to be a very successful model in replacing Swarna rice variety with a submergence tolerant version called Swarna Sub1. In a similar manner, improved varieties of pulses and groundnuts are being scaled up. In 2002, the Hybrid Parent Research Consortium (HPRC) for sorghum, pearl millet and pigeon pea was established by ICRISAT, that was later replicated for rice and maize. The model offers small and large seed companies access to elite breeding lines and provides public sector breeding programs with feedback on trait prioritization and multi-location testing to increase the confidence that improved varieties will perform in diverse production systems and meet diverse market demands.

The HPRC (Hybrid Parent Research Consortium) offers an example of how the public system can foster partnership with the private sector. Delivering innovation and knowledge at scale requires to be promoted as “Science of Delivery”.

2.6 Science of Delivery for Impact

Science of Delivery is a disruptive concept that will motivate scientists and development practitioners to collaborate beyond their own disciplines and institutions. Popularizing innovative technologies and achieving larger impacts on the ground requires the involvement of majority of stakeholders. Further, Science of Delivery will require focused funding, institutional incentives, behaviour change, and rethinking on the role of public extension systems (World Bank, 2013). Though development of Agricultural Technology Management

Agency (ATMA) has given an institutional identity to extension, it needs to strengthen linkages with other line departments, Krishi Vigyan Kendras (KVKs) and ICAR/SAU institutions. For strengthening the technology delivery system, KVKs should play a larger role in skill development and participatory technology demonstration to address location-specific constraints. These solutions can then be scaled through targeted dissemination that leverages SDI with India Stack which will empower farmers to act on ecologically sound and marketable options to increase their incomes.

2.6.1 Anthropology of adoption

Understanding the decisions of farmers to not adopt new varieties and technologies must be better comprehended. For most humans, “seeing is believing” and hence the role of lead farmers in demonstrating technologies can be critical in their communities. In this regard, SDI and India Stack can be leveraged to target the testing of improved technologies with lead farmers. Using real-time mobile-based monitoring, the transaction costs and latency of feedback can be dramatically reduced.

2.6.2 Failure of formal science to adequately recognise the importance of teams or partnerships

Diverse teams focused on outcomes consistently out-perform individuals. Despite this common knowledge, incentives in the R&D sector are structured around specialization and not ‘convergence’ to take on the complex challenges facing society, especially the agriculture sector. This is starting to change with the private sector taking the lead and forming joint ventures to build diverse teams outside their sector. Leadership is needed to demonstrate and support convergence within and between institutions. Technology can be used to effectively identify and assemble willing and strategic teams, track progress and allocate resources to provide the incentives for behaviour and mindset change to unlock innovation and deliver impact at scale. This is not easy, but it will be essential for innovation-based economies, especially in the agri-food sector that is arguably the most complex given the current level of farmer access to knowledge, current state of natural resources, and challenges of markets against the backdrop of climate change. **Rainfed agriculture holds the most promise for growth but is also at greatest risk which means the very best teams need to be assembled (physically and virtually) to deliver robust innovations.**

2.6.3 Converge institutional cultures, processes and individuals

To build successful partnerships, so as to achieve tangible economic benefits for farmers will require research systems to adopt and operationalize a holistic approach through convergence and collective action (Wani et al., 2003a, 2009). To achieve the goal of DFI, backward and forward linkages in terms of providing necessary inputs (seeds, fertilizers, pesticides, machineries, credit, insurance), local value addition and preservation (primary processing and storage) and market integration supported by grades and standards, pragmatic policies and private sector partnerships are required.

The right institutional incentives and partnerships will be required to drive this change at multiple levels, and federal and state budgeting will be the key incentive. Based on state priorities and “Labs” that bring critical independent value chain actors together, research priorities should be set, not only to increase productivity, but also profitability for farmers – reduce production costs while increasing the unit market value of surplus production. Appropriate grades, standards and certification (again a rich space for innovation in India) can increase market value realized by farmers by incentivizing better quality output. With the support of SDI and India Stack, these lofty visions can be translated into reality with the commitment of leadership at all levels and to work as a consortium of public and private sector partners to implement with speed and at scale (Wani et al., 2011).

2.7 Science of Delivery needs to be Rewarded

Science of Delivery is focused on HOW to realize large and sustained impact that draws on knowledge management and diverse methods of sharing that include large-scale demonstrations to inform decisions, adapt approaches and changed mindsets that **accelerate the innovation cycle** and ensure local conditions, context and culture are considered in developing and delivering products and services. It also helps compress timelines from discovery to delivery.

The process of understanding how delivery works in agriculture needs to be informed by a broad range of partners across sectors and regions and new tools like social media that aid immensely in this endeavour. Better understanding of delivery challenges and failures will significantly improve system ability to achieve consistent and transformational impacts in farmers' fields and consumers' plates. It needs to be recognized that soft skills are required to work effectively in the domain of delivery, but these are neither taught in agriculture science curricula nor are there incentives within institutions to hone these critical skills.

2.7.1 Science of Delivery is challenging

Science of delivery is a relatively new subject for many scientists, development practitioners and extension agencies. Innovation is happening at an amazing pace but many innovations are not being translated to practical use. **Using all known interventions appropriately could increase grain yield by at least 50 per cent and resource use efficiency from 50-70 per cent and reduction in cost of cultivation by 20 per cent (Wani et al., 2017).** However, in India, technology transfer can benefit from a changed and improved mindset, suitable infrastructure, institutional support and policy guidelines to translate these innovations into impact.

2.7.2 Need to understand the complexities of agricultural systems

Farming is a complex and risky business in the wake of increasing water scarcity, land degradation and climate change. Its success heavily depends on the attributes of the land, weather, markets, knowledge, access to inputs, support services, capital and infrastructure. Hence, solutions need to be flexible in terms of being able to tailor them to local needs and production situations and scaling them through “trust networks” that leverages ICT. Science of

Delivery for agriculture development requires strengthened farmer organizations, better functioning service providers and an enabling institutional framework.

Demand for high-quality agricultural advisory services will likely emerge from market players who want to compress supply chains to increase quality, integrate traceability, ensure supply and be competitive in the market place. This trend started with high value horticulture and livestock products and is now starting with staple crops.

2.7.3 Four ICEs framework for effective delivery of impacts

Past experiences suggest that, effective delivery of technology needs an integrated approach to complement different sectors and disciplines on the ground. ICRISAT-led consortia, for example, have demonstrated an integrated holistic approach to converge programs and resources to achieve system level outcomes. This approach considers four ICEs which are central to scaling-up of technologies and sustainable intensification.

The framework to innovate in an inclusive and integrated manner to deliver intensification (4 “I”s) draws on the principle of convergence, consortium, capacity building and collective action (4 “C”s) which are critical in developing strong intermediaries to address the consortium goal through 4 “E”s (Efficiency, Economic gain, Equity and Environmental protection) which are the important pillars for sustainable intensification and inclusive development (Wani et al, 2011). The framework emphasizes efficient use of land and water resources and, for example, targeted fertilizer blends for sustainable intensification while maintaining the environment.

The approach of the consortia programs has been to strengthen input and output supply chain linkages to meet the 4 Es through 4 Cs by establishing seed villages, custom hire centers and small-scale businesses to undertake best-bet options for increased agricultural productivity and profitability. Community based organizations (CBOs), service providers and emerging models of Farmer Producer Organisations will be key consortia partners for scaling impact.

2.7.4 Science of delivery is neither taught in business schools nor agriculture universities

Agricultural Universities or broader business schools have not emphasized Science of Delivery in their curricula. While specialisation is important for the **Science of Discovery** across biological, engineering, social, economic and environmental sciences, integration across these and other disciplines is limited and practical tools to partner with the private sector and liaise with policy makers are few.

It is only in recent years, that the importance of “**soft systems science**” has come to be appreciated as an enabler of transition from pilot projects to large-scale implementation and impact. Organisations like ICRISAT have only recently taken initiatives to train the next generation on these skills that draw heavily on emotional intelligence and partnership engagement and business planning. Similar adoption is also needed by ICAR and SAUs in their research and technology transfer systems.

2.8 Compressing Science of Discovery to support Science of Delivery

The first mile (discovery) needs to have the last mile (delivery) in mind. In this regard, the National Agricultural Research System (NARS) should be committed to reducing the time for discovery science to reach farmers' fields.

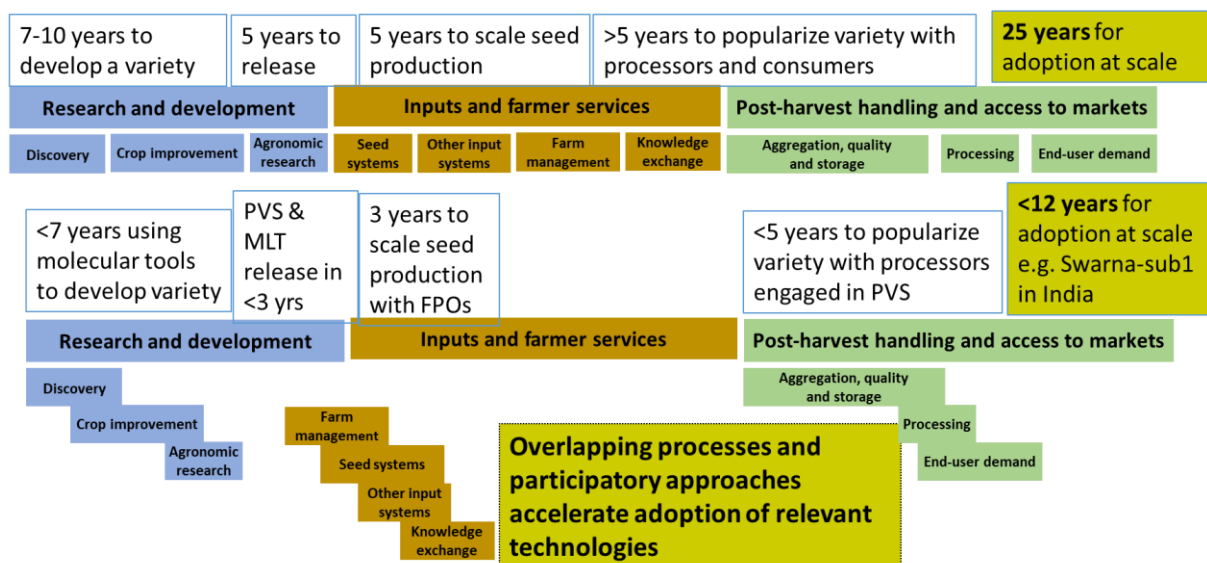
ICRISAT and its partners have adopted this approach in modernization of crop improvement programs to accelerate the development and release of new varieties.

Assessing the status of breeding programs is the entry point for modernization based on best practices used in public and private sector breeding programs. Based on this assessment, prioritized investments were made and implementation of best practices were monitored. New tools included the adoption of a cloud-based breeding management system (BMS), standardized trait ontologies, bar-coding to reduce data error, high throughput genotyping to support marker-assisted breeding, early generation multi-location testing, and crop modelling to target product development and release.

Development of the molecular tools to integrate multiple traits is supported through international and national partner networks that are now utilizing genome sequences to resequence a wide diversity of crop germplasm to develop molecular markers in service of developing diverse, robust and nutritious new varieties.

Another area of rapid innovation is in the integration of modeling, remote sensing, advanced geo-spatial analytics, cloud-computing, internet-of-things and mobile phones. Integration of these tools is providing timely and targeted insights for farmers, agri-business, markets and policy makers. However, the research community is in the early stages realizing the potential of integrating this domain with that of modern crop improvement and farming systems to optimize variety development in the context of farming systems and market demands.

Figure 2.2 Compression of time: science of design, development and delivery



Source: ICRISAT

A third important domain for the research community is to work on compression of time to develop and delivery demand-driven innovation to farmers' fields at a large scale. A few examples of this exist already in India (see examples below for chickpea and rice). The process deployed in realising these need to be adapted in other crops and States so as to harvest economic opportunity and climate smart options at farmers' end at the earliest.

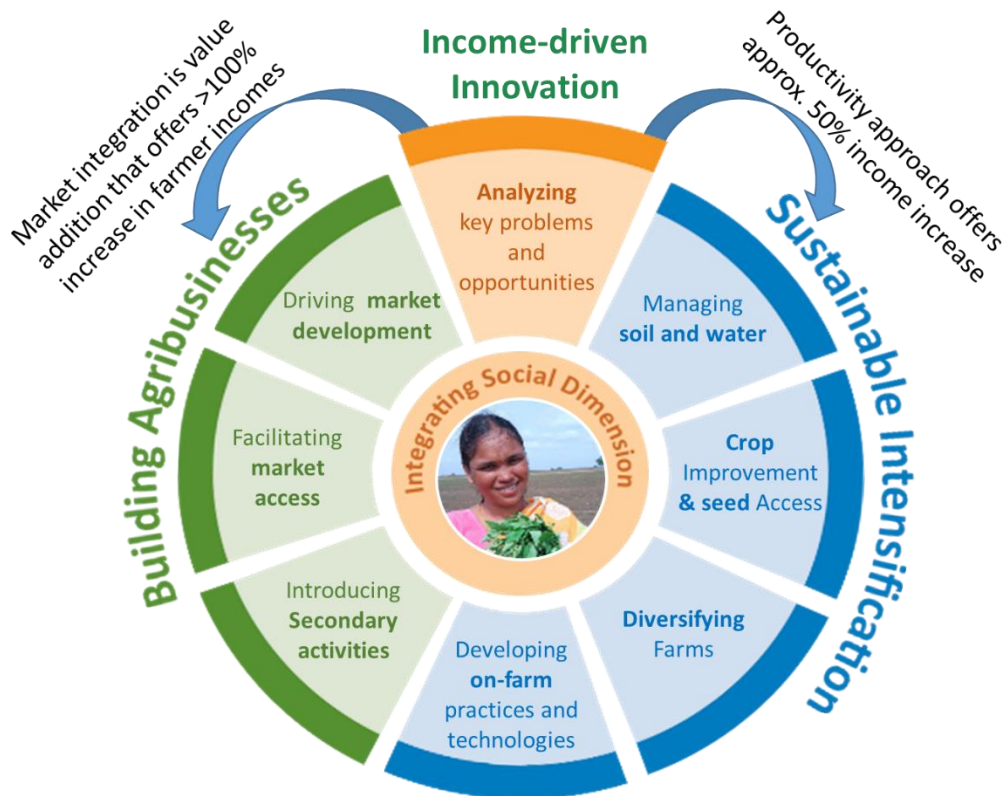
Science of Delivery involves the compression of processes and strategic partnerships to accelerate innovation cycles and squeeze the time of delivery of farmer- and market-preferred products and services. Example shows how this was applied in replacement of the popular rice variety Swarna with the submergence tolerant Swarna-sub1. (Drawing on lessons from Yamano et al. *Agricultural Economics* under review).

2.9 Science of Delivery to Double Farmers' Incomes

2.9.1 Mindset towards Demand Driven Innovation

Moving from supply-push research to a demand-pull research will require a mindset change among the scientific community. A new mindset orientation towards participatory approaches to support bi-directional exchange between farmers and researchers to accelerate the design, development and delivery of farmer-preferred and sustainable farming systems will need to be adopted by public research institutions.

Figure 2.3 Transition of supply-push to demand-pull research



Source: ICRISAT

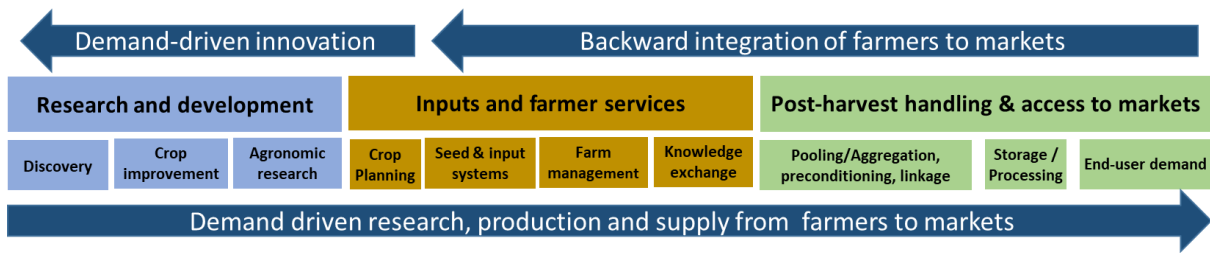
A fundamental shift is required within the science community as society demands more from public institutions charged with delivering solutions to serve meet its dynamic needs. This is especially true in case of Indian farmers who require innovations and the knowledge to optimize inputs to reduce production costs and maximize unit price of surplus to increase their incomes.

Research and innovation also need to embrace and leverage new technologies such as cloud computing, mobile, remote sensing and innovative partnerships with the private sector to deliver timely, targeted and tailored products and services to empower farmers to realize their full economic potential, produce safe and nutritious food for the nation within the ecological boundaries of India's natural resource base. Participatory research that engages farmers, other value chain actors and researchers will be key and need to provide feedback to determine priorities, budgets, monitor progress and adjust implementation plans as required to accelerate impact – this is the Science of Delivery.

2.9.2 Backward integration of value chains

Matching farmers' surpluses with market demand and enabling entrepreneurs to compress supply chains that provide value adding primary processing closer to rural communities will reduce losses, increase convenience and diversify diets for better nutrition and resilience.

Figure 2.4 Integrate science & production with market



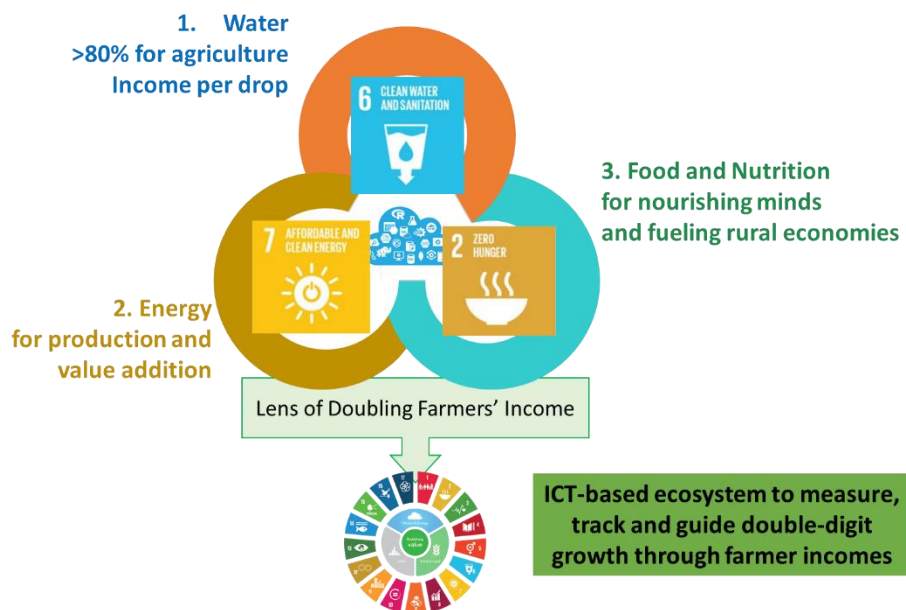
Most agricultural commodities have long and often inefficient supply chain linkages with a host of intermediaries. However, the era of online marketing is now influencing innovation in the agri-food sector to compress these linkages; and innovative business models are delivering higher prices to farmers and higher quality to consumers creating a win:win situation. This is an innovation space that is evolving quickly and will introduce significant disruption into existing market mechanisms.

What is needed to support and accelerate this process is more facilities like that of ICRISAT's ihub to integrate Science of Delivery with data assets and innovative business models to address past market failures in delivering value to farmers and consumers. There could possibly be other such well tested platforms, that can be identified and adopted with suitable changes to meet specific needs.

2.9.3 Research from the perspective of increasing income

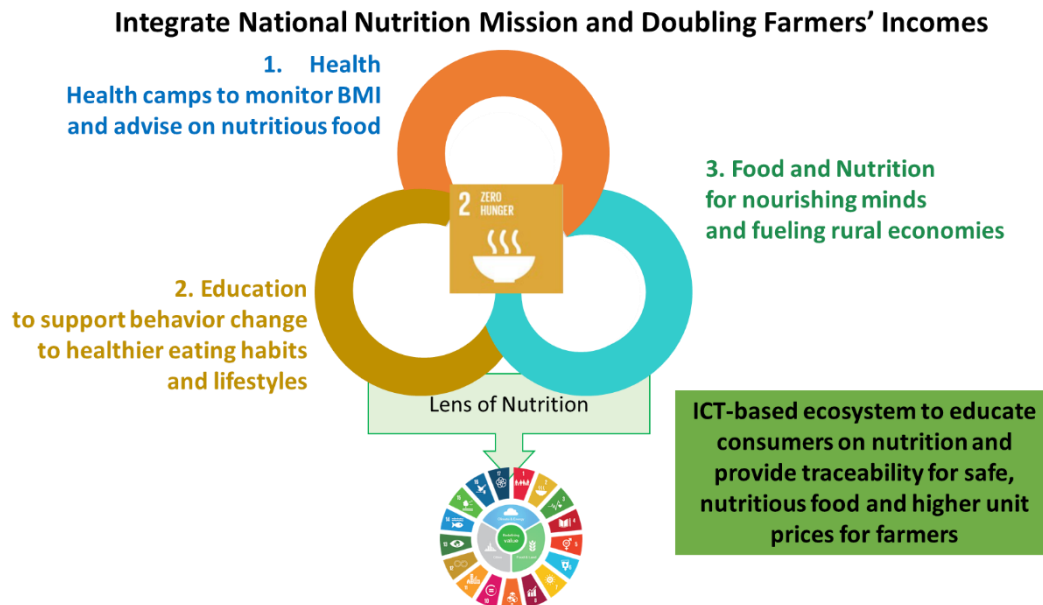
Agricultural research should labour using the lens of increasing farmers' incomes. An example is illustrated via the figure below.

Figure 2.5 Nexus of water-energy-nutrition



Research into improving water-use efficiency, providing clean and sustainable energy to promote value addition at the community level and providing nourishing food at the community level will contribute to increasing incomes. ICT tools can serve as decision support systems while also help guide implementation and monitoring.

Figure 2.6 Income, Nutrition, Education-Health



Inclusion of education and agriculture domains into the recently-launched National Nutrition Mission can play a crucial role. Multi-disciplinary research to address the synergies between health, agriculture and education is vital to tackle malnutrition and ensure that farmers get a premium price for producing nutritious food.

2.9.4 Putting in place Spatial Data Infrastructure (SDI)

Spatial Data Infrastructure (SDI) and institutional incentives to aggregate data across research organizations (ICAR, CAUs, SAUs, ISRO, IITs, etc.), industry (fertilizer, seed, pesticides, processing), Ministries (see MITrA, 2016) can support agro-ecological-based agri-food research, technology targeting and adoption. Leading agriculture nations now use SDI to unlock innovation, track implementation and create accountability for modern agri-food systems. Aadhaar IndiaStack can be integrated with SDI by National e-Governance Division (NeGD) *if focused on DFI* in partnership with State e-Mission Teams.

Sectors such as finance and IT have been leading the application of advanced analytics to deliver business solutions, while agriculture, which is data-intensive, has made the least use of big data analytics. In large part, this is due to the scarcity of structured data and meta-data to drive digital innovation. Two key interventions to address this would be the implementation of Spatial Data Infrastructure that complements the Aadhaar India Stack via cloud storage provided by commercial providers through hybrid (public + private cloud) services. These resources should be opened to the public and private sectors to foster data-driven innovation for agriculture that is now fueling agriculture in advanced economies.

The second intervention needed is to put in place institutional incentives to ensure that the publicly funded data is stored on such services in a structured manner with clear ontologies and meta data to support integration across institutions. This would support collaboration within the agriculture sector and also with other key allied sectors such as health, development and education. The concept and aim of farmers' welfare has to go beyond the enterprise of agriculture and include several government promoted, as also market-centric welfare services.

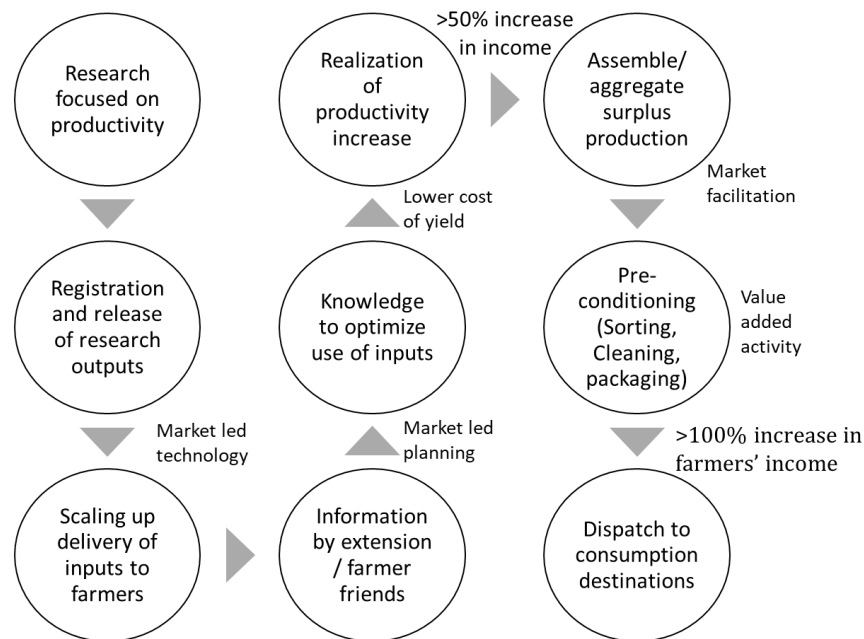
This will likely involve building on the existing partnership between government (Union and State) and IT sector established by the National e-Governance Division. Key data sets to start with will be soil, hydrology and weather data assets that can be made available to public and private sector researchers and development partners. In the case of hydrology, watersheds could be integrated as meso- and macro-watersheds and further into sub-basins and basin level for the effective planning, management and monitoring to realize sustainable development of rural economies.

A research and development unit at the state level needs to be set up to study agro-ecological regions staffed with adequate and appropriately qualified/trained human and financial resources. Incentives should be in place to promote sectoral convergence at farm level by linking different programs and schemes through SDI and Aadhaar, so that subsidies are based on needs of the farm and farmer to maximize input use efficiency (irrigation and fertilizer that include micronutrients), support market price stabilization, and eventually offer farmers with simple options in advance of the growing season to reduce risk (production and market), optimize inputs and integrate into structured markets. Aadhaar offers a unique platform to track the performance of these subsidies and, if designed well, a means to track DFI in real time.

2.10 'Systems Approach' to Research

Research needs to take a Systems Approach to diversifying farming systems that includes the optimization of water resources to increase economic opportunity, especially for high value crops, horticulture and livestock (including aquaculture). SDI and mobile-enabled implementation of agro-ecologically appropriate schemes and solutions will be an important step towards a systems approach that also compresses impact pathways.

Figure 2.7 Need to compress impact pathways



2.10.1 Agro-ecological framework for a sustainable agri-food system

Agro-ecological intensification for farmers will be key to achieving increased productivity and profitability by optimizing local resources, maximizing returns from external inputs, improved stability and diversity of nutritious foods, reduced greenhouse gas emissions, enhanced ecological resilience and environmental service provision. Simple interventions such as better seed, nutrients, and water management are yet to reach many parts of India. Moving to knowledge-intensive forms of agriculture will require SDI, integration of ICT coupled with policy and market incentives. In crop production, agro-ecological intensification based on good agronomic management principles for a given context includes:

- Profitable and sustainable crop rotations.
- Quality seed of a well-adapted, high-yielding varieties or hybrids that also meets market demands.
- Planting at the right time to maximize the attainable yield by capturing water and nutrients.
- Maximize water harvesting and efficient utilization of available water.
- Integrated soil and nutrient management, including conservation agriculture, balanced and more efficient use of fertilizers. Priority attention to building organic carbon (OC) in the soil.
- Integrated pest management, including biological control and the judicious use of pesticides supported by emerging cloud and mobile-based diagnostics.
- Optimize recycling and use of bio-mass and agricultural by-products.
- Enhance suitable crop-tree-livestock interactions.

Box 2.1: Technology helps farmers get better returns in shorter time

Why (The issue): Banana farmers in Siddipet, Telangana, suffered from a lack of transparency around market demand. Therefore, they sold to intermediaries at rock-bottom prices.

Who (The stakeholders): Agri-preneur Keansa collaborated with Farmer Producer Organizations to **map data about the farmers' produce** (bananas) to traders in far-off towns interested in buying them.

How (The technology): **i.** Traders could **access key data** – number of farmers, type and amount of produce available, historic price points– on the app and plan their purchases for a sustained period of time. **ii.** Ensured of a **continued supply**, they agreed to pay a **premium price** for the farmers' produce. **iii.** Farmers gained an **assured market** for their produce and therefore were able to charge higher prices than what they could charge for a distress sale in a local, saturated market.

What (The benefits): **61 per cent** increase in farmer income; Time for sale cut down to half; **Zero** revenue loss due to miscalculations

2.10.2 Research institutions working with rural entrepreneurs

Research institutions need to work with rural entrepreneurs to accelerate the delivery of science-based solutions that can attract youth back into agriculture and treat agriculture as a business. To harness the benefits of scale in supply chains, cooperation and collective action through Farmer Producer Organizations (FPOs) is needed. Past experiences point to the success of FPOs to gain bargaining power, as experienced with milk cooperative societies. The opportunity now is how to leverage ICT, India Stack and SDI to drive the democratization of markets to empower farmers to realize their full economic potential.

Governments play a key role by providing young people with a favourable investment environment and developing policies that incentivize their participation in agriculture. At present, youth face many challenges to access government and private financing to engage in agribusiness. Training young farmers on best farming practices, post-harvest handling, and packaging is also important as well as developing businesses that provide production, processing and aggregation services to shift more economic opportunity to rural youth. One catalytic opportunity has been realized through developing ICT-based business solutions to attract youth to farming and farm linked enterprise business models.

2.10.3 Public private funding and partnership as a business model

Public-Private Partnerships (PPPs) enable an optimal policy approach to promoting of social and economic development, thus bringing together efficiency, flexibility, and competence of the private sector along with the accountability, long-term perspective, and social interest of the public sector. In developing countries, the share of private sector in the total agricultural research investment is only 6.3 per cent as against 55.2 per cent in developed countries. There

is an urgent need to strengthen public research system in terms of efficiency, evolving technologies to address problems in the order of priority, and strengthening PPP wherever it is more beneficial. (Ramasamy, 2013).

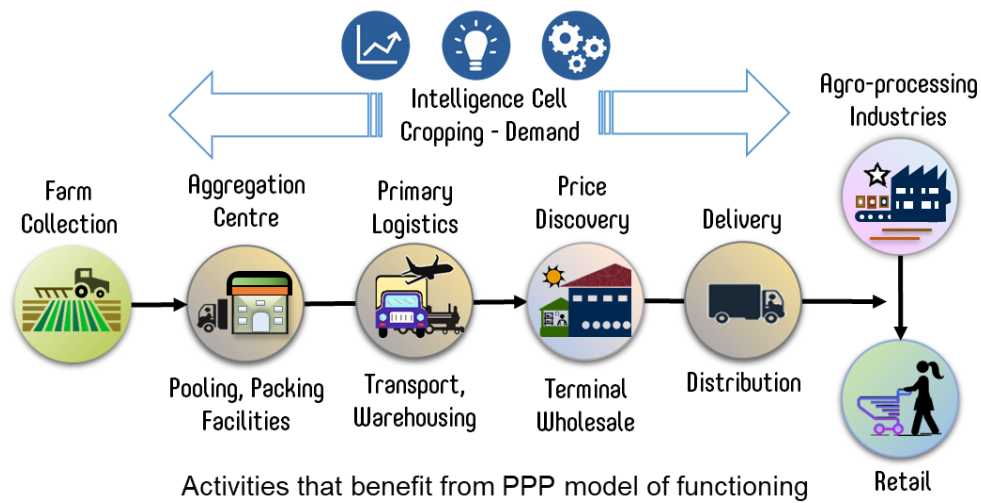
Development of non-farm entrepreneurship opportunities in secondary agriculture encompassing primary processing, food processing, agri-logistics, new generation infrastructure (assaying labs, soil testing labs, weather gauge stations, custom hiring centres, etc. resource aggregation as a business (eg., aggregating paddy straw or cotton stalk dispersed as small lots across small & marginal farms and connecting them to large compost units or bio-methanation plants and advisory and extension services are other avenues that can contribute to rural economic development. A number of collage and village level activities under secondary agriculture (Volume IX) are also possible.

PPP interventions in such business models by way of additional investments in infrastructure, business support networks and skill development avenues will further augment the investments made by the Government. Value added activities that help farmers link with consumers as well as value addition that is based on consumer demand needs to be promoted through business incubation towards creating demand pull and sustainable income for the smallholder farmers. Such facilitation is proposed in Volume IV of this Report at the Rural Agri-Markets (GrAMs) which will undertake value added functions such as aggregation and linking terminal markets with villages, as well as provide value addition options at village level to specific farm produce

In terms of PPP, engagement of a private sector agency for the front-end marketing can be a crucial and successful model, wherein, the produce from the GrAMs (Grameen Agriculture Markets), which is cleaned, sorted and graded before being dispatched to terminal markets in a well-packed and finished form to direct purchase by the last mile customer.

Such a model is successfully being implemented in 10 districts by the Government of Tamil Nadu under their supply chain management project for fruits and vegetables. Similar models can add a higher margin of profits for farmers organized through the GrAMs. These models are likely to be more successful than any efforts put in by any individual stakeholder.

Figure 2.8 Activities that benefit from PPP model of functioning



An example is also seen in how ICRISAT addressed this need by establishing its Agribusiness & Innovation Platform (AIP). Promising intervention models that empower FPOs (or similar collective models) to adopt value-adding opportunities at the farm level have contributed towards increasing farmer incomes and create rural employment. An emerging area is collection centres as well as primary processing activities that compress and integrate the supply chain and enable farmers to capture a higher percentage of value.

2.11 Leverage DFI Agenda to Drive Convergence

The national mandate on Doubling Farmers' Income (DFI) is an opportunity to drive convergence across Ministries (State and Union), schemes, local value chain actors and farmers to accelerate the adoption of sustainable (economically, socially, and environmental) options to empower farmers and produce nutrition to a growing nation.

Research and innovation for impact are most important, where, challenges are greatest and the best solutions are delivered by diverse teams – this is true of Indian agriculture. Fortunately, India has been putting in place the digital infrastructure to deliver personalized interventions to farmers through Aadhaar, alongside a wide range of policy support measures to create an enabling environment for farmers and a clear goal to work towards.

In this context, the agenda of research and development needs to be changed to crowd in greater efforts on integrating research and development through active public-private partnerships that are demand-driven and based on sustainable economic growth engines for rural communities. This will require a framework to prioritize research within each agro-ecology and state to frame convergence of schemes, institutions (public and private) and disciplines that include new areas such as nutrition, health and education to deliver on both short- and longer-term development goals of India.

Box 2.2: Example of demand-driven innovation to help farmers cater to markets profitably

Why (The issue): Commercial confectionary groundnut processors had **specific commercial requirements** and was looking for specific high oleic acid varieties that offer superior taste, longer shelf life, and consumer health benefits. Groundnuts from Australia and USA have upto 80 per cent oleic acid, while Indian varieties had only 40-50 per cent oleic acid content.

Who (The stakeholders): ICRISAT groundnut scientists foresaw the **increasing demand** for high-oleic groundnuts and used innovative technology to breed similar varieties in India.

How (The technology): **Cutting-edge molecular research and crop improvement tools** helped to quickly and efficiently identify varieties that combine high-oleic trait that are **adapted to growing in Indian agro-ecologies**.

What (The benefits): Advanced technology helped **cut costs and bring down crop selection time** from breeding (first step) to national testing trials (final step) from over 10 years to just six years. This means farmers get access to **higher value marketable varieties** with better nutrition to **increase their incomes and deliver in half the time**.

2.12 The Way Forward and Annotations

State governments require to build various consortia, where knowledge partners and government converge to take a systems approach to sustainable rural and agricultural growth. This would especially be apt for rainfed production systems that face most critical challenges, while offering the highest scope for growth to double farmers' incomes.

Given the complexity of convergence and the data-intense nature of agriculture, a strong recommendation is to put in place SDI (Spatial Data Infrastructure) and incentives for their adoption by research organizations, government ministries/departments and progressive private sector partners in order to enable the delivery of timely, targeted and tailored solutions to the farmers and enable them to double/enhance their incomes.

A focused effort is required to push the concept "Science of Delivery" to increase rural incomes. Each state needs to take ownership, create robust implementation plans along with adequate budgetary support and leverage Aadhaar India Stack and SDI to provide the technology backbone. Given the past success of the National e-Governance Division (NeGD) in supporting e-Governance reforms, the NeGD should now pivot its focus towards DFI in collaboration with State e-Mission Teams.

In developing countries, the share of private sector in the total agricultural research investment is only 6.3 per cent against 55.2 per cent in developed countries. It would be good to build a policy framework that crowds in greater private sector participation in R&D.

While agriculture will be the engine for rural growth, it must be seen in the context of agri-food systems to deliver better incomes, nutrition and health. **To this end, coordination of schemes that bring together Agriculture, Health and Education will be key for long-term growth and reaping the youth dividend of India to translate Innovation into Impact.**

NeGD can pivot focus on DFI strategies by working with State e-Mission Teams along with SAUs, CAUs, ICAR, CGIAR, private sector and FPOs to define state growth engines for each agro-ecological zone. Focus needs to be on a few leading States that can offer full support preferably at the level of respective Chief Ministers and a direct report supported by the State e-Mission team that has license to work across Ministries within the State. The key steps that need to be actioned before the next production season:

- Spatial Data Infrastructure is supported by government and commercial cloud services that integrate spatial data assets starting with digital soil maps, hydrology and weather that will drive agro-ecologically focused innovation systems and stimulate private sector investment, especially entrepreneurs.
- Grades and standards for all major commodities (including agriculture, horticulture, livestock, fisheries) are established that can be graded using mobile-based devices. This will support traceability needed to more than triple agri-exports by 2022 so farmers can access international markets.
- National Nutrition Mission should synergise its efforts with Ministry of Education, Ministry of Health and Ministry of Agriculture to create consumer awareness of diets for children and young mothers to ensure children reach their full genetic potential and farmers can access local markets.
- Shifting primary processing closer to farmers and farm gates for value addition, reduced postharvest losses and provide convenience to rural consumers to diversify diets.

Leverage Aadhaar India Stack and SDI to converge schemes with progressive States to deliver targeted and timely subsidies for farmers based on the ecology, soil requirements and forecast market requirements to dampen price volatility and prioritize local investments in processing and storage. In a quick span of, say, within a year, farmers in participating States could have a mobile-dashboard to optimize farm resources, access service providers and connect to e-NAM clusters, processors or consumers to shorten the supply chains and consolidate logistics to double their income. This can then be scaled up for universal coverage of all geographies and farmers.

Key Extracts

- The optimal approach to R&D is to move from ‘Science of Discovery’ to ‘Science of Delivery’, focussed on increasing rural incomes.
- Need to focus on demand-driven innovation to help farmers to market their produce efficiently and earn profits.
- Each state needs to take ownership, create robust implementation plans along with adequate budgetary support, and leverage Aadhaar India Stack and Spatial Data Infrastructure (SDI) to create a technology backbone.
- There is urgent need to encourage and strengthen public research system in terms of efficiency and evolving technologies to address problems in order of priority, and strengthening PPP (Public Private Partnership) wherever it is beneficial.
- Innovative models on seed systems that leverage participatory variety selection with farmer producer organizations (FPOs) and state seed corporations (SSCs) will help in maintaining the desired seed replacement ratio in different crops.
- Farming is a complex and risky business in the wake of increasing water scarcity, land degradation and climate change. Hence, solutions need to be flexible in terms of being able to tailor them to local needs and production situations and scaling them through “trust networks” that leverages ICT.
- Incentives should be in place to promote sectoral convergence at farm level by linking different programs and schemes through SDI and Aadhaar. This would allow subsidies to be targeted on needs of the farm and farmer to maximize input use efficiency (irrigation and fertilizer that include micronutrients), support market price stabilisation, and eventually offer farmers with simple options in advance of the growing season to reduce risk (production and market), optimize inputs and integrate into structured markets.
- Shifting primary processing closer to farmers will reduce post-harvest losses and provide convenience to rural consumers to diversify diets.

Chapter 3

Unaddressed Research & Development and Its Impact

Green Revolution – I (1965-80) aided by appropriate and robust science & technology has brought in success, the most visible being food security for the nation. The next revolution, GR – II has to similarly adopt new science & technology to achieve success based on the principles of comprehensiveness, sustainability and profits. It would, therefore, be more appropriate to paraphrase the new transformation phase as 'Farmers' Income Revolution'. Critical gaps in R&D in this context are identified and solutions suggested.

3.1 Research and Development in India's Agriculture – Road Travelled

India's agriculture since independence, and more particularly since 1965 has mostly been driven by the concerns about food security. This vision was successfully translated into reality on the back of a robust crop science & technology comprising high yielding seeds, irrigation and intensive use of associated inputs. The technology developed around these parameters has come to be popularly called as 'Green Revolution'. This phase encompasses more specifically the years between 1965 and 1980. While it has succeeded in imparting food security to the country, and the growth in subsequent years has also succeeded in generating surpluses in certain crops, creating scope for exports, many inadequacies of the green revolution (GR-I) technology have also come to surface over the last decade. The major observations on green revolution technology, that call for appropriate amendments in the current context can be delineated as follows:

- It has not been secular across all the crops and sub-sectors of agriculture (horticulture, livestock, fishery etc).
- It has not been universal across all categories of land holders and all geographical parts of the country.
- It has not addressed all links along the agri-value system. More particularly, the post-harvest management failed to receive full attention.
- True food security has not been achieved as yet, and it can more appropriately be defined as 'cereal security', as seen from pulse inadequacy that the country suffered till 2016-17; and the continued deficit in oilseed production and edible oils.
- It has been highly resource use intensive resulting in depleted water table and degraded soils. There is technology fatigue.
- Large swathes of rainfed systems have not received fair & rational attention and treatment.

It is now time to redefine 'food security' to encompass the ability to meet the domestic needs of carbohydrates, proteins and vitamins. Food security must come to intrinsically mean food and nutrition security, for supporting healthy life styles of modern India.

In addition to the popular green revolution around wheat and paddy, there have been several other radical changes in different sub-sectors of India's agriculture including dairy and livestock sector. These have been referred to as 'White Revolution' (in respect of milk), 'Blue

Revolution' (in respect of fisheries and aquaculture), 'Rainbow Revolution' (in respect of pulses) and the like. Yet there remain wide gaps, on account of which, it can be said, that a wholesome transformation of agriculture is still awaited.

While today food security in the conventional sense overshadowed by cereals may not be a concern, the income security of the farmer has emerged as the new challenge. Sustainability of resources and productivity-production is of course critical. It is, therefore, time that an all-encompassing next green revolution (GR-II) is launched with support from science & technology, described by pluralistic features, some of which are identified below:

- It should be universal across geographies, all agro-climatic conditions and agricultural systems of the country.
- It should be secular across various sub-sectors – agriculture, horticulture, dairy & livestock, fishery and aquaculture; as also across the cafeteria of crops, animals and birds within each of these domains.
- It should be based on low input use and efficiency, to impart production efficiency and sustainability to the system.
- It should be agri-value system based, that addresses both value-chain and supply-chain leading to minimal food loss and maximum share for the farmer in the consumer's rupee.
- It should be farm income-centric in contrast to production-centric.

3.2 From Green Revolution to Income Revolution

The approach to monitoring of growth has to be farm income basis and not area, productivity and production as has been the norm so far. The advantage of such a growth monitoring mechanism, is that a farm income captures all variables of the agriculture profession including productivity and production, input costs and the value monetised. Such a parameter would be a more wholesome measure of agriculture as a profession and the farmers as the stakeholders. It logically follows that the next transformation in agriculture – green revolutions (GR-II) can more appropriately be named as **Farmers' Income Revolution (FIR)** or in short '**Income Revolution (IR)**'.

The term Green Revolution, unwittingly brings primary focus on production alone with little reference to other aspects of the agricultural value-chain. It is no gain saying, that the frontiers of science are not circumscribed by any boundary, and it is also neutral in deployment and application. It would be left to the scientists and policy-makers to take advantage of science for addressing issues of choice and needed answers/solutions to the challenges of the day and for translation of the vision identified by the nation into reality. Based on the findings of science, it would be feasible to convert the same into technologies, which will then need to be transferred to the farmers without loss of time and content. The transfer of technology has always been a challenge. The common reasons attributed are illiteracy and lack of awareness

among farmers, and inefficiency of the extension machinery. While these may be true, there is always scope for improving upon this situation.

It must not, however, be forgotten that the great achievements in the field of Indian agriculture are not only an outcome of the efforts of scientists and support of policy-makers, but more importantly, the credit is that of the farmers who responding positively have absorbed and adopted the technologies. They have demonstrated their willingness to take risks. The farmers, for e.g., in the Indo-Gangetic Plains who have been the torch bearers of the country's food security, through impressive outputs of paddy and wheat, have exhibited their ability to respond to the new technology and policy built around these crops, only because they were able to monetise the produce and find profits. Similar is the story of adoption of Bt Cotton in India, or large scale cultivation of maize in Bihar or record milk production through cooperatives or the aggressive cultivation of horticulture across the country in the last decade. Hence, one of the key requirements of technology transfer would be its ability to prove the monetisability of the produce and conversion into net profits. The farmers possess the wisdom and rationality to make appropriate decision regarding adoption of new technology if they see value in it. The implication is, that if R&D outcomes are income-guided, transfer of technology would be much easier.

In addition to the above, some critical gaps that need to be emphasised are:

- i. Focus on harvesting yield potential of different varieties and species
- ii. Integrate resilience to various natural calamities like drought, flood, heat stress (early, mid and terminal), cold wave and other probable manifestations of climate change.
- iii. Alternate production systems like organic farming, conservation agriculture etc., which are advocated face the problem of scaling up, because they have not been empirically validated by research & development outcomes as yet.
- iv. In promoting organic farming, develop varieties and technologies that would not compromise the yield potential and various demands of the country in the long run in accordance with the mandate of agriculture. The mandate of the agriculture has to go beyond meeting food security (Read Volume VIII).
- v. R&D has to reorient itself by adopting systems approach and not be circumscribed by crops and commodities. In continuation of this, it has to focus on small & marginal holdings along with large farms.
- vi. One of the weaknesses of NARS has been the neglect of:
 - a) social sciences in agricultural education & research;
 - b) post-harvest management.

- vii. There has not been enough focus on use of agricultural by-products. Apart from R&D support, by-product management also requires policy and institutional support. It may noted that:
 - a) agri-waste management in India is yet not an organised activity; and
 - b) organised waste management will help in creating additional jobs and wealth.
- viii. Sustainable practices should become the core of R&D. Integral to this approach is resource use efficiency. In addition to soil, water is another critical input that deserves due attention of R&D. Use of poor quality water in soil dissolves organic carbon and makes its unavailable to plants. Hence, R&D as also policy approach should become more wholesome in dealing with resource use efficiency and not treated partially as has been the approach.

3.3 Domain Specific Research Gaps – An Examination

In the sections that follow, priority research domains have been discussed and suggestions made in the context of the contours laid down in Section 3.1.

3.3.1 Irrigated ecosystems

India accounts for only about 2.4 per cent of the world's geographical area and 4 per cent of world's renewable water resources, but is destined to support about 17 per cent of the world's human population and 15 per cent of livestock. The net sown area has remained at around 140-141 million ha. (M ha) since 40 years, while the number of farmers over this period has increased from 70 to about 140 million. About 10 million farmers are being added every five years. Hence, the country faces the twin challenges of meeting its water needs and sustaining the desired pace of development. The irrigated area in the country is about 65.7 million ha, which is 47 per cent of the net cultivated area of 141 M. ha; and further only about 26 million ha is under irrigated double cropping. The remaining extent of land (53 per cent of net cultivated area) is rainfed and, is therefore, vulnerable to vagaries of monsoons.

The primary objective should be to enhance the irrigated area under double crop. A better water management for every farm enterprise with its assured source of irrigation lays the foundation for a more secure production system at the farmer's level. At the same time, the production per unit of various inputs, as also investment in irrigated agro-ecosystems, must be optimal. There is a gap in the development of required irrigation infrastructure. Further, per capita availability of water has been steadily declining, from 5177 m³ in 1951 to 1820 m³ in 2001 to 1588 m³ per year in 2010 due to increase in population, rapid industrialization, urbanization, cropping intensity and declining groundwater table. There is gap on the water resources development. Already more than 80 per cent of the available water is marshalled for agriculture – with no further scope for additional allocation. Unfortunately, there is a wide gap between irrigation potential created and its utilization. This gap needs to be bridged through use of potential technologies. These include breeding water use efficient varieties, adopting water use efficient cropping system (crop alignment), water use efficient technologies like micro-irrigation, sensors etc.

3.3.2 Rainfed ecosystems

The farm productivity and resource use efficiency in both irrigated and rainfed systems are declining over the years due to inappropriate water and land management practices, water scarcity, soil degradation, land fragmentation, lack of access to credit and markets etc. Further, the climate change has enhanced the probability of vulnerability of food production in the country. Despite huge investments (approx. 60 billion USD), the area under irrigation has not been increasing at the desired rate. Therefore, future food security largely depends on greater productivity and sustainability of the rainfed systems. Farmers' yields are currently lower by two to five times the potential yields achievable.

Rainfed agriculture suffers from a number of bio-physical and socio-economic constraints, which limit the productivity of crops. There is an urgent need to understand and break the unholy nexus of drought, land degradation and poverty for improving livelihoods at individual farmer's level and food security at national level. This calls for management of natural resources by adopting science-led, holistic and sustainable development approach.

In India, rainfed agriculture constitutes 53 per cent of the net cultivated area (GoI, 2014) and is the hot spot of poverty and malnutrition as it has been bypassed by the desired package of intervention when compared with irrigated areas, that have benefitted from green revolution technology. The researchers and policy makers have now realized the importance of rainfed agriculture to meet the demand for food which would continue to rise with the growing population expected to reach 1.6 billion by 2050, and also to a meliorate the socio-economic status of the farmers. Equally important it is to enhance land productivity of such vast tracts of the country's arable land.

There is vast untapped potential in rainfed areas, and with appropriate soil and water conservation practices higher productivity, on-farm jobs and incomes can be realised. Even in tropical regions, particularly in the sub-humid and humid zones, agricultural yields in commercial rainfed agriculture exceed 5-6 t ha⁻¹. At the same time, the dry sub-humid and semi-arid regions have experienced the lowest yields and the weakest improvements of yield per unit land.

Yield gap analyses carried out for major rainfed crops in semi-arid regions of India have revealed large shortfalls. They are lower than achievable yields by a factor of 2-4 times.

There is variability in the spatio-temporal rainfall in the country. Average rainfall in the country is 1183 mm (75 per cent of it is received in about 100-120 days); 68 per cent of the sown area is subjected to drought in varying degrees; and 21 per cent of the sown area receives rainfall of <750 mm which is located in peninsular India and Rajasthan. Drought-prone areas lie in the country's arid (19.6 per cent), semi-arid (37 per cent) and sub-humid (21 per cent) regions that occupy 77.6 per cent of its total land area of 329 million ha. There is a gap in mitigation strategies to cope up with these variabilities in rainfed ecosystems. Rainfed agriculture is

relatively more risk-prone, linked as it is majorly to monsoons. There exist wide gap in technology & management adoption for risk negotiation at farm level.

There is need for evolution & promotion of appropriate technologies including crop diversification; developing crop genotypes with high and stable yields coupled with abiotic and biotic stress tolerance; location-specific soil and water conservation measures, alternate land use systems and the like. These can be evolved through participatory research approach.

Increasing resource-use efficiency for enhancing system productivity is pivotal for increasing and sustaining the productivity levels in rainfed agriculture. For sustainable livelihoods, current extension system promoting commodity based technologies needs to be reoriented towards system based approach. In order to strengthen such a reoriented extension system, R&D has to primarily reset itself and adopt system (eg. IFS, watershed based etc.) and small & marginal farm based hypotheses and objectives for appropriate outcomes.

3.3.3 Hill agriculture

The hill agriculture displays its own unique characteristics and its potential has remained under-utilised due to various reasons. The unique features include undulating topography, lack of system specific technologies, poor marketing and processing infrastructure and under developed supporting institutions. Gaps exist in harnessing the potential. Agricultural growth can be accelerated through diversification from low to high value crops. Demand for attribute based products that can be produced only in hill ecosystem is rising rapidly, and this can be taken advantage of provided agri-logistics and marketing issues are addressed.

Separate hill agricultural policies need to be formulated. Market driven production and market led extension systems are lacking in the developmental programs of hill states. There exists gap in construction of basic infrastructure coupled with institutional support which would harness farming externalities. Hill areas need expansion and up-scaling of watershed development and programs. Watershed approach would include ridge to valley based treatment of the hilly & undulating topography. Simultaneously, the intervention has to be livelihood-centric, so that all the inhabitants find a stake in watershed treatment and subsequent management. There is need for research relating to introduction of improved and adaptable varieties of crops & breeds of animals; efficient management of soil, water and pests & diseases and increasing the animal production by adopting scientific system; hill topography specific agriculture machinery; increasing the rural income and employment through developing high-value low-volume products, that can be sold at a competitive advantage outside the region. Local opportunities for value creation are also necessary.

3.3.4 Coastal agriculture

Coastal ecosystems are often fragile and can be irreversibly damaged. Scientific and precautionary measures are necessary to avoid possible detrimental effects of agricultural practices on coastal ecosystems. Agricultural plans must address issues of efficient use of land and water, appropriation of new land for agriculture, and the maintenance of the water flows

and stocks and water quality necessary to support coastal ecosystems, as well as the use of agro-chemicals and such other factors. Coastal agriculture has major positive, but also potentially negative effects on the coastal environment. Hence, the system needs sensitive approach to R&D, as also agricultural practice.

Sustainable agricultural policies are, therefore, needed to minimize the negative impacts of inland agriculture on coastal areas. There is gap on the research on environmental threats to coastal areas; understanding the relation between lack of linking on demographic and occupational pressure & sectoral dependence; arresting ecosystem degradation and natural resource loss. There is a need to revamping of agriculture, forestry and fisheries sectors. The gap also exists on integrated coastal area management policy, and its implementation in the country

3.3.5 Crop sector

Gaps exist in harnessing conventional and modern scientific knowledge, tools, and cutting-edge of science for development of improved crop varieties or hybrids suited to diverse agro-ecologies and situations, and efficient, economic, eco-friendly and sustainable crop production and protection technologies; promoting excellence in basic, strategic and anticipatory crop science research. Gap also lies in refinement of seed-production technologies and production of breeder seed with added emphasis on hybrid cultivars.

In the year 2012, it was estimated that by 2016 hybrid rice would cover an acreage of 5 m ha. This has not however been realised. The main factor is the consumers' preferences. Some prefer firm rice, while others like sticky rice. Yield of rice hybrid achieved in India is a maximum of upto 7 t/ha, while according to media reports China has witnessed yield of rice hybrids at around 11t/ha. This can be attributed to the fact, that still 80 per cent of the seed industry depends on narrow genetic pool and lines developed way back in 1980s. The solution for achieving massive hybridisation in rice would lie in new elite germplasm that matches the quality requirements of rice coupled with much higher yield advantage and value added traits.

Maize is another important cereal, that throws up opportunities for enhancing productivity to realise higher production in the country. India needs to produce at least 45 million tonnes of maize by 2030 and 65 million tonnes by 2050. The average productivity of maize in USA is around average 11-12 t/ha while in India it's about 2.6 t/ha. It is more than 5.5. t/ha. in other major maize producing countries like Brazil, China etc. The increase in production should preferably come from increase in the productivity rather than area. The most critical factors to realize this would be enhancement and diversification of germplasm using modern tools and techniques, development of diverse and productive breeds, development and fine-tuning of resource conservation techniques and reduction of cost of cultivation by enhancing resource use efficiency. More than three-fourth of maize cultivation in India is under rainfed conditions. This puts a limit on productivity of the crop. The high yielding cultivars are yet to reach one-third of the farmers. The most productive cultivar type i.e. single cross hybrids (SCHs) are grown on 25-30 per cent of total acreage under maize. It would be necessary to popularise

SCHs and cover the entire maize area for realising higher productivity. The productivity status of Bihar and Tamil Nadu has shown the usefulness of SCHs in realising high production by bringing their major cultivation area under SCHs. Timely availability of improved seed is still an issue. Now, more rigorous efforts are necessary to fulfil this demand.

Another crop which has gained in yield as high as five times is pearl millet over the last five decades. This is however not sufficient. To realise further gain, improved single cross hybrids need to be popularized in pearl millet growing areas. Enhancement and diversification of germplasm using modern tools and techniques is a continuous process, but needs due emphasis.

Hybrid vigour in pigeon pea is still untapped at the level of farmers' field, which needs further attention in terms of research and investments.

There is need for conservation and sustainable use of genetic resources of plants, insects and other invertebrates, and agriculturally important micro-organisms; and also for providing knowledge-intensive advisory and consultancy in crop-science.

Genetically Modified (GM) cotton in India has provided important learnings, both pros and cons, including the use of genetic engineering to mitigate crop specific and location specific problems/challenges in non-food crops. Since use of GM in food crops is an issue under debate, the latest technologies could be assessed and adopted for important non-food crops as of now. Simultaneously, the apprehensions about safety of G.M. based food crops can be addressed and the issue settled at the earliest. It is said, that in the absence of transgenic technology, that the world came to adopt since 1996, several food & non-food crops have benefitted from high productivity and other resistance/tolerance traits; and that in the absence of this technology, the world may have had to find an additional 100 million ha. of cultivable land to meet the increased demand for agri-commodities.

3.3.6 Seed sector

The availability of quality seed is still a major concern in the country. Even though, in case of most of the crops sufficient seed is being produced, through public and private sector (Table 3.1), there are however many concerns. The quality of such seed is highly questionable since it does not pass through quality checking system, as in India certification is not compulsory. As of now, of the total quantity of seeds used, only 35-40 per cent is certified seed, and the balance is mostly farmer saved seeds.

A more robust seed production system, that will increase the ratio of certified seeds is necessary. Even the quantity of farmer saved seeds needs to be taken care of by promoting and closely monitoring the 'Seed Village Programme'. Both Seed Hubs (that produce certified seeds) and Seed Village Programme (that promote farmer saved seeds) need to be supported by new and location-specific seeds, as also seed processing infrastructure. This would help in maintaining the desired levels of quality and standards.

Table 3.1 Seed requirement and availability of major crop groups

Crop group	Seed requirement (Lakh quintals)	Seed availability(Lakh quintals)
Cereals	215.15	235.53
Pulses	30.49	27.24
Oilseeds	59.45	51.39

Low seed replacement rate (SRR): The minimum seed replacement rate to achieve higher productivity is 25 per cent in case of varieties of self-pollinated crops, 35 per cent in case of varieties of cross-pollinated crops and 100 per cent in case of hybrids (National Seed Plan, 2005). The emphasis on seed replacement advocated through various fora and extension activities along with rapid growth of seed industry in India has resulted in reaching the optimum SRR in most of the food crops like wheat, paddy, maize, soybean, mustard, mung bean etc. in a span of one decade (Table 3.2).

Table 3.2 Change in seed replacement rate of major crops at five years interval in India

Year	Wheat *	Paddy *	Maize **	Jowar **	Soybean *	Mustard **	Sunflower **	Mung bean *	Chickpea *
2001	13.04	19.22	20.98	18.36	12.44	38.39	13.73	13.47	4.17
2006	21.76	22.41	43.78	19.37	28.40	60.71	66.92	19.97	9.04
2011	32.55	40.42	56.58	23.85	52.75	78.88	32.47	30.29	19.35

* optimum SRR is 25 per cent; ** optimum SRR is 35 per cent

Table 3.3 List of states where the seed replacement rate of major crops is below optimum

Crop	States	SRR in 2011	Crop	States	SRR in 2011
Paddy*	Rajasthan	7.34	Mung bean*	Karnataka	21.09
	Madhya Pradesh	16.85		Tamil Nadu	21.53
	Jammu & Kashmir	22.41		Rajasthan	18.35
	Orissa	21.65		Madhya Pradesh	21.26
	Uttarakhand	13.23		Uttar Pradesh	20.80
	Jharkhand	17.12		Orissa	2.41
	Sikkim	20.00		Bihar	20.24
	Meghalaya	23.50		Chhattisgarh	3.65
	Nagaland	12.40		Jharkhand	21.21
	Arunachal Pradesh	7.36		Mustard**	Chhattisgarh
Soybean*	Uttarakhand	8.79	Assam		26.18
	Sikkim	6.00	Uttarakhand		19.07
			Jharkhand		20.50

* optimum SRR is 25 per cent; ** optimum SRR is 35 per cent

However, in certain crops viz., chickpea, sunflower, jowar etc. the minimum SRR required for better production and productivity is yet to be achieved. Similarly, in case of the crops where the national average is more than optimum, lot of disparity exists among individual states. For example in crops like paddy, mung bean, mustard etc. where the national average is above the optimum, there are many states that are still lagging behind (Table 3.3).

Low varietal replacement rate (VRR): The release of new varieties at both state level and central level is very encouraging in almost all the crop groups. The new varieties are generally high yielding relative to the existing varieties or are better protected through tolerance or resistance to pests and diseases or have some additional quality attributes. By using these newly released varieties, the cost of production can be reduced with reduced used of pesticides; better quality will fetch better price; or higher yields will help in increased production and productivity. Any of these situations will help the farming community with higher revenue. However, the penetration of new varieties is still far lower than the expectation in most of the crop species. Along with SRR, VRR also needs due attention.

Simultaneously, inclusion of new releases, that are more location-favourable will need to be integrated into the seed chain. R&D efforts will be needed screen large number of releases already made for location-specific recommendations.

Lack of seed grid: At present, there is no seed grid available in the country. The development of seed grid will reduce the problem of quality seed availability at the national level.

Absence of cooperative system of seed production: The cooperative system of production is absent in seed sector. The example of successful milk cooperatives can be initiated in seed production sector also. Farmer Producer Organisation (FPOs) including farmer producer companies (FPCs) and contract farming can also be adopted for scaling up seed production and making available quality seeds to the farmers at low cost.

Designer seeds suitable for abiotic and biotic stresses: Development of situation-specific varieties is the need of the hour. By using various technologies including modern bio-tech tools like Crisper- Cas9 technology and other GM technologies, particularly in case of non-food crops varieties that possess resistance to abiotic and biotic stresses can be designed. In recognition of the larger concerns of bio-safety of GM based food crops, greater emphasis on using untapped genetic diversity through conventional breeding would be an option.

New generation molecules for seed treatment: Seed treatment is an important technology which can be used successfully for various purposes, including enhancement of higher initial vigour, tolerance to pests and diseases, suitability for sowing under abiotic stress situations

Varietal identification through fool proof technology: Use of modern tools for faster detection of varieties in short span is warranted for successful implementation of registered traded seed concept.

Safe seed storage technologies: A series of seed storage chains should be developed under public private partnership for safe storage of seeds to meet the requirement in distress situations

3.3.7 Natural resource management sector

The major concerns in natural resource management are low farm productivity & profitability, land degradation including depleted organic carbon (OC) content in soil, low water productivity, soil health deterioration & low nutrient use efficiency, abiotic stresses including climatic aberrations and loss of tree cover & deterioration in ecosystem services. Gap exists in addressing these issues of updated land resource inventory, characterization & agricultural land use planning; integrated water management & waste water utilization; nutrient and bio-waste management; management of saline, alkaline, acid and waterlogged soils, soil and water conservation, organic farming, climate resilient agriculture and abiotic stress management, agro-forestry management, development of integrated farming systems, arid land management and solar farming, conservation agriculture and resource conservation technologies and nano-technology.

3.3.8 Horticulture sector

There is a need for advanced research and development on horticulture and hi-tech production. The research priorities should be on genetic resource enhancement and its utilization, enhancing the efficiency of production and reducing post-harvest losses.

Research and developmental gaps exist in respect of effective management, resistance to pest and disease and tolerance to abiotic stresses; development of technologies to improve the efficiency of applied inputs; increasing the value of production by reducing variability in yield, quality, reducing crop loss and increasing marketability through development and site specific technologies for different horticultural crops; developing system for productive use of nutrients, water and reducing impact of pest and disease through the use of innovative diagnostic techniques; improved understanding of interaction between native ecosystem and production system and development of best practices to conserve bio-diversity and sustainable use of resources; developing the production system that minimizes the production of wastes and maximizes the re-use of waste; enhancing the shelf life of perishable fruits, vegetables, flowers, product diversification and value addition for better profitability; understand social needs of communities and build the capabilities for practice the change for effective utilization of resources and adoption of technologies and respond to needs including bio-security needs. There should be thrust on secondary agriculture as most of the produce is perishable in nature, which results in great loss if proper care is not taken. Moreover, farmers can fetch more price for their produce once subjected to value addition. Secondary agriculture aims at value addition to both primary products & by-products of the crops. Science should enable maximum value addition of various biological production that the crop generates.

One of the areas, that needs strengthening of both manpower & technology, is breeding programme in horticulture. In case of perennials, that take many years for results, an individual

scientist may not find enough zeal & incentive. Hence, breeding & research in perennials must necessarily be assigned to a 'Group of Scientists', so that continuity is retained, even when some move out for various reasons. Plant breeders from crop science may be brought in, till horticulture builds its own manpower strength & capacity. This is true even in case of seasonal horticulture crops like vegetables, flowers etc.

3.3.9 Animal husbandry and fishery sector

Although this sector has shown significant achievement, there are gaps in research and development on maintenance of indigenous livestock resources, marker-assisted disease resistant breeds etc. Gaps exist in research on livestock/poultry genomics, stem cell research for animal health and production, improvement of reproductive efficiency, fodder and forage research, nutrigenomics, nutraceuticals and functional foods, nutrient utilization & mitigation strategies in methane emission. There is also a need for development and improvement of technologies for value addition, shelf life enhancement and quality assurance of livestock and poultry products.

3.3.10 In conclusion

It can be said, that majority of the research-led interventions have mostly recommend new fertilisers, varieties or agronomic practices but without considering status of resource availability, farmers' specific interests and capacities. Therefore, scientists and development practitioners should adopt 'advice on demand' approach, combined with scientific inputs along with demonstration of new technologies for showcasing the suitability, sustainability and profitability. This should come with capacity or interest in helping famers move towards a more sustainable crop production system that depends less on external inputs.

3.4 Developmental Gaps

After having delineated various domain-specific R&D gaps, it is also important to examine the challenges that lie in making best use of the new science & technology. It is against this backdrop, that the delivery-developmental apparatus necessary for an efficient & sustained growth of agriculture is discussed. These need the attention of science and management at various stages of the agriculture sector.

- In the absence of quality and timely seed availability, most of the farmers use traditional low yielding crop cultivars. For some farmers more than the issue of profit and loss, and resource management, growing of enough food to feed their family and livestock is a greater concern. Thus, it is very important for the researchers, extension and community workers to build rapport with farmers based on trust and mutual respect. However, few farmers still remain cautious about the outcomes and are slow to accept changes, because of several perceived and real uncertainties in farming. Many farmers involved in decision making processes, in spite of their keen interest in using new cultivars and technologies, persist with their own management practices in fear of unforeseen effects. Therefore, researchers and extension agencies have to demonstrate

new crop cultivars and technologies for their efficacy as well as impact and results, for dissemination of their appropriateness and wider impact.

- Despite the renewed interest and investment in agricultural extension in India, both adequacy & quality of extension services do not measure up to the desired level. Public extension programs, extension services of the national agricultural research system, cooperatives, and non-governmental extension programs have a very limited outreach (NSSO 2005). The public extension service is constrained by many factors including inadequacy of finances, human resources, poor infrastructure including roads in rural areas, and poor internet connectivity. As a result, many farmers have not benefited much from public extension services in terms of information relating to new technologies. The results of the NSSO (2005) survey clearly showed that only less than 20 per cent of the farmers are reached by public extension services for performing their agricultural activities. Further, the recent NSSO survey revealed that farmers continue to remain far removed from new technologies and guidance from state run research institutes (NSSO 2013). Over 59 per cent of the farm households received no assistance from either government or private extension services. Of the 40.6 per cent households who have received extension assistance, only 11 per cent of the services came from physical government machinery – extension agents, KVK and agricultural universities. More farmers depended on other progressive farmers (20 per cent), media including radio, television, newspaper (19.6 per cent) and private commercial agents (7.4 per cent).
- Therefore, it is critical to revitalize advisory services, complementing the investments being made in agricultural research. Experience highlights, that the research and extension systems, should be more demand-driven, multi-stakeholder and multi-sectoral in approach. It is necessary to reshape agricultural education by shedding long established traditions of academic isolation, increasing the collaboration between scientists and line departments, and emphasizing on research and extension through innovative teaching. (This aspect has been dealt with in detail in Volume XI on Extension and may be referred to).
- The demand for extension system varies according to the landholding size and a distinction can be made among subsistence farmers, medium farmers with small marketable output, and large farmers with medium and large marketable output in terms of their potential demand for agricultural extension services. As discussed in Volume XI dealing with agricultural extension and technology transfer, there is scope for both public and paid extension services.
- Recent advances in information technology are making it more feasible to provide farmers with the marketing information they need. However, farmers may not benefit from these facilities as most of them are not able to operate these sophisticated tools. Collection of required information is one thing but dissemination in a form accessible to farmers and adopted to their needs is another issue that needs attention. Though farm related information has been provided by the Radio, TV and Newspapers, there was no mechanism to analyse, interpret and convert this vast volume of information into

simple, comprehensible trade intelligence as possible now through compilation of real-time data and subjecting it to big data analytics. This calls for a farmer friendly, easily accessible market intelligence system.

- In rural areas, communication needs and available channels are undergoing positive changes through structural transformations. Subsistence oriented farming remains the basis for food security especially in disadvantaged areas, while there is a general shift of intermediate farmers into market-oriented production. Market-oriented farmers need to stay competitive in an increasingly global business environment. While agriculture remains the mainstay of economy for rural people, information and skills for alternative livelihoods gain in importance, not only as an exit strategy, but also for the increasing division of labour. A facilitative ecosystem needs to be created to transition India's agriculture from subsistence to income-centric enterprise. Science & management practices that can address this change management are need of the hour.
- On the other hand, efforts to close the information gap and, in particular, the digital divide in rural areas, have been supported by the wider availability and accessibility of communication technologies and infrastructures, like internet, rural radio and mobile phones. However, in the absence of scientific and up-to-date information, development agencies have tendency to provide conflicting information which is based on their perception. Therefore, to minimize the damage, agricultural extension agencies including development agencies should be involved while disseminating scientific information and build the capacity of development agencies.
- The existing technology dissemination and input supply system need to be revitalized and fine-tuned to meet the emerging needs of farmers. Special emphasis on seed sector, input use efficiency, financial and insurance institutions and a paradigm shift in technology transfer mechanisms involving both the public and private sector including non-governmental organizations would be critical in achieving the desired goals.
- Agriculture is accompanied by risks associated with climate change. Role of knowledge system and institutional mechanisms for input supply, credit, crop and livestock insurance would, therefore, be important in reducing both risks and uncertainties in order to attain the much needed resilience in Indian agriculture. At the same time, balanced and evidence based use of chemical fertilizers and pesticides, and efficient use of water, energy and other inputs, including timely farm operations with major emphasis on small farm mechanization would help achieve faster growth in agriculture.
- The agricultural growth experience of India since independence was essentially an outcome of the massive efforts aimed at ensuring availability and use of quality seeds, chemical fertilizers, irrigation, pesticides, farm machinery and equipment, agricultural credit, etc. Quality seeds are crucial for enhancing agricultural production. It is estimated that quality seeds contribute to around a quarter of the overall increase in productivity (GoI, 2016). Efficacy of all other agricultural inputs, such as fertilizers, pesticides and irrigation, etc., as well as impact of agro-climatic conditions on the crop, is largely determined by the quality of the seed used. The green revolution of the 1960s-

1970s, the maize productivity and production growth in the 2000s, the cotton production revolution in the 2000s as well as the increased productivity of fruits and vegetables has seed or planting materials as the primary driver of agricultural growth. However, the weak input delivery system including knowledge delivery is a critical challenge in the Indian agriculture system. Availability of improved and quality seeds along with proper agronomic practices can enhance the crop yield by 10-15 per cent (GoI, 2016). Thus, timely availability of quality inputs is essential to ensure increased production.

- Credit is the backbone of Indian agriculture and farmers access credit from both formal and informal sources to meet their requirement. Though formal sources are cost effective, farmers heavily depend on informal sources due to cumbersome procedures as well as limited access to formal sources in rural areas. Further, in the context of pending dues against previous borrowings, the accounts turn NPA (non-performing assets) and the concerned farmer is rendered ineligible. The share of institutional credit in agriculture has reached around 46 per cent, leaving a big gap. In the rural sector, it is the informal sources that dominate the credit space. Of these informal sources, professional moneylenders are the largest provider of informal credit but at high rates of interest, accounting for 64 per cent. Friends and relatives, who usually do not charge interest, provide 24 per cent of informal loans; shopkeepers account for 4.9 per cent of informal loans to the agricultural sector; and the share of employers or landlords providing informal credit to agricultural households is negligible.

Of the formal credit, it is the Banks which are the major source of credit supporting agriculture, and account for 71 per cent of the total formal credit, followed by cooperative societies (25.4 per cent) and government sources (3.6 per cent).

- It is important to expand the reach of formal credit sources in rural areas majorly to reduce the dependency on informal sector, as they charge high interest rate. This can be done by establishing formal sources at rural areas and reducing procedural complexities. Simultaneously, it may not be totally infradig to examine whether private channels of loan can also be tapped by institutionalising the system and regulating them. It is more important, that farmers find access to timely credit.
- As results of participatory demonstrations that serve as local proofs hold high value in convincing the farmers, larger number of frontline demonstrations using new crop cultivars and methods need to be conducted. Results obtained at the experimental stations alone often fail to attract the attention of farmers. Farmers have more confidence in what extension workers teach if they are convinced that their recommendations are practical and are based on local demonstrations. This is specially so in persuading the less informed and most sceptical families. The results obtained from the local demonstrations provide the basic information required to be used by extension workers. The individual farmer on whose field, the 'result demonstration' is conducted is the first person to learn about the new practice and become his own teacher and also a model teacher for others. Extension workers can use this outcome and disseminate the technology/practice among other farmers with greater confidence.

- One of the main reason for the existing large yield gaps between what the farmers harvest on their farm and the researchers realise on pilot site, is largely the knowledge gap between what to do and how to do it, apart from inability to procure the needed inputs as per recommendations. In spite of a number of new/improved technologies, large number of farmers continue to do their farming business in a traditional manner. The reasons are multifarious, as the current knowledge delivery system mainly driven by public extension system has become weaker, and is not equipped to deal with agriculture along its full complement of a value chain linked activities. Similarly, while scientists are discovering new technologies for increasing the productivity and farmers' income, they find themselves challenged in scaling up the adoption of such technologies for larger impact. For example, climate resilient improved groundnut varieties (K6, K9, TAG, ICGV 91114, ICGV 0350, ICGV0351, etc) have been released by national and international level advanced research institutes and universities to affect production increases. However, the area under these varieties has not increased, and old variety such as TMV2 continues to rule in major groundnut growing areas, such as Anantapur in Andhra Pradesh.
- Marketing is one of the major concerns, that should be addressed. An efficient market structure that helps in competitive price discovery and ensures larger share for the producer in the consumer's rupee is important. Equally critical in harvesting the efficiency of a market system is the existence of a robust agri-logistics infrastructure. This supported by R & D interventions will help in minimising food loss, and result in higher value capture for the farmer.

3.5 Annotation

Green Revolution propelled by science & technology-led high yielding varieties and supported by inputs and price support, ushered in food security for the country. India has also become export-capable in certain commodities. However, a critical examination of GR brings to surface certain shortcomings, as manifest in its benefits reaching a limited number of cereals and irrigated cultivation environments. Further, the technology being resource intensive, it has caused soil degradation & depletion of water table in particular. The current challenges include achieving yield breakthrough, cost reduction and marketability for higher returns on produce. Also, the need of the hour is to impart the technology a more secular (i.e., covering all sub-sectors including horticulture, animal husbandry and fishery) and universal (i.e., all geographies and agro-climatic situations) character, so as to benefit all farmers, and achieve a more robust and income generating agricultural production for the country.

The next phase of transformation through Green Revolution-II has to be not only more comprehensive, but also income-centric in contrast to production-centric GR-I. It would, therefore, be more appropriate to use the nomenclature, 'Farmers' Income Revolution', as it captures all the nuances along the agricultural value system.

In rolling out this new paradigm shift, the multiple agri-systems that exist in the country, namely, irrigated, rainfed, hill and coastal need to be given appropriate attention. Further, within each of these systems, various production systems, including crops, seed, natural resource management, horticulture and animal husbandry will need to be the centre-piece of R&D activities. The new revolution around farm incomes, will have to ride on new science & technology.

Further, to harness the full potential of the R&D outputs, the succeeding apparatus comprising the developmental & delivery system has to be put in place.

This chapter examines the gaps that exist in respect of the above mentioned specific macro- and micro-level domains and indicates the nature of research & development initiatives called for.

Key Extracts

- It is necessary to build on the success of Green Revolution-I and adopt a more comprehensive and wholesome transformation of agriculture.
- Similar to the role that R&D played in Green Revolution-I (1965-80), Green Revolution-II, more appropriately to be called as 'Income Revolution' should also ride on the back of science & technology.
- There is a specific need to assess the constraints and potential of irrigated, rainfed, hill and coastal agriculture; and deploy R&D outcomes for solutions.
- Efficacy of all other agricultural inputs, such as fertilizers, pesticides and irrigation, etc., as well as impact of agro-climatic conditions on the crop, is largely determined by the quality of the seed used. So, there is need to further strengthen the seed sector in partnership with private players for sufficient, high quality and timely supply of seeds at reasonable price.
- Research in horticulture should prioritise on improving genetic resource, higher productivity and reduction of food loss.
- In case of livestock sector, research gaps relate to animal health, reproductive efficiency, fodder & forage, mitigation of methane emission and productivity.

Chapter 4

Science-led Future Research and Technology Development

Research and Development in agriculture needs to be supported through higher public sector allocations and facilitation of private sector participation. There are several challenges relating to yield improvement, resource use efficiency, negotiation of biotic and abiotic stresses, and market-friendliness. Science and Technology can help find answers to both short term and long term needs and challenges in the context of climate change and income aspirations of the farming community.

4.1 Background Information

Indian Agriculture is confronted with critical issues characterised by low per capita water availability, land degradation, low response to inputs, climate change, stagnating/lower agricultural productivity and less than remunerative prices on farmers' produce. In addition, there exist structural challenges emanating from high density of agriculture dependent population, small & fragmented holdings and inflation management approach impacting agriculture produce monetisation and terms of trade that are not always favourable to the farmers. All these need to be addressed appropriately to improve productivity, income and welfare of the farmers. Low average productivity at national level and large variations at regional level are a concern, as low productivity translates into higher cost of production per unit of output. This is further compounded by inadequacy of agri-logistics (storage etc), inefficient market structure, absence of warehouse based post-harvest storage & institutional credit and non-existence of organised agri-supply chains. Above all, agrarian distress also comes from frequent occurrence of natural disasters such as droughts, floods, cyclones, storms, etc. In case of most farmers who lead subsistence existence, such disasters can cause extreme distress and hardship.

Under such circumstances, one needs to adopt a new approach that ensures high returns and sustainability. It calls for a paradigm shift in agriculture that draws sustenance primarily from the principles of production ecology to achieve improved productivity and efficiency of agriculture while reducing negative environmental impacts. While modern agriculture has used chemical inputs to achieve an optimized uniformity in many areas, future agriculture can benefit from agro-ecological intensification based on optimized complexity. Strengthening the consortium of public-private institutions and development agencies with the state institutions is a challenging task, as it calls for changing the mind-set. Therefore, future R&D approach should be such as to address the following:

- More yield per acre
- More crop per drop/per litre of water
- More crop per unit of inputs (fertilizer, pesticides etc.)
- Fighting abiotic and biotic stress through seed and biotechnology
- Reducing the environmental and safety impacts of crop protection chemicals and fertilizers & improving fertilizer use efficiency

- Digitization of soil nutrition maps & precision in fertilizer application
- Miniaturization of farm machines – reducing labour requirement and drudgery
- Data capture from field using sensors, weather gauge stations and satellite technologies for weather forecast.
- Farm advisory service using ICT
- Demand & Price forecasts well ahead of sowing and plantation season
- Market reforms through electronic platforms; market competitiveness; value chain.

More importantly, R & D has to focus on regions/areas and farmers therein who have been bypassed largely by green revolution technology. The large swathes of India's rainfed agricultural systems including the hilly tracts, now deserve to become the core of research and technology innovations.

4.2 Investments on R and D

Agriculture has made significant strides following the technological advancements initiated during the sixties and the seventies of the last century. The transformation of India from food deficiency to self-sufficiency and from a net importer to a net exporter of agricultural commodities is a matter of great pride. In fact, the outcomes have been incredible, as the country now (2017-18) boasts of producing about 276 million tonnes (mMt) of foodgrains, 300 mMt of horticultural crops, 164 mMt of milk, and 11 mMt of fish. Unequivocally, the budgetary outlays allocated towards the development of scientific infrastructure and human resources in the past have paid rich dividends. However, a deceleration in the rate of productivity growth experienced from the last decade (2000s), along with technology fatigue, will soon jeopardise such gains unless the country make adequate investments in Agri-R&D, and also the approach is reoriented to meet the new challenges.

The allocations to the National Agricultural Research System (NARS) under the aegis of the Indian Council of Agricultural Research (ICAR), State Agricultural Universities (SAUs), and other organisations have largely been constricted. India spent Rs 6,238 crore on Agri-R&D in 2016-17, which is even less than 0.5 per cent of the total income earned from agriculture and allied activities, ie gross domestic product. The expenditure on Agri-R&D in India has been hovering around 0.3-0.4 per cent of Agri-GDP since 2001, except in 2011 when it registered 0.52 per cent share because of higher plan allocations of the Union government. The allocations are minuscule in most of the poorer states situated in the eastern region of the country. The amount spent on Agri-R&D is substantively lower in comparison to many developed countries, and also when seen vis-a-vis comparable developing economies. The share of Agri-GDP is much higher in Brazil (1.8 per cent), Mexico (1.05 per cent), Malaysia (0.99 per cent) & China (0.62 per cent); and in the high income countries it stands at 3.01 per cent. Another worrisome trend in India is, that more than 90 per cent of the allocated amount is spent on salaries and day-to-day expenditures in the ICAR, agricultural universities and research organisations,

leaving little for capital investment. A gross under-investment calls for serious attention to upgrading infrastructure – buildings, laboratories, research fields, access to global best practices.

The contributions of the NARS towards an increase in exports in recent years deserve special mention. India is exporting basmati rice to the tune of Rs 25,000 crore, as also pomegranate worth Rs 490 crore, grapes valued at Rs 1,780 crore, and banana at Rs 390 crore. Most of these exports are attributed to the efforts of the NARS. A single variety of basmati rice (Pusa 1121) released by the ICAR is generating Rs 15,000 crore of export value annually studies also shows that public spending on Agri-R&D in India is much more effective in accelerating growth and lessening poverty, compared to other economic and social expenditures. The returns on investments in Agri-R&D are high at 33 per cent. Even at the disaggregated state level, there exists visible evidence to show much higher payoffs from additional investment in research, especially in the low-income agriculturally dominant states.

Considering the evidence of high dividends from Agri-R&D, the funds allocated in the budget should rise. Investment in Agri-R&D is crucial to support increase in farmers' income and overcome agrarian challenges. In the long run, sustained increases in income will warrant full support of R & D. Knowing that private investment in research is minuscule and is mostly in-house expenditure by the seed companies, making available increased public resources to ICAR and SAUs is critical to raise capital intensity, technological upgradation and its transfer to the fields. The Committee on Doubling Farmers' Income, recommends stepping up of public investment in agriculture by an additional amount of nearly Rs 240 billion by 2022-23 at 2015-16 base (Volume II). As percentage of income from agriculture and livestock activities, the investment should increase from the current 1 per cent to 2.3 per cent over the targetted seven years of DFI period. It goes without saying, that the research activity must get its due share of this increase on a sustainable basis. The government in its annual budgets can shift the composition of expenditures across various economic activities by allocating a larger proportion of additional revenues for investment in Agri-R&D. **Concerted efforts should be made to raise expenditure on agricultural research up to 1 per cent of Agri-GDP. Importantly, higher investments in research should be supplemented with extension services and institutional reforms to enable wider dissemination of research outcomes to the farmers.**

In the following sections, the needed research for spewing out appropriate technologies both in the short term and long term is discussed and suitable recommendations made.

4.3 Short-term Research

4.3.1 Crop Research

Search for new genes: Climate change is no more a myth but now a reality. To combat climate related challenges, there should be continuous and constant attempt to search for new genes. These genes may either be mobilized from related wild species or through mutations, which

aims to be “reservoir of genes in need”. This should be mandatory for all important crops which are being affected by climate change. Pre-breeding for such crops should be mandatory for every research institutions.

Research on crop phenotyping: The era of post-genomics has been ushered in with vast knowledge about the genome sequences of various crop species during recent years. It has increasingly become easier and cheaper to sequence and map genomes, giving scientists access to information. Nevertheless, carrying this vast information to practical field applicability has remained a bottleneck especially for evolving multiple stress tolerant crops.

State-of-the-art phenotyping platform with automated non-destructive imaging based scan analysis of crop growth and development need to develop to speed up breeding for drought and other abiotic stresses. Different traits need to be combined in various selection indices to assist breeders to produce desired phenotype for the specific agro- climatic conditions.

Molecular biology and bio-informatics: A situation of multiple abiotic stresses is a key challenge for the rainfed cropping system in future. It is probable that, in the same season, crops can face drought in early part and water logging in the later mainly due to erratic and uneven distribution of rainfall. Heat stress is another factor which could influence crop yields particularly during rabi season. Molecular techniques offer hope to evolve crops tolerant to multiple abiotic stresses. Novel genes, promoters, transcription factors and alleles for traits that confer tolerance to abiotic stress need to be studied & identified.

Future smart foods as health foods: Water scarcity, land degradation and climate change have come to trouble Indian agriculture. These need to be addressed for a more sustainable crop production and ensure the benefit and balance of both farmers and the environment. Promoting climate resilient crops could be an answer to the country's agrarian distress. Crops such as millets and legumes are highly drought resilient while also being highly nutritious, which will help combat malnutrition among children and the most vulnerable in society.

Food-based nutrition is the most important way to fight hidden hunger, under-nutrition and mal-nourishment, particularly when nearly half of the population (about 600 million people) spends more than 50 per cent of the income on food. The ratio of poverty is relatively higher in rural areas. Among the land holding class the poverty is higher among small & marginal farmers. Further, majority of the rural resource- poor are concentrated in rainfed areas. Under such settings of arid and semi-arid regions receiving low to scanty rainfall (200-600 mm), the cereals that can be grown profitably are millets which can withstand drought like conditions and are more climate-resilient. Moreover, millets are nutritionally superior to the commonly consumed cereals, especially in respect of micro-nutrient content. Along with millets, livestock and dairy activities are well suited to rainfed arid and semi-arid areas, and the two commodities (crops-livestock) are highly complementary in socio-economic and ecological terms. For instance, pearl millet in rainfed areas provides the main source of nutritious staple foodgrain,

high-energy feed grain (for milch and draft animals, as well as for poultry, fish, and other mono-gastric livestock), and green and dry fodder for ruminant livestock.

So far, the investment in Indian agriculture has majorly been on cereal crops like rice, maize and wheat. Focussed attention on R & D relating to these (3) three crops, more particularly, rice & wheat since the 1960s, has resulted in seeds capable of high yields, conditional upon intensive use of inputs. Concomitantly, the associated inputs too have benefited from subsidies as an incentive, apart from that on MSP based procurement, further integrated into PDS. Without saying, that other crops & other sub-sectors of agriculture have not benefited from R & D, it can at the least be said, that rainfed system should have got greater focus. A positive amendment in favour of rainfed systems brooks no delay.

However, with increasing income and changing food habit, food consumption pattern is shifting from major cereals to millets and pulses, as also animal based proteins. Given the economic condition of majority of the population, there is greater opportunity for popularizing nutrition rich crops such as sorghum, pearl millet and finger millet along with other minor millets. This is where the concept of Smart Food assumes importance. Smart Food is defined as food that is good for people (highly nutritious), good for the farmer (climate resilient) and good for the planet (eco-friendly). To mainstream these smart foods constant efforts, policy back up, and incentive mechanisms are essential. Achieving this will be what is needed to make a major impact on food security and some of the biggest global issues in unison such as malnutrition, poverty, and environmental issues. Also, the incomes of the farmers in rainfed areas will increase.

However, a major challenge with these foods is the absence of appreciation of their nutritive value and lack of development of the value added chain. Millets which were the traditional crops across many parts of the country have over the last one-two decades suffered less preference. There has been less investment in these crops. Thus, there is an urgent need to develop value based chain from the seed system through to modern convenience products. There is also need for greater emphasis on millet & pulse related R&D, for higher productivity and resilience against biotic and abiotic stresses. In the recent years, there has been some effort in this direction and a positive response is already visible.

4.3.2 Seed research

Strengthening of quality assurance system for seeds: The availability of quality seed is to be assured through compulsory certification. For this, private certification agencies with qualified seed technologists also need to be promoted. This will not only assure the supply of quality seed but also generate employment for the well qualified youth. All the varieties may be registered for value for cultivation and use (VCU) and only the varieties specified for the state/local agro-climatic zone should be allowed to be traded in the region.

Strategies for enhancing SRR and VRR: The seed replacement rate (SRR) can be enhanced only by providing sufficient quantities of quality seed through both public and private sectors.

Special emphasis either through subsidies or direct benefits on crops and in states, where the SRR is low be implemented. The lack of awareness among the farmers about the new varieties, which are better than the existing varieties, is one of the reasons for low VRR and resultant low yield and higher vulnerability to biotic & abiotic stresses. Further, lack of large scale demonstrations of new varieties and absence of market segmentation in case of public sector varieties of major food crops are some other issues that need to be addressed. The denotification of old varieties particularly where new replacement varieties are available should be taken up more vigorously, coupled with massive field demonstrations by the extension departments in collaboration with breeders for the spread of newly bred varieties among farming community.

Development of seed grid and e-marketing systems: The development of seed grid will reduce the problem of quality seed availability at the national level. The seed grid should be a dynamic online system where the real time for seed indenting can commence. Similar to e-marketing systems, the nodal agencies can be in contact with seed producers and supply is made through online indenting. This model can be extended to grain market and it also reduces the intermediaries in the agriculture sector, benefiting both the farmer and consumer in sequel.

Public-private partnership in seed and grain storage chains: Seed storage is one of the crucial components at both farmer level as well as at corporate level for the supply of quality seeds in the next season. The cold storage facilities if available at nominal costs will help the producers and suppliers to store sufficient quantities for future use, thereby reducing the chances of using poor quality seeds particularly during calamities like drought, floods, crop failures. The same concept can be extended to grain storage also where farmers can store their produce and distress sale can be avoided. This will directly help in realizing better revenue to the farming community. The infrastructure development of cold storage chains can be taken up through public and private partnership where operation of those godowns shall be managed by public sector organizations and construction and maintenance by private sector on cost basis.

Encouragement to cooperative systems in input management: The success of milk cooperatives can be simulated for development of seed production cooperatives, where societies can be formed with farmer groups involved in seed production. Seed production is a very profitable enterprise and already many farmers are involved in such ventures through MOUs with National Seeds Corporation, State Seed Corporations and private firms. The development of cooperatives will not only empower farmers with better bargaining capacity but also provide quality seed to their fellow farmers at reduced cost. The agriculture department can adopt these cooperatives for providing technical guidance, which helps in successful implementation of this idea. The spirit of cooperatives can be enlarged by promoting other forms of farmers-mobilisations like farmer producer organisations (FPOs), contract farming etc.

4.3.3 Research for natural resources management

Despite considerable progress in irrigation development in post-independent India, 85 per cent of nutri-cereals, 83 per cent of pulses, 42 per cent of rice, 70 per cent of oilseeds and 65 per cent of cotton area still remain under rainfed system. Therefore, public and private investments in R&D for generation of suitable climate-resilient technology and emphasis on transfer of such technology and upgradation of concomitant manpower & infrastructure needs are important.

Design of water harvesting structure: For effectiveness of rainwater harvesting, research emphasis should be on:

- Appropriate designs for different rainfall zones and soil types.
- Optimum size of farm pond, given the catchment area available under different farming situations.
- Reduction of capital cost of farm ponds through convergence of other on-farm developmental programmes.
- Innovations in checking evaporative losses, cost effective sealants, water lifting devices for conveyance.
- Best options available in terms of crop choices to realize the best returns from stored water.
- Resolution of the issue of sharing water in case of small holders where catchment and command area belong to different farmers. Calls for adoption of Water Users Associations (WUAs).
- On-site and off-site benefits including environmental pay-offs due to rain water-harvesting.
- Potential of water harvesting through farm ponds in adaptation and mitigation of climate change; water-harvesting in drought affected areas needs to be designed and up-scaled in the form of field bunding, dug-out ponds, recharging ponds, diversion weirs and other water harvesting & conservation structures.

Design of integrated farming system (IFS) model: IFS is a viable option to achieve food and nutritional security at household level and even at individual level. Such land use system could provide round the year employment to the farming family. Integrated farming system models in irrigated and rain-fed ecosystems incorporating location-specific climate-resilient features must be scaled up in order to achieve food and nutritional security, and also to mitigate adverse climate change impacts. Suitable farming systems by integrating crop-livestock-fishery with duck, vermi-composting, bee keeping, mushroom cultivation, and field and horticulture based crops is an optimal approach to harvesting the strengths of different farm and locally available resources, besides de-risking the highly vulnerable profession of agriculture.

In the context of income approach to farming, it must be noted that IFS leads to fragmented system of production over already fragmented cultivation areas, challenging the need for efficiency in marketing. The solution to this lies in promoting IFS in clusters, and building an insituational system for aggregating diverse products arising in small lots over such a cluster.

Drought mitigation: Crop diversification (including horticulture and plantation crops) with low water requiring crops and with in-situ rainwater conservation could minimize the risk of drought. About 11.6 M ha (million hectares) of land is mono-cropped with rice, and remains fallow after harvest. A second crop of oilseeds, pulses, vegetables, millets and fodder crops can be raised through effective utilization of residual moisture and appropriate rainwater management/conservation technologies in rice fallow areas. Large scale demonstration of scientific 'rice-fish cultivation' is also possible. Further, fish hatchery should be given due consideration (as a commercial venture for supply of fish seed) so that the appropriate fish seed can be available at farmers' door steps.

In about 3 to 5 million ha of the vast rice-wheat based cropping systems, and other crop fallows of Ind-Gangeic Plains, depending on soil moisture and water availability, introduction of short duration pulse crop, viz.mungbean (green gram) or urdbean (black gram) or cowpea or horse gram would help. In addition, adoption of conservation agriculture techniques is the need of the hour for enriching nitrogen and carbon in soils, encouraging protein nutrition and triggering income growth.

Table 4.1 Potential area available in different districts for cultivation of pulses in rice fallows.

State	Potential area (m ha)	Districts
Chhattisgarh	0.88	Bilaspur, Dhamtari, Kanker, Jashpur, Raipur, Durg, Rajgarh, Kabirdham, Korba, Mahasamud and Rananadgaon
Madhya Pradesh	0.53	Annupur, Chhatarpur, Damoh, Dindori, Raisen, Jabalpur, Katni, Jhabua, Rewa, Satna, Shahdol, Seoni, Mandla, Narsingpur and Umeria
Odisha	0.37	Baleswar, Dhenkanal, Sundergarh, Mayurbhanj, Kalahandi, Bolangir, Kheonjar, Puri and Cuttack
West Bengal	0.52	Bankura, Purulia, Medinapur, West Dinajpur, Malda, Jalpaiguri, Bardhaman and Birbhum
Assam	0.16	Marigaon, Naogaon, Lakhimpur, Kokrajhar, Bongaigaon, Nalbari, Kamrup, Barpeta, Darrang, Cachar, Goalaghat, Jorhat, Dibrugarh, Tinsukia and Sonitpur

Consistent with the overall national mandate of food security and farmers' income, diversification from rice-wheat system to pulse/oilseed-wheat crop system may turn out to be more sustainable without sacrificing farmers' income. Short duration (120-125 days) pigeonpea genotypes, now available, can fit in a pigeonpea-wheat cropping pattern with

economic returns analogous to those from the prevalent rice-wheat system, plus offering the farmer a huge bonus in terms of soil fertility, reduced water consumption, and enhanced human nutrition.

Micro-irrigation: The water resources potential of India which occurs as a natural runoff in the rivers is estimated at about 186.9 Million hectare metres (M ha-m). Considering the uneven distribution of water resource over space and time, about 112.2 M ha-m of the total potential can be put to beneficial use, 69 M ha-m through surface water resources and 43.2 M ha-m by groundwater (Kumar and Kar, 2013). India experiences high degree of spatial variability of annual rainfall. Highest annual rainfall of 11,690 mm is recorded at Mousinram, Meghalaya, and lowest of 150 mm at Jaisalmer of Rajasthan. An average of 75 per cent of precipitation of the country occurs during southwest monsoon season (June to September) only. The country's vast extent of cultivated area (82 M ha) is still rainfed. For adequate living standards as in western and industrialized countries, a renewable water supply of at least 2000 m³ per person per year is necessary. As against this, the per capita per annum water availability in India now stands at less than 1500 m³. This is expected to go down further with increasing population.

If only 1,000-2,000 m³ per person per year is available, the country is 'water stressed', when the value comes below 500 m³ per person per year, the country is called 'water scarce' (Kumar and Kar, 2013). With rapid population growth and rising expectation of better life, there will be ever increasing demand of water for various competing sectors like domestic, industrial and agricultural needs. Also more and more water will be required for environmental concerns such as aquatic life, wildlife refuges and recreation.

With changing global climatic patterns coupled with declining per capita availability of surface and ground water resources, sustainable water management in agriculture is turning out to be a great challenge in India. Therefore, the available utilizable water resources would be inadequate to meet the future water needs of all sectors unless the utilizable quantity is increased by all possible means and water is used efficiently.

The crop yield and water use efficiency under conventional flood method of irrigation, which is predominantly practised in Indian agriculture, are very low due to substantial conveyance and distribution losses. Pressurized irrigation system is a well-established efficient method in saving water and increasing water use efficiency and crop yield as compared to the conventional surface method of irrigation, where use efficiency is only about 35-40 per cent.

The area under micro-irrigation is on the rise. The pace of coverage needs to be, however, strengthened. The micro-irrigation system has brought focused attention on water soluble fertilizers (WSFs). Some of the WSFs marketed in India are : Potassium nitrate (13:0:45), Mono potassium phosphate (0:52:34), Potassium sulphate (0-0-50), NPK fertilizer (13:40:13); (18:18:18 +2MgO+TE); (6:12:36); (19:19:19), Urea phosphate (17:44:0), Mono ammonium phosphate (12:61:0). Manufacturing and use of liquid fertilizers can save considerable energy spent on solidifying the fertile.

Rainwater use efficiency: Water is a scarce resource and a key determinant of poverty and hunger in rural areas. Hence, improving rainwater use efficiency (RWUE) is important for achieving food security and better livelihoods. Soil test-based balanced fertilizer use is found to produce more food with less water and significantly increased rainwater use efficiency in crops by channelizing unproductive evaporation loss into productive transpiration (Chander et al. 2014a). In Rajasthan, the RWUE of existing farmers' cultivars with applied N and P in maize varied between 3.36 and 7.39 mg kg⁻¹ ha⁻¹ (Chander et al. 2013b). The introduction of improved cultivar in on-farm trials in target districts increased it from 5.43 to 10.8 mg kg⁻¹ ha⁻¹, and thereby proved the ability of improved cultivars to best utilize the limiting water resources. The integrated approach involving soil-test-based addition of fertilizers including micronutrients to improved cultivar, however, recorded the maximum RWUE (8.20 to 16.2 mg kg⁻¹ ha⁻¹) (Chander et al. 2013b). Therefore, integrated soil and crop management involving improved crop cultivars and soil fertility management, with a purpose to increase proportion of water balance as productive transpiration is one of the most important rainwater-management strategies to improve yields and water productivity (Rockstrom et al. 2010).

Sustainable intensification in food systems: Inter-cropping or mixed cropping systems are more resilient compared to mono-cropping system in rainfed areas due to efficient and better utilization of resources such as green water, soil and nutrients. These systems are also stable under adverse weather and pest/disease situations. Land smoothing and forming field drains are basic components of land and water management for conservation and safe removal of excess water in a guided manner. Broad bed and furrow (BBF) system is an improved *in-situ* soil and moisture conservation and drainage technology for clayey soils with low infiltration rate, as soil profile gets saturated and waterlogged with the progression of rainy season.

Field-scale intervention of improved management comprises sowing of crops on graded broad bed and furrow (BBF) of 45 cm practice for *in-situ* soil and water conservation, and safe disposal of excess runoff during heavy downpour. This improved management significantly increased soil porosity, infiltration rate and carbon content compared to traditionally managed fields. Such changes in bio-physical properties also led to change in hydrological cycle, as runoff was reduced in BBF fields and stored more rainfall into green water form. Significant amount of total rainfall is used in productive transpiration therefore crop yield in BBF fields were found consistently higher than 4.5 t ha⁻¹, irrespective to several deficit and surplus water years. On the other hand average crop yield in traditionally managed field was found as 0.9 t ha⁻¹. Average crop water productivity of BBF fields was found 0.65 Kg m⁻³ compare to 0.15 Kg m⁻³ in traditionally managed field.

Taking advantage of the sufficiently available soil moisture post the harvesting of rice crop, during the winter season in the eastern India, growing of early maturing chick pea in rice-fallow areas with best-bet management practices provide opportunity for intensification. An economic analysis has shown, that growing legumes in rice fallows is profitable for the farmers with a B: C ratio exceeding 3.0 for many legumes. In addition, utilizing rice-fallows for growing legumes

could result in the generation of 584 million person-days employment for South Asia and make the country self-sufficient in pulses production.

Conservation agriculture and zero tillage: Conservation Agriculture (CA) designed on the principle of providing continuous soil cover (by using crop residues, cover crops, agro-forestry etc.), minimum soil disturbance and crop rotations bears a high potential of sustaining Indian agriculture by increasing productivity, while protecting natural resources and environment, that are already under stress.

Under the present scenario of global warming due to emissions of Green House Gases (GHGs) from land use change, and the available scope for carbon trading in India adoption of conservation agriculture becomes imperative. The potential of carbon (C) sequestration in C depleted soils of India is high with adoption of conservation tillage. Thus, the future perspectives include the evaluation of conservation tillage practices affecting savings on water, nutrients, energy and time for raising the productivity off-farms. Studies on water, nutrient and tillage interactions are desired for improving input use efficiency. There is also a need to look for strategies for zero tillage in dryland farming situations.

Management of acid soils: Nearly 25 million hectares of cultivated lands with pH less than 5.5 are critically degraded. The productivity of these soils is very low (one tonne/ha) due to deficiencies of P, Ca, Mg, Mo and B and toxicities of Al and Fe. Liming and nutrient management technologies have been developed to ameliorate acid soils and increase their productivity. But economics of liming is questionable because of high lime requirement in case of most of the acid soils of India, further compounded by the effect of liming not persisting for long. Therefore, the liming effect of other low cost materials such as paper mill sludge, press-mud, household wastes-ash and limestone has to be taken advantage of as an alternative.

Enhancing nutrient use efficiency: The country has now realized the absolute necessity of integrated plant nutrient management systems involving a sensible blend of chemical fertilizers along with composts, vermi-composts, green manures, bio-fertilizers, non toxic organic wastes, bio-pesticides, etc. These are now almost universally advocated along with recommendations on judicious use of irrigation water. Research is needed on management of soil biota, bio-fertilizer, PSM, VAM, earthworms etc. for the enhancement of nutrient supply, solubilization developing efficient techniques for inoculation and composting; transformation and turnover of microbial biomass and biomass nutrients; recycling of organic wastes and organic matter dynamics. R &D with time bound solutions

Over the years, farmers have increased their reliance on chemical fertilizers and have abandoned or reduced the use of organic manure drastically. Long-term experiments have clearly demonstrated increased sustainability of systems with Integrated Nutrient Management (INM) strategies, that encompasses harnessing of biological sources and using legumes in crop rotation, organic manure, and soil test-based inorganic fertilizers for different crops. Incentives are required to promote the use of organic manure/fertilizers as well as biological sources like

bio-fertilizer in order to encourage farmers to adopt integrated nutrient management approach. These recommendations need to be tethered to the soil test results. This presents a major challenge as the nutrient content of organic manures and fertilizers are highly variable.

There is an urgent need to examine & adopt policies and innovative institutional arrangements for ensuring quality supply of bio-fertilizers and organic manure to the farmers by recycling organic wastes generated both in urban and rural areas. Mechanisms should be developed for recycling the organic wastes through aerobic-compost, vermi-composting or other methods so that the farmers can use the recycled organic matter for crop production. Moreover, micro-irrigation systems can be effectively used for the regulated supply of essential plant nutrients through fertigation and addition of micro nutrients and secondary nutrients based on soil tests.

Residue management and promoting conservation agriculture: Indian agriculture produces about 500-550 million metric tonnes (mMt) of crop residues annually. These crop residues are used as animal feed, soil mulch, manure, thatching for rural homes and fuel for domestic and industrial purposes and thus are of substantive value to farmers. However, a large portion of these crop residues, about 90-140 mMt annually, is burnt on-farm primarily to clear the fields to facilitate planting of succeeding crops.

The problem of on-farm burning of crop residues has intensified in recent years due to use of combines for harvesting and high cost of labours in removing the crop residues by conventional methods. The residues of rice, wheat, cotton, maize, millets, sugarcane, jute, rapeseed-mustard and groundnut crops are typically burnt on-farm across the country. This problem is severe in irrigated agriculture, particularly in northwest India where the rice-wheat system is mechanized. Burning of crop residues leads to plethora of problems such as release of soot particles and smoke causing human health problems; emission of greenhouse gases such as carbon dioxide, methane and nitrous oxide adding to global warming; loss of plant nutrients such as N, P, K and S; adverse impacts on soil properties and wastage of valuable crop residues.

Developing crop varieties to improve palatability and digestibility of the crop residues for improved livestock production: Alternate uses of crop residues need to be optimized. Based on the analysis of benefit: cost ratio, socio-economic and technical feasibility of on-farm and off-farm uses, crop residues having competing demands for fodder, fuel, etc should find channelization into conservation agriculture along with other end products like dung, slurry, ash etc. There are several options such as animal feed, composting, energy generation, bio-fuel production and recycling in soil to manage the residues in a productive and profitable manner. Use of crop residues as soil organic amendment in the system of agriculture is a viable and valuable option.

Fortified fertilizers: About 48.5 per cent of Indian soils are deficient in various micro-nutrients, namely, zinc (Zn) (it is expected to aggravate to 65 per cent by 2025); 33 per cent are deficient in boron (B); and 12 per cent are deficient in iron (Fe). Zn deficiency is reported to be the highest (40-86 per cent samples found deficient in available Zn) in Haryana, Punjab,

Uttar Pradesh, Bihar, Odisha, Madhya Pradesh, Andhra Pradesh, Karnataka and Tamil Nadu, followed by Assam and West Bengal (30-40 per cent soil samples deficient in available Zn). Further, most boron (B) deficient soils (32-65 per cent Deficient Soil Sample) are in Bihar, West Bengal and Karnataka. Of all the micro-nutrients, Zn is most widely deficient in Indian soils and crop response to Zn has been reported for almost all crops. Cereals, especially rice responds well to Zn fertilization on almost all kinds of soils.

The deficiency of secondary and micro-nutrients can thus be overcome by fortification of the presently manufactured N/P/NP/NPK fertilisers to develop value-added/fortified fertilizers.). Some of the fortified fertilizers are: Boronated single superphosphate (16P0.15-0.20B Zincated urea (43N2Zn); Zincated phosphate (suspension) (12.9P19.4Zn); NPK fertilizer fortified with B (10N26P26K0.3B); NPK fertilizer fortified with B (12N32P16K0.3B); DAP fortified with B (18N46P0.3B) etc. There is an urgent need for developing customized fertilizers for different regions and crops.

More efficient nitrogen fertilizers: Use efficiency of fertilizer nitrogen, which constitutes more than 60 per cent of the total plant nutrients consumed in India is abysmally low; 30-40 per cent in rice and 40-60 per cent in other crops. The global warming potential (GWP) of NO₂ is about 310 times that of CO₂. Nitrates leached down increase the nitrate content in ground waters above the safety limit of 45 mg L⁻¹, which can lead to health disorders in humans, especially in infants causing methaemoglobinemia (Blue baby syndrome).

A recent report from Punjab indicates the increase in nitrate content in water of some shallow wells. Thus, low nitrogen use efficiency not only leads to financial loss to the farmers and government, but it also creates environmental problems. Development of efficient low-cost, slow-release fertilizers is therefore an immediate necessity of the country and world as a whole. Nitrogen use efficiency can be increased by treating urea with nitrification inhibitors or coating with some hydrophobic substances to retard the release of urea in soil solution or its microbial oxidation to nitrates, which leach down or are lost to the atmosphere as N₂ or NO₂ gases.

4.3.4 Horticultural sciences-research and processing

By 2050, India with about 1.7 billion people will be the most populous country in the world, accounting for a dominant percentage of the global population but only 2.4 per cent of land and less than 4 percent of water. And about 60 per cent of the country's population, counting to nearly 1 billion, will be urbanized and a good part of it will be rural migrants. The rapid urbanization will further accelerate the demand for higher quantity of quality food, especially of high value foods such as fruits, vegetables, milk, meat and eggs, from the shrinking land, water, biodiversity resources.

In face of the above challenges, following basic, applied and strategic research initiatives are needed:

Urban and peri-urban agriculture/horticulture: Urban and peri-urban agriculture-horticulture which refers to food production and supply chain systems within cities and their surroundings, must become an integral part of the national agricultural production and distribution systems. Research is needed to grow vegetables, ornamental plants and herbs in pots, shade, trays; and by deploying aeroponics, hydroponics, and small scale protected cultivation structures for roof top gardening as well as for peri urban production of fruits, vegetables and flowers. There is a huge threat of urban and peri-urban waste accumulation to the fragile environment; management of which in peri-urban and urban horticulture after necessary remedial procedures is very essential.

Vertical and protected cultivation: Factor productivity needs to be enhanced through protected cultivation/vertical farming and sky farming. Breeding of horticultural crops which are suitable for protected cultivation and vertical/ sky farming is required. Development of technologies is essential to promote aeroponics, hydroponics and soil less culture. Developing efficient water and nutrient management systems including automated and pulsed micro-irrigation and fertigation technologies will facilitate in enhancing both water and nutrient use efficiency.

Minimization of post-harvest loss: Integrating pre- and post-harvest protocols for minimizing post-harvest losses is of critical importance. Research is needed for value addition and product diversification, utilization of by-products, residues and wastes

Enhancing quality of horticultural crop: Breeding is required for high nutritive value and aesthetic value and processing and export quality. Developing sustainable land management technologies including safe production technologies and organic farming, breeding varieties for higher shelf life will be helpful to enhance quality of horticultural crops and for a more efficient marketing.

Carbon sequestration and foot prints from horticultural systems: Linkages within the value chain for cultivation and marketing of medicinal and aromatic crop for small & marginal farmers.

Molecular biology and genomic studies: The study includes exploring bio-diversity for tagging genes and pre-breeding lines for resistance to abiotic and biotic stresses through association mapping; broadening of genetic base through inter-specific hybridization, space breeding, haploidy breeding, mutation breeding, polyploidy etc., and their characterization; development of improved varieties / hybrids through conventional breeding and space breeding ; male sterility system, non-nuclear genome manipulation, transgenic technology and nano technology for abiotic and biotic stresses.

Understanding the stress physiology and the metabolic pathways which regulate various stresses is need of the hour. This calls for genetic enhancement and field phenotyping of horticultural crops, root stock breeding and grafting technology for important environmental

stress (heat, drought, flooding, etc.) tolerance. Studies on the role of microbes in mitigating the effect of abiotic stresses like high temperature and drought should be documented and response of terrestrial microbial communities to climate change to be studied.

4.3.5 Research in Animal Sciences

The livestock sector plays an important role globally in terms of providing food and livelihood security to millions of people. Globally, more people live in urban areas today than in the rural areas (UN, 2013) and this trend is likely to continue, with urban growth expected to increase in the coming years. With growing income and living standards, especially of the middle class in India, the demand for animal origin foods (milk, meat and fish) is expected to rise sharply. In 2050, the projected consumption of poultry meat in India will be 2.3 times higher and that of other livestock products will be 1.4-1.8 times higher than today. This demand can only be met by at least doubling the animal productivity, which is a serious challenge to the livestock sector.

With increasing demand for animal products and by-products, the production and productivity of livestock sector in the country need to be enhanced, where livestock is majorly with resource-poor farmers. Livestock also serve as financial instruments, by providing households with an alternative for cash savings, which can be sold and transformed into cash as and when needed. For some poorer households, livestock provide a means of income diversification to help deal with times of financial difficulty.

India's livestock productivity, however, is 20-60 per cent lower than the global average. India cannot afford to be a poor performer in livestock production considering the vast genetic diversity of the country's livestock and the opportunities available after globalisation of food market. For improved productivity, the use of bio-technological, molecular and nano-technology approaches in breeding, feeding, reproduction and health care need to be considered (ICAR-CIRG Vision 2050; ICAR-IVRI Vision 2050).

Augmenting fodder resources: As of the year 2017, the country faced a net deficit of 32 per cent of green fodder, 11 per cent of dry crop residues and 44 per cent concentrate feed ingredients. Despite this precarious situation, forage production and development have not received due importance. It has remained a 'Grey Area' as far as forage seed production and availability are concerned. The confusion as regards the ownership of this responsibility between the agriculture and animal husbandry departments needs to be sorted out at the earliest. Dairy farmers now require new knowledge on innovations which can help them to produce more from less input and support them to improve their livelihood. Largely the livestock farmers are small and landless, and they require both technical and financial supports. Under this circumstance, the strategies like area-based approach for cultivated green forage production, integrating forage production with food and other crops, rejuvenation of grazing lands/common property resources, promoting forage production from problem soils/wastelands, judicious uses of forages from forests, promoting area/situation specific hydroponic green fodder production, growing forages on bunds or fodder tree based boundary

plantations under non-competitive land use approach etc need to be considered on priority. In fact, augmenting forage resource is a more complex issue than food and commercial crops. Lack of momentum in fodder development in the country owes also to poor organizational structure, which needs to be strengthened. Keeping in view the huge livestock population and the nutritional security they can offer, the area under fodder cultivation should not be less than 10 per cent of the gross cropped area.

Providing better feeds and nutrition: Even today, poor nutrition is the major constraint in the country's resource poor smallholder livestock production systems. To make the livestock production self-sustaining, economic and eco-friendly nutritional strategies like the search for newer/under-utilised and unconventional feed/fodder resources are needed. These should provide green herbage to animals under varied management conditions like spineless cactus, feed additives and strategic supplements for better bio-availability and improved health as well as production of designer livestock products by modifying the rumen microbes using conventional and advanced techniques. Bio-technological interventions, modulating rumen fermentation for better nutrient utilization as well as reducing methane emission from feed resources need to be exploited for combating the adverse effects of livestock production on environment.

Better health care and monitoring of diseases: Control of animal diseases is very important when trying to improve the animal productivity and adopting intensive and commercial system of production in place of extensive system. Development of new generation diagnostics and vaccines along with appropriate adjuvant and improved delivery system for the endemic, emerging and exotic diseases of animals is important. Research on developing technologies for early and accurate diagnosis of different diseases should become a priority programme. Use of advanced technologies like DNA fingerprinting for surveillance, Polymerase Chain Reaction (PCR) tests for diagnostics and understanding resistance and genome sequencing is expected to help in effective and early diagnosis and control of diseases. Health related research activities should focus on controlling and eradication of important zoonotic and trans-boundary diseases. There is need to develop sensitive sero-diagnostic, molecular, chip- and biosensor-based diagnostics for important bacterial, viral, mycoplasmal, fungal and parasitic diseases of animals. Studies on host pathogen interactions, functional genomics and immuno-modulations of pathogens, molecular pathology, stem cell and cytokine therapy of different diseases need to be strengthened. Nano-biotechnological approach needs to be adopted for efficient drug delivery system, diagnostics and vaccines for better health care of animals.

Promotion of contract farming: Contract farming needs to be facilitated specifically in case of small ruminants where all inputs like feed, vaccine, treatment etc are supplied to the farmers, along with extension services by the sponsor-contractor and lambs/kids at slaughter age are procured by them at reasonable (pre-agreed price as per contract) price. This will enhance production and at the same time farmers will get better remuneration for their produce and consumer will get quality meat at reasonable price.

Improvement in marketing facility: Studies on livestock markets need to be taken up so as to understand the market trends, structure, competitive landscape and the outlook of the Indian livestock farmers. Such information is expected to help in developing intelligence system for investors, researchers, consultants, traders and policy planners in boosting the animal productivity in India. There exists a need to strengthen the farmer's ability to absorb and adopt appropriate technologies for improved and sustainable livestock production. Adoption of comprehensive value chain systems would help the farmer in benefiting from higher output and income. Farmers should be provided with policy advice and assistance by reorienting extension services towards creating a pluralistic, demand-led and market orientated system, new financing mechanisms and use of information and communication technologies (ICTs) for monitoring and evaluation.

Frontier research: The research in the frontier areas of stem cells, pharmacogenomics, nutrigenomics, transgenic animal technology, proteome analysis, siRNA technology, biosensor applications, IVF-ETT, etc. will have to be gainfully utilized for strengthening research efficiency. The focus would be on strengthening diagnostic imaging, anaesthesia and surgical techniques; development of facilities and expertise in specialty areas like ophthalmology, neurology, cardiovascular diseases, dentistry, geriatrics, sports and space medicine; search for newer healing promoters, biomaterials and implants for tissue engineering; modern therapeutics like stem cell therapy, modern diagnostic biomarkers and expertise for early detection of structural and functional disorders in sick animals; search for newer therapeutics like alternative medicine, research on production, deficiency, toxicological and metabolic diseases of animals and developing strategy for their mitigation.

Disease surveillance, diagnosis and control of diseases: Though there has been a general reduction in the occurrence of animal diseases during the last few decades, largely due to the improvement and development of diagnostic technologies, vaccines, drugs and services, there has also emerged a global concern due to some new diseases and their potential of transfer from animal to man. Several outbreaks of zoonotic diseases that have emerged in India include avian and swine influenza, Crimean Congo haemorrhagic fever, Japanese encephalitis, Nipah virus disease, and food-borne infections and intoxications are also a matter of growing concern. Hence, there is a critical need to make progress in disease surveillance, forecasting and assessment of changing disease pattern to control and combat the spread of emerging and zoonotic diseases. Development of improved diagnostics and early detection, along with increased awareness and preparedness to deal with highly infectious and emerging diseases would help in reducing the levels of morbidity and economic losses.

Climate change adaptation: Animal production and animal bio-diversity are an evolutionary physiological manifestation of animals varying in their abilities, capabilities, and production capacities. Meat, milk, eggs, wool and other animal products, therefore, are end products of physiological processes, which are greatly dictated by the integrated cell structure, function and gene expression and external climate and environment. Climate change is likely to affect the animal health and production, directly by altering the homeostasis and other physiological

thermo-regulatory responses to maintain the thermal balance, and indirectly by affecting the supply of feed and fodder, increasing vulnerability to diseases and pests. In results, the climate change influences the production capacity of the animal.

Livestock infertility and its management: Good reproductive performance is essential for efficient livestock production, and therefore, livestock improvement programs should aim to increase reproductive efficiency. Integrated strategies for improvement of reproductive efficiency are need of the hour which include feeding strategies to meet optimum nutrient requirements, appropriate management practices.

Improved fertility, improvement in availability of genetically superior females and bulls, good quality semen and artificial insemination services; strengthening breed nucleus herds/bull mother farms, young bull rearing centers, semen collection and cryo-storage banks will also help to improve livestock fertility. Application of modern bio-techniques of semen sexing, in-vitro fertilization and embryo transfer should be implemented for long term improvement of livestock germplasm. Important diseases which cause infertility and abortion in cows and buffaloes like brucellosis, leptospirosis, listeriosis, FMD etc. should be controlled; vaccination and other preventive measures should be strictly followed to control these diseases. There is an urgent need for implementation of multiple ovulation and embryo transfer (MOET) selectively for faster multiplication of superior germplasm.

4.3.6 Research in Fishery Sciences

4.3.6.1 Freshwater aquaculture

Feed formulation and preparation: Feed formulation and preparation need to be stressed upon specially for larval rearing with particular reference to its cost after using locally available low cost feed ingredients. Feeding strategies are yet to be chalked out for different maturity stages along with quantification of requirements of indispensable amino acids, vitamins and mineral mixtures for diversified species as well as deciphering the role of gastro-intestinal hormones on feeding rhythms, regulation of the expression of genes related to increased carbohydrate utilization and biosynthesis of the highly unsaturated fatty acids.

Wastewater treatment and use for aquaculture: Wastewater use through treatment and recycling deserves special attention, as a vast volume of wastewater resource is available in different metropolitan cities. Its utilization, perhaps, is the cheapest and best source to produce edible food products thereby harvesting economic, environmental and biological benefits that will accrue from use of treated wastewater. This is a win:win situation, wherein water productivity is enhanced, while simultaneously agriculture in the hinter-land of large urban agglomerations will stand to benefit.

4.3.6.2 Post-harvest technology and value addition

Post-harvest technology and value addition is an area that has not yet received much attention in freshwater aquaculture sector. The subject has a major role in saving wastage of eatable commodities of low grade (economically less important) by converting them into value added

products to serve the customers of their choice. A huge quantity of fishes and prawns is wasted while transporting, and these being perishable are vulnerable too. Some fishes in their original body colour and taste are not liked by many, and therefore, need to be processed and value added for human consumption. Nano-technology has great potential to revolutionize the field of fish processing.

4.3.6.3 Availability of quality seed

Fish production in a pond largely depends on the availability of quality seed for stocking. The quality seed of fish refers to the seed to be robust in terms of its genetic material, and as well good in size and health at the time of stocking. Captive breeding with the same population over the years causes inbreeding depression and results in poor genetic base leading to retarded growth and low disease resistance. Providing adequate isolation to prevent contamination, testing of genetic purity and adopting seed certification system may be some of the important measures to achieve good quality seed.

4.3.7 Building global competitiveness through value chains

A value chain refers to various steps a business enterprise takes to output a product or service, and deliver it to the consumer from its conception to its end use and beyond. This includes activities such as research and design, production, marketing, distribution, and support to the final consumer. Reductions in communication and transportation costs and the emergence of new technologies have enabled firms of all sizes, from anywhere in the world, to supply and market products and services internationally.

4.4 Long- Term Research

4.4.1 Crop science

Genetically Modified (GM) crops and genome editing tools: GM crops are the products of introduction of one or more of well characterized genes in a crop plant using recombinant DNA technology, such that the gene introduced may belong to either a distant species (including prokaryotes), or a closely related species or even the same species (as in case of the so-called cisgenic plants). In some cases, the introduced gene may even be a synthetic gene or may result from targeted mutagenesis. The GM technology is a powerful tool for developing future crop varieties with in-built genetic resistance to various biotic and abiotic stresses for reducing crop losses and enhanced input use efficiency, yield potential and quality traits. Their use will be crucial for the food and nutritional security of the country, and therefore, research on them must be continued with the aim of developing safer, more productive and nutritious food crops. However, this should be done in a more transparent and socially inclusive manner for wider public acceptance. Also, concerns of the opponents of GM technology should be addressed to allay the public concerns on food safety, environmental and economic security before deploying this technology in food crops.

At present, 96 per cent of India's cotton cultivation area is under Bt cotton varieties but it wasn't always so. Bt cotton was the first genetically modified crop to be approved for

cultivation in India in 2002, with the introduction of Monsanto's GM cotton seeds. Bt stands for *Bacillus thuringiensis*, a bacterium that produces toxins harmful to a variety of insects, including bollworms that attack cotton. Bt cotton was created by introducing genes from the bacterium into the cotton seed, creating a crop resistant to this pest.

The introduction of Bt cotton led to a dramatic increase in production across the cotton producing states, and soon Bt cotton took over most of the acreage under cotton cultivation. Cotton production rose from 14 million bales in the pre-Bt year of 2001-'02 to 37.5 million bales in 2017-'18, a quantum rise helping in reducing India's cotton imports and growth of exports.

In the backdrop of scarce labour, another area of work is developing herbicide tolerance/resistance plants. GM free technology like CRISPR cas which has no associated risk as apprehended in GM by some, is another area of research that deserves attention. In advanced countries, it is coming up in a big way as an opportunity to handle farm problems, and India should not lag behind. Mineral use efficiency like nitrogen use efficiency or phosphorus use efficiency either through conventional means or by using modern tools like CRISPR cas is an area full of potential for research and investment.

Crop improvement for disadvantaged areas: As high as 107 million hectares of the country's geographical area is degraded and barren, which can't be readily used for agriculture. Scientific development of such wasteland can offer scope for expansion of area under cultivation, afforestation, and promotion of such other biological activities. There lies greater scope for such intervention in central Indian states like Madhya Pradesh with vast tracts of such wastelands. It calls for huge investments of the order of Rs. 50,000 crore for developing half a million to 1 million hectares of wasteland. It would be worth the investment if suitable and cost-effective technologies are developed. India has diverse climates, including tropical wet and dry, sub-tropical humid, semi-arid, arid, tropical wet and alpine climates.

Taking advantage of climate variations and outcomes of field studies, climate-resilient farming can be undertaken in these developed wastelands. Crops that deserve priority are millets, pulses & oilseeds.

4.4.2 Research in seed

Public private partnership: The private sector may engage with the public sector, which is the main custodian of Indian germplasm for the development of new varieties and hybrids through contract research. The quality enhancement is one of the key research area where there can be collaboration between public & private sectors. The prioritization of research in public institutes by reducing the burden of extension will help in developing a mutually beneficial system. Proper guidelines for intellectual property rights can be notified and revised on regular basis; and procedural delays reduced at public institutes which will agricultural research system. A policy framework that promotes partnership in joint research, as also mutually

exclusive research based on clearly delineated domains will help in speedy and expansive turn out of required seeds based on research.

Investment in prioritized research areas: The prioritization of research needs is one of the key issues in the country. The targeted research with sufficient funding and its timely utilization will help in resolving several bottlenecks for the enhancement of production and productivity in the country.

Infrastructure development: The state of art laboratories and institutes are required for conducting the latest research. The lack of maintenance of the infrastructure developed is one of the major reasons for the failure in public sector. A public private partnership can be developed, where the maintenance responsibility of instruments is transferred to contract organizations.

4.4.3 Natural resources management

Nano-technology and bio-sensors: There is a need to focus on sustainability of production, monetisation of farmers' produce, re-strengthening of extension services, recognizing agriculture as an enterprise and enabling it to operate as such, by addressing various structural weaknesses.

Nano-technology is finding increasing applications in agriculture, particularly, in soil & water conservation and farm machinery engineering. Products based on nano-materials are being developed to absorb soil moisture when it is in excess and release slowly to plants during dry periods. Use of nano-quotedtynes in planting equipment could significantly decrease the wear and tear, prolongs the life and brings down the cost of operation besides reducing weight and cutting down on the draft requirement.

Use of low cost bio-sensors is yet another emerging application in crop field that can indicate water-stress or nutrient stress experienced by crop. By using electronic sensors, fertilizers can be placed precisely in moist zone, based on the spatial variability in native fertility. This will improve the fertilizer use efficiency in rainfed agriculture and encourage farmers to use fertilizers more effectively despite the risk of weather aberrations.

Machinery for using crop residues with conservation agriculture: Development of appropriate farm machinery is needed to facilitate collection, volume reduction, transportation and application of residues, and sowing of succeeding crop under a layer of residues on soil surface. Modifying combine harvester to collect and remove crop residues from field; developing twin cutter bar type combine harvester for harvesting of top portion of crop for grain recovery and a lower cutter bar for straw harvesting at a suitable height and wind rowing for proper management of straw will help. Developing straw spreaders for uniform distribution of the crop residues is also useful.

Flood-prone and wet land area management of eastern India: In flood-prone areas, drainage development, link and secondary drainage system in low lands, peripheral embankment, land configuration according to need, and renovation of village and other ponds should be given due consideration. Agro-forestry based land use is very vital for rehabilitating waterlogged/marshy and degraded lands. Raised bed method could be adopted in marshy areas for planting of saplings. Species like *Anthocephalus chinensis*, *Casuarina equisetifolia*, *Dalbergiasissoo*, *Eucalyptus spp.*, etc have been found suitable for cultivation in such areas besides various bamboo species. Such lands could also be rehabilitated with land configuration and by adopting pisciculture and agro-forestry together.

In seasonally water-logged areas, water chestnut & makhana could be cultivated in a cropping system mode (water depth- up to 0.60 m). Vast waterlogged and wetland of the region offers unique opportunities for agricultural development and employment generation by veritable technological interventions such as cultivation of makhana, water chestnut, fish and lotus and adoption of various combinations of integrated crop-forestry-fish-animal farming systems. Importantly, the wetlands must be protected for biodiversity conservation

Resource use efficiency at watershed catchment scale: Development at watershed/catchment scale is one of the most trusted and eco-friendly approaches to managing soil and water resources, and is capable of addressing many natural, social and environmental intricacies. Management of natural resources at the watershed scale produces multiple benefits in terms of increasing food production, improving livelihoods, protecting the environment, addressing gender and equity issues along with addressing bio-diversity concerns. It is also recommended as the best option to upgrade rain-fed agriculture to meet the growing food demand globally on a sustainable basis.

Improved watershed management by way of constructing water harvesting structures, cultivation across the slope, planting of *Gliricidia* on the bunds & less-exposed soil due to increased cropping intensity, increased use of organic manures, and better crop growth due to adoption of balanced nutrition and other best practices results in restriction to free flow of water leading to more infiltration and thereby reduced runoff in comparison to the rainfall received (Wani *et al.* 2012c). The impact of soil management for conserving in-situ and ex-situ moisture in watershed interventions is recorded as improvement in the groundwater. As a result of watershed interventions, the water use efficiency by different crops increases with substantial productivity improvement, resulting in higher profit margin. Enhanced water availability enables farmers to increase cropping intensity and diversification into more remunerative land use systems involving horticulture, forage production on sloping lands, etc. Forage promotion strengthens livestock-based livelihoods which provide an alternative source of income and livelihoods, in addition to improving resilience to shocks.

Remote-sensing and geo-informatics: Remote sensing and Geographical Indication System (GIS) tools are already being used widely in agriculture, particularly in planning and monitoring of integrated watershed development projects and land use planning. With the

expansion of technology and availability of high spatial and temporal resolution satellite data, many novel applications are emerging. Monitoring the status of natural resources over time, seasonal drought monitoring through NDVI, in-season crop health monitoring over large areas for timely interventions on irrigation and pest management and locating potential water harvesting structures are some such applications. Remote sensing products will also be useful for assessing crop damage due to natural disasters and crop insurance claim. Application of GIS-based Decision Support System (DSS) should be encouraged for assessing site suitability for aquaculture which can enhance fish production in the Region. Efforts may be made to increase the fish productivity extending the innovative scientific tools primed by policy support

Minimizing soil pollution: Soil is a crucial component of rural and urban environments, and in both the places, land management is the key to soil quality maintenance. Due to increased anthropogenic activities, soil is the recipient of several pollutants like pesticides, herbicides, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, heavy metals and many inorganic salts. These pollutants have adverse impacts on soil physico-chemical environment, nutrient cycling/transformation processes, soil biodiversity, plant growth, food quality through contamination etc. Large quantity of urban wastes is produced in different cities causing water, air and soil pollution.

Mining, manufacturing and the use of synthetic products (eg. pesticides, paints, batteries, industrial wastes, and land application of city and industrial sludge) can result in heavy metal contamination of urban and agricultural soils. Excess heavy metal accumulation in soils is toxic to humans and other animals. This leads to introduction of toxic elements in the food chain and might pose a serious threat to animal and human health.

Remediation measures generally employ physical, chemical or biological means or their combinations. The first two are referred to as engineering strategies, and the latter as inputs, improve and maintain carbon stocks in soils, develop nutrient models to aid nutrient management decisions for important agro-ecosystems, assess soil quality to monitor long term changes in soil fertility under different agro-ecological systems and build up models for predication of changes in soil health

4.4.4 Research in Animal Sciences

Improvement and management of genetic resources: Majority of the livestock in India are non-descript with lower production potential. With shrinking resources and increasing demand of livestock products, there is urgent need to genetically improve and manage these animals through modern reproductive tools. Breed improvement programmes need to be undertaken more intensively following artificial insemination technique. For widespread dissemination and conservation of superior germplasm cryo-preservation and banking of semen, embryo, embryo transfer and cloning need to be exploited. Introduction of genes through cross-breeding and selection of disease resistant/tolerant animals through molecular genetic markers may become useful. DNA markers for disease resistant genes and the ability to diagnose specific genotypic markers that correlate with susceptible and resistant phenotypes will make it possible

to identify genotypes resistant to diseases across a range of breeds available in the country. Complete genome sequencing for different livestock species will lead to possible advances in evolutionary biology and animal breeding. Genomic selection is expected to revolutionize animal breeding by at least doubling the rate of genetic gain in dairy animals.

Smart reproductive management: Improved diagnosis and therapeutic management of infertility and reproductive disorders are important for sustainable and speedy growth in livestock sector. Alternate animal model systems, cryo-banking of germ cells and mammalian cells, development of diagnostic markers and therapeutic strategies for augmentation of fertility are the major activities those require attention in the near future. Adoption of new technologies like spermatogonial stem cell research to manage poor fertility in breeding sires, sexing of semen, fertility markers for bull selection and improving freezability of spermatozoa are going to be important for smart management of livestock fertility and productivity.

Raising climate resilient animals: Climate change would be affecting animal health and their productivity, directly and indirectly through alteration in homeostasis and other thermo-regulatory responses needed to maintain the thermal balance of animals. Productivity is also associated with changes in expression of different genes under the changing climatic conditions. Hence, identification of heat stress resistant animal breeds and proper shelter management systems need to be developed to mitigate the adverse effect of climate change. These breeds should selectively be bred by using molecular markers such as identifying single nucleotide polymorphism (SNP) related with enhanced resistance to climate change and using them as selection marker in breeding programme. Indeed, molecular characterization of candidate genes for productive, health and adaptability traits in animals under the prevailing climatic conditions needs to be studied.

Nano-technology: Nano-technology is another highly diverse field, which can be utilised to enhance livestock production and health. Food and nutritional products containing nano-scale additives, nano-sized, multi-purpose sensors to assess the physiological status of animals are some of the research areas. Nano-particles may enhance nutrient uptake and help in efficient utilization of nutrients for milk production. In the coming years, nano-technology might find application in various areas in livestock health and management.

4.4.5 Research in Fishery Sciences

Bio-technology and genetic engineering: Bio-technology and genetic engineering would play vital role in enhancement of aquaculture production. Traditional selective breeding in aquaculture can be supported by molecular genetic tools in order to reduce time, space and investment on one side and to assure sustainability on the other. This will come about from greater survival or from faster growing animals or from a combination of attributes. There has been a paradigm shift in the approach to trait associated gene identification with the advent of high throughput genomics platforms and associated technologies. Therefore, the future of marker assisted breeding schemes in fish would lie in the prediction of total genetic value with highest precision by developing and using genomic resources.

Research in immunology and virology: Research in immunology and virology of fishes at cellular and molecular level is important.

4.4.5.1 Marine fisheries

Assessing Ocean Health Index and Potential Fishing Zone: The Ocean Health Index (OHI) deals with measurements of food provisioning services, traditional fishing opportunities, non-food products, carbon sequestration, livelihoods and economies of coastal communities, tourism and recreation value, aesthetic value and bio-diversity assessment of marine ecosystems. The Potential Fishing Zone (PFZ) Advisories present a good example of integration of the power of Satellite Remote Sensing (SRS) with fisheries. Ocean health can also be monitored by remote sensing data and for coral reef health advisories.

Blue carbon: India is blessed with large areas of mangroves and coastal wetlands which give the country a distinct advantage in a carbon-led economy. However, in order to utilize the economic benefits arising from 'Blue Carbon', these sensitive ecosystems need to be conserved and propagated in years to come. Additionally a viable market needs to be created for carbon trading (as on land – called the Green Economy), although significant efforts are required to develop this into reality, including science background and policy reform.

Seaweed farming: Seaweed farming offers immense scope as a livelihood opportunity and for developing a large number of by-products with several applications. Seaweed farming has the advantage of low capital input as it is a primary producer requiring no feed inputs. Additionally in future years, seaweed farming can earn carbon credits for the farmers. In India, seaweed farming is at its infancy even though there exist technologies for farming many species. The current industrial demand for raw material is not met by farmed and collected seaweeds in the wild. Hence, research and development thrust is needed to address the issues facing seaweed farmers and to popularize seaweed farming in India. Seaweeds can be used not only for food purposes but also as supplementary feeds for livestock and as liquid fertilizer. They can also be used for removing heavy metal pollution since they are good agents of biosorption or metal adsorption from water. Nutraceuticals and metabolites obtained from seaweeds play a major role in health and pharmaceutical industries. Marine primary producers are good carbon sequestering agents since they utilize large quantities of dissolved CO₂ thereby controlling ocean acidification.

Algal bio-refinery-based industry: The production of algal bio-fuels is a novel area of research in India. Algae are known to produce more oil per unit area than conventional oil crops.

To overcome the shortage of raw materials for extraction of carrageenan, better seaweeds can be explored. Using algae as a source of bio-fuels presents a future of immense possibilities for the world including India. The country can build a framework to integrate the algal bio-fuel-based bio-refinery, with other industries such as livestock farming, ligno-cellulosic industries

and aquaculture. The various co-products from the algal bio-fuel processing can be used as inputs for a number of other industries, e.g. the pharmaceutical industry which will bring in additional benefits to the algal bio-fuel industry in India. Policy and regulatory initiatives for synergistic development of the algal bio-fuel sector with other industries can bring many sustainable solutions for the future existence of mankind.

Applications of bio-technology in mariculture: The potential applications of bio-technology in mariculture include induced breeding, cryo-preservation of gametes and gene banking, marker assisted genetic improvement, chromosome manipulations (especially polyploidy, in bivalves), health management and production of transgenic fish with superior traits. The area of modern bio-technology which will probably have the most significant impact on genetic improvement of aquaculture species is transgenesis. Transgenesis offers an excellent opportunity for modifying or improving the traits like growth and efficiency of food conversion, resistance to pathogens, tolerance to environmental variables, commercially significant flesh characteristics, colour variants of ornamental species, control of reproductive activity and also in producing novel medicinal substances with fewer animal welfare problems than when mammals are used.

4.5 Annotations

The agriculture sector encompassing its multiple sub-sectors of agronomic crops, horticulture, dairy, livestock and fisheries has benefitted from Research and Development (R&D) activities of the well established National Agriculture Research System (NARS) under the public sector. The NARS is now called upon to play another important role to catalyse a new flush of growth triggers across the sub-sectors. This is necessary to address the challenges that the agriculture sector is facing in terms of stagnant yields, poor response to input use, stressed natural resources, climate change and impact on the production system, as also the need for a more market-facilitative production and post-harvest management environment. Various concerns and challenges relating to both production and post-production environments vis-a-vis all the sub-sectors of agriculture have been delineated, and they need to be addressed through both short and long term research initiative.

In order to benefit Indian agriculture from appropriate, accurate and timely technological outcomes, the NARS needs to reorient itself to address the issues from the perspective of incomes and sustainability. Further, the budgetary support for Agri-R&D needs to get more robust. Since 2001, it has averaged around 0.3 to 0.4 per cent of income from agriculture & allied activities. It is well known, that the benefits from Agri-R&D on accelerating growth and reducing poverty surpass investments made in other economic activities. Simultaneously, the Agri-R&D robustness can be further upgraded by adopting a Science Policy that promotes R&D in private sector in partnership with public sector, as also exclusively.

There also exists scope for transgenic technology in both crop and animal sectors. However, in due regard to the apprehensions of bio-safety relating to GM-foods, as also ethical and environmental concerns, the technology deployment may now be confined to non-food crops.

Improvements in food crops can be effected by relying upon conventional breeding programmes. These initiatives can take advantage of the rich genetic diversity that exists in case of both crop & animal sectors, and very little of it has been utilised as yet.

Key Extracts

- There is a need to focus and enhance investment to get more yield per acre, more crop per drop/per litre of water, more crop per unit of inputs (fertilizer, pesticides etc.)
- Reducing cost of cultivation through economic crop production technology viz. conservation technology and zero technology etc. is a sustainable alternative.
- Promote climate resilient agriculture and negotiate abiotic and biotic stresses through seed and biotechnology/ crop production technologies
- Reducing the impact of crop protection chemicals and fertilizers on environment and food safety by improving use efficiency of the agro-chemicals.
- Market reforms through electronic platforms; market competitiveness; Farm advisory service using ICT; and demand & price forecasts well ahead of sowing/plantation season will help a rational production decision at the farmers' level.
- Digitization of soil nutrient maps & precision in fertilizer application
- Innovation and miniaturization of farm machines will reduce labour requirement and drudgery.
- Research in animal sciences should focus on fodder resources, health care & monitoring of diseases, marketing, livestock infertility & management etc.
- Research in fishery sciences should address issues relating to feed formulation & preparation, waste water treatment, post-harvest technology and value addition.
- Genetically Modified (GM) technology is an important aspect of long term research.
- There is an urgent need to enhance budget/investment on Agri R&D. Studies show that return on public spends in Agri-R&D in India are high at 33 per cent; and R&D spends are much more effective in accelerating growth and lessening poverty, compared to other economic & social expenditures.

Chapter 5

Genetic Engineering for Crop Improvement

Conventional plant breeding has served India well, in building its food security. Beginning 1996, transgenic crop technology has demonstrated its ability to achieve breakthrough outcomes, and several countries, including India, have benefitted immensely. The science of this technology, its impact, pros and cons need to be examined to arrive at a logical conclusion on its adoption in India.

--To be added--

Chapter 6

Promoting Science-led Technology - Policy Recommendation

Technology is the daughter of science, and science has no limitations. As already validated by the impressive performance of India's agriculture, new science & technology are required to embark upon another leap forward, that considers farmers' income and farmers' welfare as the core of transformation. Further, the change should be based on the fulcrum of sustainable technology. Towards this end, it would help to progress from 'Science of Discovery' to 'Science of Delivery'.

6.1 Science of Scaling-up to achieve Impacts

- The operational farm holding size in India is declining and over 86 per cent of the 137 million holdings are below the size of 2 ha. Due to ever increasing population, increasing demand for alternate uses and land being inelastic in nature, there is no scope for horizontal expansion of land for agriculture. Only vertical expansion is possible by integrating farming components requiring lesser space and time and ensuring reasonable returns to farm families. The integrated and holistic solutions therefore assume greater importance for sound management of farm resources to enhance farm productivity, reduce environmental degradation and improve living standard of small farm holders. In order to sustain a positive growth rate in agriculture, a holistic approach is the moment's critical requirement. This approach is not only a reliable way of obtaining fairly high productivity with considerable scope for resource recycling, but is also a concept that is in consonance with ecological soundness leading to sustainable and profitable agriculture. Demand driven holistic solutions are needed by farmers and policy makers. Farmers need holistic solutions and not merely a part of solution
- Such of those farmers solely dependent on agriculture especially in dry lands, stand exposed to high uncertainty and risk of failure emanating from various extreme climatic events, pest and disease attack, and market shocks. Therefore, integration of agriculture and non-agriculture activities is required as a risk management approach and for creating a consistent source of income and support for livelihood. For example, agriculture, horticulture, livestock production and dairy farming system, together can make a more resilient and sustainable system compared to adopting cropping practice alone.
- Innovative knowledge delivery business models are needed using local youth; and productivity and profitability must be linked with sustainability. However, linking productivity and profitability calls for efficient use of scarce resources like water and land. Knowledge intensive and mechanized agriculture can only link profitability and productivity with sustainability. Further, without value chain optimisation and market linkages, profits cannot be harnessed by the farmers
- Land and water are fundamental to sustainable development of any economy. Several concepts in water and land management promote integration as a means to achieve sustainable development. Management institutions and policies aiming to put these concepts into practice are developed around the world with varying successes. The natural resources are inter-linked as producers and service providers to maintain

environmental health, augment agriculture production and ensure economic development. One of the major concerns in this regard is to rehabilitate existing vast tracts of degraded land and efficiently manage water resources to ensure livelihood support to the rural population in the region. The present scenario, however, shows poor adaptability of soil and agricultural water management practices by the farmers. Thus, soil and water conservation measures need to be innovative to suit to local conditions and easily manageable by farming community. The past decade has seen a considerable drive towards more formal forms of collaboration between institutions and policies. This drive is largely due to the popular concept of watershed management and integrated water resource management which promotes both watershed and basin-wide approach to conservation and development. The experience however highlights the critical need for creating a stake for every inhabitant of the watershed through livelihood options.

- Overall, public investments especially in dryland areas have been very low. While cumulative public investment in major and medium irrigation schemes is estimated at Rs 5.5 lakh crore at current prices, watershed development has cumulatively received less than Rs 40,000 crore. Private investment, the major contributor to irrigation, is perhaps even lower in dryland areas. Also, procurement and price support policies have favoured wheat and rice, neglecting millets and other crops most suited to dryland areas (GoI 2007).
- Report of the working group on natural resource management has suggested three inter-connected goals for developing dryland areas. They include:
 - enhancing current livelihoods for most people (equity);
 - enhancing current carrying capacity (growth); and
 - setting in motion regenerative processes to enhance future carrying capacity continuously (sustainability).

This calls for re-shaping the interactions between people and natural resources, as well as those between nature's elements to produce multiple, long-lasting, synergetic effects rather than merely maximizing current production. Relationships between people need to be re-ordered by fostering institutions to regulate resource use and facilitating joint action to develop resources, so that everyone gains and future needs are balanced against present demands. Alternate resource use systems need to be developed by changing people's interaction with resources to expand the production frontier in a viable way.

- Science tools like remote sensing images and data, soil health mapping, scenario development simulations along with Geographical Information System (GIS) and soft skill planning participatory tools need to be used while planning activities. The GIS techniques help in estimating the important variables such as soil nutrient status based on interpolation technique. In addition, systems modelling is also one of the emerging techniques which guides about resource availability, its management and various

alternatives to achieve yield potential. As adequate number of trained human resource is a major constraint in agriculture extension system, various information communication tools (ICT) are available which can be deployed to bridge the gap between farmer and knowledge generator.

- Crop diversification to high-value crops and enterprises such as horticulture, livestock and fisheries that contribute significantly to the income growth of farmers is critical. In order to capture the optimal value from farm produce by the farmers, there is a need to develop integrated cold-chain. Further, strengthened linkages with micro, small and medium enterprises would accelerate growth of farm income and generation of employment.
- There is an urgent need to enhance overall input efficiency, which can be achieved through implementation of resource-conserving technologies viz. zero-tillage, micro-irrigation, system of rice/crop intensification; mechanisation of farm operations, integrated pest management, integrated farming systems, farm extension services, adaptation to climate change and agri-market reforms at the state levels.
- The marginal efficiency of capital is much higher in minor- and micro-irrigation than that found in the major and medium irrigation systems. This justifies the allocation of greater resources towards the former by the respective state governments, in view of the level of groundwater resource usage.
- The cost of cultivation of major crops in real terms should be reduced to optimize the net income of farmers. It is therefore, imperative to strengthen the input delivery mechanism, especially with regard to seeds and extension services, and enhance the efficiency of public agencies within the existing institutional set-up.
- Private and public investments should be prioritized to facilitate crop diversification towards horticulture, infrastructure development viz. storage houses, greenhouses and micro-irrigation, and promotion of new culture for fruits and vegetables. Offering credit support is highly desirable at the individual farmer and cluster levels to ensure the success of diversification.
- Special attention needs to be given to the north-eastern, eastern and rainfed eco-regions for augmenting the scope of access to institutional credit. The dependence levels of landless, small and marginal farmers on non-institutional credit need to be reduced.
- The state governments need to reform their respective agricultural marketing systems for enabling better price realisation by the farmers. The auction system in wholesale markets should be more transparent. Private traders should take into account the as well as the services.
- It is important to raise investment intensity and improve capital use efficiency in the infrastructural projects of the government, including irrigation and others, by investing in area-specific and domain-specific needs, in order to maximise dividends. This also necessitates effective governance and institutional interventions in each state.

- The government's investments in agriculture can be strengthened by convergence of resources through various schemes being implemented in different departments and ministries. The funds under MGNREGA should be utilized for small irrigation facilities and rural roads.
- There is a need to assess and monitor the farmers' income, savings and investments over time on a regular basis to facilitate the formulation of evidence-based appropriate policy interventions. Monitoring and adoption of interim correction, if any is needed for doubling farmers' income.
- An important set of linkages involves those between productivity enhancement and natural resources management and the real challenge is the selection of appropriate technologies and scaling up to produce impacts. These include: soil and water conservation technologies, soil-test based fertility management approach, crop diversification and use of new science tools for enhancing impact.
- The impact at farm scale requires a holistic solution through integration of various technologies. The new integrated community watershed model has adopted science of delivery which provides technological options for the management of runoff, water harvesting, *in-situ* conservation of rainwater for groundwater recharging and supplemental irrigation, appropriate nutrient and soil management practices, waterway system, crop production technology, and appropriate farming systems with income generating micro enterprises for improving livelihoods, while protecting the environment .

6.2 Setting up of Linkage/Partnership/Networking/Infrastructure Facilities

- Modern grades and standards to be set for all major commodities (including horticulture, livestock and fisheries) that can be graded based on mobile devices. This will support traceability to realize higher prices for the farmers and support the nation's vision to triple agri-exports by 2022.
- National Nutrition Mission should integrate with DFI strategy for creating consumer awareness to diversify diets and farms. Farmers should be incentivized to produce better nutrition to fuel the development of children and expecting mothers.
- Primary processing should shift closer to farmers for value addition, reducing post-harvest losses and providing convenience to rural consumers.
- Leverage Aadhaar India Stack and Spatial Data Integration (Kisan Stack) to converge schemes with progressive states to deliver targeted and timely subsidies for farmers based on the ecology, soil requirements and market requirements to dampen price volatility and prioritize local investments in processing and storage. The farmers in the participating states with access to mobile dash board can optimize farm resources, link up with service providers and connect to e-NAM clusters, processors or consumers to optimise on the value chains and consolidate the logistics linkages.

- Accelerating the innovation cycle will require agricultural research to compress the long research-into-use pathway into a shorter and more impactful pathway that leverages participatory research approaches coupled with ICT to provide real-time feedback on farmer and consumer acceptance of new products and services, so that they can be adapted and then adopted quickly by farmers.
- Modernizing agriculture will draw on the rapid evolution of molecular biology and information technology to integrate across disciplines to develop new varieties with multiple production and market traits integrated. In a similar manner, modern tools (cloud computing, artificial intelligence, mobile, remote sensing, and systems research) are driving transformation of agriculture in advanced economies that are incentivizing youth to return to agriculture as a commercially attractive and sustainable enterprise.
- Convergence of data (agriculture, nutrition, environment, hydrology, soil health, weather, farm diversification, markets, socio-economics and government schemes/policies) is critical to the implementation of a modern agri-food system to optimize resources, ultimately accelerating equitable and sustainable rural economic growth.
- Spatial Data Integration (SDI) offered through commercial cloud services will be a key component, as Artificial Intelligence is used to distil complex data into actionable recommendations for farmers/FPOs. It will also provide real-time M&E (monitoring & evaluation) to policy makers to identify bottlenecks and accelerate DFI schemes. Additionally, it will give visibility to the opportunities for multi-disciplinary research efforts to work in concert to increase farmers' incomes, safeguard the environment, and deliver better nutrition to farmers and consumers.
- Partnership with the private sector and supporting agri-entrepreneurs will provide modern value addition, delivery of inputs and provision of extension services by bringing together agriculture sciences, Information and Communication Technology (ICT), and allied sectors to deliver sustainable and scalable solutions.
- Backward integration of value chains ensures that farmers' surpluses will enjoy market opportunities. Agri-entrepreneurs are recognizing their rapidly emerging role to compress lengthy value chains and provide primary processing services closer to rural communities to reduce losses, increase convenience to diversify diets, and shift value capture closer to farmers.
- A consortium of research organizations, government ministries, public and private sector organizations and non-governmental organizations needs to work in a coordinated and accountable manner with the appropriate cloud-enabled databases and dashboards to scale-up science-backed solutions for farmers. The past experience shows, that enhancing partnerships and institutional innovations through the consortium approach was the major impetus for harnessing the potential of community watershed management to reduce poverty and environmental degradation. The underlying element of the consortium approach is to engage a range of actors to harness their strengths and synergies with the local community as the primary implementing

unit. Through the consortium approach, complex issues can effectively be addressed by the joint efforts of key partners, namely, the National Agricultural Research System (NARSs), non-governmental organizations (NGOs), government organizations, international institutions, agricultural universities, community-based organizations and other private interest groups, with farm households as the key decision makers. Thus, consortium approach brings together the expertise in different areas to expand the effectiveness of the various initiatives and interventions.

- These kind of innovations should be encouraged with enabling policies, appropriate institutional arrangements along with reward mechanism for achieving best results. The reward mechanism will work as an incentive for different stakeholders/partners to innovate new ideas and demonstrate for impact. The recognition and reward mechanism should be part of the assessment.
- Government of India has been emphasizing on collective action of farmers through Small Farmers Agribusiness Consortium (SFAC), a dedicated organisation established in 1994. Its basic objective is to link the small farmers to the larger agricultural value chain, which includes investments, technology and markets in association with private, corporate or cooperative sector. It also provides capital support in the form of Venture Capital Assistance and Project Development Facility. One of the mandates of SFAC is to promote Farmer Producer Organisations (FPOs) and their integration in the agriculture value system. Apart from SFAC's initiative, it is heartening to note that many states have formed FPOs with the help of NABARD aiming to link farmers to markets. Past experiences suggest that the collectivization of farmers is successful as it enhanced the collective action and bargaining power as experienced with milk cooperative societies. The landholding structure that obtains today demands, that the process of mobilising farmers, particularly the small & marginal into FPOs is scaled up, so as create thousands of them by 2022 and not just in hundreds. This is not the time for pilots and neither is there a need for it.
- Building partnership with diversified agencies for benefiting the farmers is the need of the hour. First, lack of institutional arrangements such as input delivery system including local extension system which is a prerequisite for technology transfer at the village level. Although the extension system exists in the country, lack of appropriately trained human resource to undertake this particular activity is a real challenge. Second, in the absence of strong extension system, knowledge delivery mechanism has become weak creating vacuum in information dissemination and technology demonstration. These challenges can effectively be addressed through institutional support, building partnership with multiple partners as well as ensuring enabling policies for demonstrating innovative models for scaling up.
- In recent years, research and development (R&D) funding has seen major shifts in the policies, whether multilateral lenders or bilateral donors. The new norms of grants imply shifts in control and emphasis on the targeted outputs and outcomes. It can be argued that accountability at the system level needs to be further developed so as to take account of the deliverables. Furthermore, there is an identified need to base

approaches on agreed principles, with clear responsibilities, and the prior participation of the stakeholders

- Research and development projects usually include multiple actors, and the effectiveness of these projects depends on the co-operation of these actors. The agencies which receive development assistance or grants through fund raising from the state, multilateral or bilateral donor agencies provide services. As such, they are involved in explicit or implicit contracts in which their output must measure up in some way to show accountability towards received grants. Accountability entails the duty to provide an explanation or reckoning of those actions for which one is held responsible.
- For achieving better outputs and outcomes, there is a need to adopt strong monitoring mechanisms with key performance indicators. The activities are to be associated with key performing indicators to be measured with a time frame. This will not only help to track down the progress of the work, but also provide an opportunity for course corrections and avoiding delay in delivering the outputs. The monitoring mechanism should be backed up by ICT tools which will help in fast tracking the progress as well as reducing transaction cost.
- Given the wide diversity within the country, partnership and networking of research and development agencies at the level of agro ecological regions, state and national levels is important to collaborate and coordinate projects. The national, international and local research and development organizations should collaborate on most emerging issues to minimize transaction cost and increase the efficiency of the system. The objective should be to strengthen research and development, training and information exchange for improved and sustainable agriculture. This networking should work towards identification of regional research priorities, implementation of research activities, training and sharing of information through publication of research results and scientific meetings/workshops.
- The Public-Private Partnerships (PPPs) are viewed as the governance strategy to minimize transaction costs and for coordinating and enforcing relations between the partners engaged in production of goods and services. They enable an optimal policy approach to promote the social and economic development, thus bringing together efficiency, flexibility, and competence of the private sector along with the accountability, long-term perspective, and social interest of the public sector. For soil health management, there is need to identify business models for devolving the responsibilities of sample collection and soil analysis while ensuring quality standards as well as economic feasibility and also explore public-private partnerships involving fertilizer manufacturers, private service providers, state agricultural universities, and selected KVK.
- Research and development is needed with a focused growth that helps in realising the vision of doubling farmers' incomes by 2022. To achieve this, there is need for convergence of schemes with the support of pragmatic policies and targeted budget allocations. This calls for a holistic approach to support rapid cycle innovation, agri-

entrepreneurs and farmer organizations to translate effectively the science of discovery into the science of delivery.

- Farming should generate sufficient income opportunities. Thus, innovation is required to reduce production costs and to strengthen market systems as well as appropriate technologies should reduce the production risks.
- Research should be oriented towards demand-driven; findings should reach farmers' field. This may be facilitated by development agencies in public-private partnership mode. Solutions should match with farmers' needs and consumer preferences. Science of delivery requires strengthened farmer organizations, better functioning of service providers and an enabling institutional framework. Demand for agricultural advisory services will likely emerge from market players who want to compress supply chains to increase quality, integrate traceability, ensure supply and be competitive in the marketplace.
- Delivery mechanism must be oriented towards accelerating the innovation cycle, modernizing agriculture, convergence of schemes under agriculture, nutrition, environment, hydrology, soil health, weather, farm diversification, markets, socio-economics etc. A multi-disciplinary effort would give better visibility to increase farmers' incomes, safeguard the environment, and deliver better nutrition to farmers and consumers.
- Capital investments are required for long-term and sustainable growth in farm income. This will call for private and public inflows to the farming systems. At the same time, both private and public investments should be increased annually.
- There is need for scaling up of post-harvest operations and directly linking with wider markets. For this, creation of farmer groups such as farmer producer organizations would be essential to enable aggregation and pooling of the outputs from farms and in organizing the market linkages which would reduce post-harvest losses as well as transaction costs. It would help farmers realise higher prices for their produce. This long-term approach would generate considerable off-farm/non-farm employment opportunities for rural youth.
- Marginal returns tend to show diminishing trends from additional public investments; and, therefore, suggested for stepping up of investments in the less developed and rainfed regions for higher returns and for meeting the future growth challenges in agriculture. For eastern and rainfed states, an increased focus should be on raising capital intensity in irrigation and infrastructure to accelerate income growth. A greater emphasis towards agricultural research and extension is advocated as the resultant increase in crop productivity will have a concomitant effect on increase in income and reduction in poverty.
- The export earnings through rice (basmati and non-basmati) and fishery products should be promoted. There is a need to promote for fresh produce trade and also value added products for export. It is not always necessary to depend only on processed

products, as has largely been the western model. Today the consumers are showing greater preference for fresh produce, and it is possible to deliver at the consumption centres, as there exists a robust transportation and communication network. It is essential to promote partnership with the private sector and supporting agri-entrepreneur to deliver sustainable and scalable solutions.

6.3 Use of GM Technology in Agriculture

Notwithstanding the existence of comprehensive framework and rigours protocol for regulating genetically modified technology in India, the safety concerns that pervade must be respected; as also ethical, social and environmental consequences of GM technology, that alters the genetic code must be understood thoroughly before its widespread application in agriculture sector.

However, given the new challenges relating to need for yield breakthroughs; resistance to pests & diseases; resilience to drought & other climate change impacts; and enabling agriculture to feed raw material to industries, crop improvement programmes call for robust application of R&D. In this context it is suggested, that:

- i. Transgenics may be used on priority in non-food sector.
- ii. Since more than 95 per cent of the genetic diversity of the country has yet not been tapped, conventional breeding programme may be depended upon in case of food crops. The genetic diversity available outside the country may also be accessed for this purpose.
- iii. Of the several GM technologies, Genome Editing may be considered after diligent examination in case of food crops, when specific trait is not available to undertake conventional breeding.

6.4 Overall Concern and Immediate Attention Needed

- Agriculture is still the mainstay for almost forty-eight per cent of India's rapidly growing population and it is generally correlated with low socio-economic status, education, health and poverty. Several emerging challenges such as limited land and water availability, degradation of natural resources, climate changes, increasing population pressure confront Indian farmers. In order to enhance the production and overcome the drudgery that results from the use of traditional farm practices and tools, farmers need to adopt new technologies.
- The changes in the sector require enhanced innovation capacity, through providing appropriate innovation support arrangements to meet new needs. Supporting smallholder farmers requires the provision of non-technical support services such as marketing support, financing, collective organizing and business management. Further, there is increased recognition that innovation is a process that occurs within networks and requires systemic support, including strengthening of interactions between diverse

actors. However, mobilizing such networks – central to enabling innovation – remains a challenge.

- There is an urgent need to understand and break the unholy nexus of drought, land degradation and poverty for improving livelihoods, food security through sustainable intensification of natural resources using science-led, holistic development approach. The effect of increasing climate aberrations would be on small farm holders located in the marginal areas. Therefore, investment options for both adaptation and mitigation, and policies which can help in reducing the impact of climate change, are urgently needed at this stage, especially to provide incentives to the small farm holders for the adoption of technologies and practices that can mitigate the impact of climate change.
- There is a wide gap between discovery-proof of concept and the impact of technologies which is called as 'death valley'. To bridge this gap, there is a need for Research for development concept which can help to overcome the 'death valley' as well as achieving large scale impact through strong network of extension system.
- Currently, the focus is on increasing the production and productivity. But it is essential to introduce innovative strategies that integrate agriculture and nutrition and such nutrition-sensitive agricultural interventions can focus on how agricultural interventions in the field can be designed to improve nutritional outcomes whilst promoting livelihood security. In this context, it is important to increase investments and credit support for the small and marginal farmers to shift them from growing low-value crops to high-value crops. This requires proper incentives, enabling policies and institutions to slowly innovate to produce marketable surplus and invest further in sustainable intensification. It is important to recognise that market information and intelligence are crucial to enable farmers to make informed decisions about the choices of crops, storage and marketing. Hence, dissemination of market information such as demand, production and prices plays an important role in the functioning of the market, by harmonizing the competitive marketing process.
- New information and communication technology (ICT) tools to be used not only as a means of knowledge exchange but also as a source of livelihoods for the educated youths in the rural areas will have to be worked out. The process of changing roles and additional responsibility and limitations of resources in public extension have created a gap, which is getting filled up by private extension. This desirable development needs governmental encouragement and regulation. There exists, a large space for public private partnership in the area of agricultural sector. However, it has to be a win-win-win proposition for all the partners. Small and marginal farmers' interest must be at the center while devising the public private partnership policies. However, to operationalize integrated and holistic strategy through consortium approach, it calls for change in the mindset of the various actors such as researchers, policy makers and development workers, farmers and private industries.
- The Science of Delivery is the collective and cumulative knowledge base of delivery that helps practitioners make more informed decisions and produce consistent results

on the ground. Central to Science of Delivery is the notion of learning from operations, revisiting past interventions to apply knowledge about the implementation process to future interventions. One of the ways to strengthen science of delivery is to use demonstrations results to build awareness among local level stakeholders especially farmers about the new technologies. These are the local proofs which have more value in convincing farmers. Extension workers can use this information and can teach with more confidence about a recommended practice when that is locally proved to be a success in that area through local demonstrations. This is the first step of scaling-up of new technologies for achieving large impact with minimum time scale.

6.5 Some specific and Urgent Issues for Reorientation of Research and Development in Agriculture

- i. R&D should serve to initiate a new & comprehensive agricultural transformation, that transcends from 'Green Revolution' to 'Farmers' Income Revolution' or 'Income Revolution' in short.
- ii. It has to be a system based science & technology in contrast to crop & commodity – centric, as has been the norm so far.
- iii. The technology outcomes and advocacy must infuse sustainability of resource use and throughput.
- iv. The emphasis has to be on small farms, apart from validating the technology for larger farms.
- v. The R and D policy has to be scaled up with greater robustness for delivery. The expenditure in Agri-R&D have been averaging around 0.3-0.4 per cent of the Agri-GDP. This compares poorly vis-a-vis other countries like Brazil, China, Malaysia and Mexico. As well known returns from Agri-R&D are much higher than in other economic activities, and growth of agriculture economy benefits positively. It is, therefore, beneficial to scale up investments in Agri-R&D.

Volume XII B

Digital Technologies for Agriculture

Chapter 7

Role of Digital Technologies

Digital technologies can play a transformational role in modernising and organising how rural India performs its agricultural activities. The technologies include Artificial Intelligence, Big Data Analytics, Blockchain Technology, 3-D Printing, Internet of Things (IOTs) and others as they are developed. Appropriate and timely adoption of such technologies can lead to smart and sustainable farming.

7.1 Transformational Role of Digital Technologies

In many developed countries, farming has been modernised by a wave of technologies, adopted at farm level. In emerging economies too, agriculture is becoming “Industrialised”, and spoken of as a “Value System”. Digital technologies are finding increasing use in the agricultural value system, and farmers are increasingly becoming more informed, as various measures are taken to provide them ready access to technology and information. High-tech farming is becoming the standard, thanks to use of sensors, logic controlled systems, data analytics, etc. In India, the increasing availability of energy and internet connectivity to the large rural landscape is further accelerating such changes. This transformation will continue as linkages with international markets also get expanded and get more robust.

The transformation comes from the stark changes that technologies bring about on age old practices and from informational inputs that effect a rethink in the decision making processes. The transformation also causes disruptions as it builds aspirations and competition, which in turn can amplify various errors and omissions. Various examples of changes that technology can bring in the operational environment abound. Some are simple and already a part of history.

When communication systems were analog, the market yards were literally assembly points for farmers to collect and exchange information. The market network was used by the government as a medium to propagate information and ideas and to regulate. With the advent of digital communication, the information dissemination progressed onto radio, television, and now over mobile and internet technologies. The physical assembly of people was not needed and markets were no longer considered assembly points but produce aggregation platforms. Digitised information allowed remote access to knowledge, gave rise to group sharing and even now continues to revamp the extension services system.

The impact on total yield through use of intensive farming technologies is already well known, as well the ecological impact from misuse of chemical and natural resources. Now, the soil health card system, can give farmers access to information which can be used to decide on optimal use of various resources as inputs. This system, as it is made more real-time, will bring transformational changes to the cost of cultivation and the sustainability of farms. There are technologies where soil health can be assessed without transmitting the soil physically to a lab, but merely by taking a spectral image of a soil sample. The digital spectrogram can be compared against a large database and spectral analysis can diagnose the contents of the sample. This analysis can happen in the cloud, and results communicated to the farmers almost

instantaneously. There various similar technologies where a sample from a field, gets converted into digital information, analysed and provide accurate results which will allow farmers to take decisions best suited to the land they farm on.

Whereas, a large share of agricultural land remains rainfed, almost half of agriculture is now being practised in irrigated conditions. This is being further refined through applying straightforward mechanisms like micro-irrigation, fertigation and protected cultivation systems. The next stage of interventions use sensors to assess soil moisture and composition, which send signals to actuators that control sluices or pumps, to initiate a controlled flow of water and nutrients and this can all be done without immediate human interface. This is another drastic change to past irrigation practices. The technology optimises on water resource use and reduces drudgery where farmer would require to wake up pre-dawn to water the fields.

In protected cultivation, sensor based systems are also in use to monitor internal humidity and light conditions and trigger lighting adjustments and fan-pad systems, etc. Such activities are also digitally transmitted for record keeping and for remote controlling the operations by human interface. In fact, such technology adoption will bring in new skills and practices in farming, such as checking and managing pumps, valves and irrigation lines, calibrating soil sensors and measuring, mixing and testing of nutrient mixtures, etc.

The availability of satellite imagery, infrared imagery, and a myriad of remote inputs allows for more accurate weather forecasts, advance warnings on pest infestation and similar, and more. These are well known examples of how digital technologies and systems have found extensive use in agriculture, and they have made a lasting impact on how agriculture is accomplished. Instead of traditional homilies about temperature and rainfall events, the farmers now consult and share the advisories and forecasts of the same.

Geo-tagging of a land, bio-tagging of livestock, bar-coding of planting material, and others are all methods of identifying and managing assets through use of digital technologies. Similarly, the use of Aadhar to identify and manage the delivery of support, directly to farmers is another transformation intervention in farming. Digitalisation of Direct Benefit Transfer (DBT) to farmers is an important step, along with building a database of farmers.

The above examples, are indicative and not comprehensive, and the technologies continue to improve. Every new technological development, sets off new and innovative utilities as they are rolled out and users apply them in their activities. The role played by digital technologies keeps getting upgraded and scaled up. There is need to continuously monitor and identify new developments and prioritise applications for the purpose of enhancing farmers income.

The digital technologies, allows for some basic rethinks on how a farmer uses mechanical tools, reduces drudgery, and how they record, access and use information. A drone, spray machine, tractor, water pump, etc. are physical machines, the use of which is made more relevant and precise when the machine systems are able to signal each other digitally. Digital technologies

allow machine systems to interact and coordinate their activities in a logical fashion. Digital technologies also allow for large amount of historic and real-time information to be recorded, sifted and correlated and this in turn optimises how information is used.

7.2 ICT based support for Farmers

Ministry of Agriculture & Farmers' Welfare targets improved awareness and knowledge efficiency of farmers. A comprehensive ICT strategy has, therefore, been developed not only to reach out to farmers in an easy and better way but also for planning and monitoring of schemes so that policy decisions can be taken at a faster pace and farmers can be benefited quickly. To empower different sections of rural areas, different ICT strategies have been devised:

- Those who have access to digital infrastructure can get the information through websites/web portals.
- Those who have smart phones can access the same information through mobile apps.
- Those who have basic phones, can get this information through
- SMS advisories sent by experts.
- To get the personalized information; farmers can call at the toll free number of Kisan Call Centre – 18001801551.

7.2.1 National e-Governance Plan – Agriculture (NeGP-A)

In agriculture, availability of real time information at the right time is the major miss. Lack of information at proper time causes a huge loss to farmers. NeGP-A aims to bridge this gap in communication by using technology. It provides an integrated approach to the delivery of services to the farming community using ICT. Under NeGP-A, around 60 online services have been developed and launched to provide ease of access and timely information to farmers. Some services are developed for monitoring of schemes so that quick analysis and reporting can be done.

7.2.2 Agriculture 2.0 (Digital Agriculture)

Under Digital India interventions, the Government has given prominence to ensuring availability of information on various agriculture and allied sectors activities, to improve the agricultural output. Agriculture 2.0 (Digital Agriculture) directly falls under Pillar No. 5 of Digital India, i.e. eKranti – Electronic Delivery of Services and broadly caters to other pillars as well, like e -Governance: Reforming Government through Technology, Information for All and Early Harvest Programmes. Some of the key thrust areas identified under Digital India for Ministry of Agriculture & Farmers Welfare are incorporation of space technologies, development of mobile apps, GIS Mapping, citizen-centric services for Cooperation, Fertilizer Testing Labs, Cold-chain availability, identification & development of services for specific sectors of horticulture

and fisheries, use of crowd sourcing, increasing online transactions, use of innovative technologies like text to speech, image recognition, Big Data Analysis and Data Intelligence, Direct Benefit Transfer etc.

7.3 Upcoming technologies

Developing technologies such as Big Data Analytics, Internet of Things, Block Chain, Artificial Intelligence, Robotics & Sensors, etc. are interrelated and used to optimise the decision making process and the operating procedures of every sphere where they find application. These technologies are practices that are deeply interwoven with computerised systems, complex digitised interactions and even self-learning models. In contrast, agriculture involves earthy processes such as attending to soil and cultivation, managing the production and supply of goods. However, agriculture, despite being civilization's primary organised production process, continues to be subject to uncertainties across various involved disciplines. Not only has agriculture moved beyond sustenance farming into commercial production, it now touches more lives than the population immediate and local to the producing region.

Agriculture no longer drives other economic and social activities, as in the past, but is subject to and is expected to reflect the demand from the wider population. Though the agricultural system, directly impacts on quality of life of all individuals, even those in non-agricultural activities, it in turn, is expected to be led by the demands from its end-consumers. A physically interconnected world has made agriculture a highly competitive production and marketing system. Nevertheless, agriculture still has a certain fuzzy logic built into its operations, as the factors that affect the system, have various degrees in how they manifest. The widening scope of agricultural activities, its continued subjectivity to uncontrollable environs, the large quantity of data it generates and the increasing need to have focused & specific deployment of agricultural sciences has made the agricultural system an important domain for use of aforesaid new technologies.

7.3.1 Big Data from agriculture

Farms and farmers provide large amounts of data, which need consolidation and analytics for strengthening agricultural system. The various on-farm cultivation systems, when integrated with the market system, agricultural demand and made responsive to such integration, makes for an optimal agricultural value system. The desired integration of physical activities requires intelligent management and assessment of complex and voluminous data. Big data analytics provides the opportunity to systemise the large amount of data that is generated from agricultural and allied activities.

Farms and farmers produce big data, which need interpretation using Information technology for transforming the agricultural value system. Agricultural Census data on about 138.5 Million Operational holdings itself constitutes a very large database (VLDB).

As automation use in on-field and off-field machinery increases, large data from sensor

technology will also be available. Such sensors are already seen in irrigation system, temperature control equipment, soil monitoring equipment, etc. The physical measurement and monitoring mechanisms, deployed through mobile imaging, satellite imagery, drone patrolling, GPS / RFID tracking and production traceability, will all require support from big data management and analytics.

National projects viz., Agmarket, eNAM, Animal Health, Soil Health and others, generate data at micro-level granularity and require extensive analysis at national, state, district and sub-district levels. It is not pertinent for this Committee to list all the various data sources and its uses in agriculture as the list is itself voluminous. Such data can be developed as “Data Marts” for utilisation. The analysis will not only help at an operational level, but also assist policy makers by identifying structural weaknesses, priority areas and on the improve monitoring capabilities. Harnessing big data, for weather-index based insurance, financial and credit programs, are also viable propositions to manage financial, weather and climate risks.

Long standing data, when compiled in a comprehensive and standardised manner, helps to unearth previously hidden patterns, provides correlation between perceived disjointed activities and opens new insights into the management and governance mechanism. The main challenges in managing big data is collecting and collating the data, data storage, rights to the data and data analysis, querying, and transfer.

Big Data Analytics get its penetration by adopting technologies viz., Social Computing, Internet of Things (IoT), Data Virtualization, Statistical Methods and Machine Learning, Data Science Methods and Tools, Data Mining Algorithms, Data Analytics Processes, Platforms, and Practices, and Information Visualization Tools and Dashboards.

Big Data Analytics is still in an early development stage in India. However, government agricultural development schemes (spread across the entire agricultural value system), AGMARKNET/e-NAM, Soil Health Card, National Animal Disease Reporting System (NADRS), Kisan Call Centre Database, DBT schemes and others, are already driving the adoption of Big Data Analytics in the agricultural sectors.

7.3.2 Internet of Things (IOT) in Agriculture

Internet of Things (IoT) basically means the internet interconnectivity of all connectable things. The things, include people and devices, i.e. anything that outputs or can use a ‘yes/no’ or ‘on/off’ signal. Therefore, IoT is a giant network of things which results a connected relation between people-people, people-devices and devices-devices. This allows the things to digitally interact to trigger action or decisions, on the basis of usable information or predetermined ‘flags’.

IoT takes forward the networking of traditional devices like desktops, phones and tablets, to a wider range of everyday things like appliances, sensors, vending machines, automobiles, etc. In a local network such connectivity is seen in use in factories or buildings, where a closed

circuit system can stream data internally (say visual, humidity or temperature sensors) – when this information is made accessible over the internet, the local web would be a part of Internet of Things. IoT facilitates the remote access to active information. For example, a farmer visiting the local market, can access his in-field soil sensor to decide on what fertilizer to buy, or remotely access health parameters of his livestock. The Web of Things (WoT), is a refinement of the Internet of Things by integrating smart things not only into the internet (network), but into the Web Architecture (application), for ease of use and bring a higher level of maturity for scalability and sustainability.

Draft IOT Policy of the Ministry of Electronics and Information Technology (MeitY) addresses IoT in Agriculture and Irrigation and provides incentives to capture investors' interest. IoT can be used in precision farming, pest management and control, soil monitoring water management, food production and safety, and livestock. Just about every branch, activity in agriculture and food needs the support of sensing and interpretation of sensor data. Indeed, the whole network of future sustainable agricultural and food technologies, capable of dealing with climate change and population growth, will benefit from an internet connectivity of the things involved.

7.3.3 Artificial Intelligence

Sensors provide the data and can be used to automate specific tasks on the triggers provided. Artificial Intelligence (AI) takes automation to another level, by incorporating analysis and learning on the basis of past and current data. AI further, adds the scope of automation even in decision making, where the integration of multiple and varied information is interpreted to balance a desired set of outcomes, which could themselves be variable. The complexity in agriculture makes it a very promising field for application of AI technology.

AI supports in decision making, provided through machine and digital learning processes. Human intelligence can take long to assimilate, understand and react to all the complex variables that comprise the uncertainties that agriculture is subject to. This tends to promote a word-of-mouth method of activity, promoting copy-cat decisions or dependence on more traditional decision taking. Artificial Intelligence can help make better sense of the inherent fuzzy data and rapidly put out answers from extremely complex inputs. Further, the logic improves with learning and these factors make AI suited as an agricultural technology.

Farmers can benefit not only from the direct on-farm applications of AI, but also from the use of AI in the development of improved seeds, crop protection, and fertility products. Besides the unpredictable biological and weather related processes during cultivation, agriculture is also dependant on variables from multiple market situations. AI can offer more reliable predictions, to be used as a basis for planning and control of all agricultural activities.

AI applications require large amounts of data to properly train the algorithms. AI deployment is a natural corollary of large data warehousing (big Data) and automation. The use of ICT by way of interactive communication with farmers, also creates opportunity for AI powered chat-bots (which are conversational virtual assistants who automate interactions with end users).

These can use machine learning techniques, understand natural language and interact with users in a personalised way, giving advice and recommendations on specific farm problems.

Cognitive technologies allow analysing and correlating information about weather, type of seeds, types of soil or infestations in a certain area, probability of diseases, data about what worked best, year to year outcomes, market trends, prices or consumer needs, and facilitates farmers to make decisions to maximise on crops and livestock output. Remote sensors, Satellites, and UAVs gather information 24 hours per day over an entire field, so as to monitor plant health, soil condition, temperature, humidity, etc. IOT and AI are thus the two technologies having progressive impact on agriculture and its future. Design and development of AI algorithms to process vast agricultural seasonal data can be challenging in an agricultural setting, but is necessary. The advent of big data and sector-specific machine learning tools related to the sector provide the necessary tools and data which when analysed will help increase agricultural productivity, inputs and produce management, and farmers income.

KVKs and ATMA centres are well positioned to be the nerve centres for AI applications, and for knowledge diffusion to farming community.

7.3.4 Block Chain Technology for Agricultural Value System

Blockchain is a database system, created by an unknown person or persons (named Satoshi Nakamoto), that maintains and shares a transparent immutable record of the history of the transactions. In the traditional world, such a record of transactions or ledger, would be maintained individually by each transacting party.

Individual ledgers require to be reconciled when settling accounts, and the method was open to corrections and manipulations. This manual and individual keeping of records was common in the banking system where the account holder would reconcile own ledger periodically with the bank provided passbook. Individual ledgers maintained by each transacting party, especially when transactions are complex, made the system inefficient, paper laden, and allowed for human error or fraud and leading to disputes at time of reconciliation. In the blockchain, a single ledger of records is shared with the transacting parties, where each must give consensus before another transaction is added, and once recorded, the transaction cannot be altered.

In any supply chain, the blockchain using parties could include the producers, retailers, logistics providers, and regulators. A digital trading platform based on Blockchain technology, modernises agricultural trade by directly connecting each transacting party to the same dataset, in a transparent manner. Blockchain is aimed at reducing transaction costs and creating financial security and supply chain transparency. Blockchain technology simplifies and lowers the cost of validation and tracking in the supply chain and in turn, facilitates smaller suppliers from the global food economy.

Major food companies have commenced using Blockchain technology to transform their supply chain. In the agricultural sector Blockchain technology can also be used to record interlinked field practices such as INM/IPM, confirm good agricultural practices, validate resource use efficiencies, build traceability for the produce from farm to fork, prevent price extortion and delayed payments. The technology also has various uses in the input supply chain, such as validating authenticity of planting material by keeping a record of high resolution images of the material in transit, provide similar traceability of other items from source to farms, record every input until point of consumption at farm level, etc. This immutable record keeping system, can help build checks in the input and output supply system. Since Blockchain relies on a distributed ledger (shared records), it is considered more secure as it makes it difficult to compromise the integrity of the data.

Blockchain adoption requires access to reliable internet connection. The initiatives to bring last mile connectivity through wi-fi hotspots and mobile data in rural India, will enable such technologies. The proposed COOPNET (Cooperative Informatics Network networking more than 100,000 Primary Agricultural Cooperative Societies – PACS) can be operationalised with such distributed cryptolegger (Blockchain) systems. The way forward is to establish a “Blockchain Technology based Testbed” for Agricultural Value System.

7.3.5 Robots and Sensors in Agriculture

Agricultural sector remains labour intensive and is a source of employment to a large section of societies across the world. However, there are specialised areas where robotics has already come into use in agriculture. While robotics and sensors are physical equipment, they use and provide inputs as digital signals and as a system are also considered part of digital technologies. The areas they are currently used, is where intensive attention or precision is required or where labour is not able to perform as per high-tech requirements. Robotics also help in automation of some tasks and can also free the individual farmer to prioritise and take on other works for added gains.

Robotics and automation are commonly used in nurseries for seeding, potting and care of the plants. Solutions are also in use in dairy facilities as in case of feeding and milking machines. Similar examples are seen in the fisheries sector, where automated feeders and pond aeration systems are used. Other reported on-farm uses are machines that recognise patterns and undertake targeted spraying of pesticide and fertilizer, the precision allowing to limit the application to individual plants. This functions much like face recognition in smart phones, where a data set of patterns triggers a precise reaction. Drones are unmanned flying machines, and make effective aerial sensors, used to control robotic machines for planting, seeding and harvesting large fields, besides other applications. The aerial view provided by drones, which can be across the digital spectrum, is digitally transmitted to computer systems, linked with geo-spatial signals and correlated and coordinated for various purposes.

In green houses, much like rain sensing windshield wipers in automobiles, rain and light sensing robotic arms can automatically retract or cover the roof as per need. Similarly, hi-tech

sorting and grading machines in modern pack-houses, sift and assay produce on the basis of optical and physical sensors, automatically package, label and move the boxes to next stage of handling. Automatic fork-lifts, pallet put-away and picking arms, and many such uses are seen in modern cold stores and warehouses. Robotic and semi-robotic equipment are also in use in poultry harvesting factories and abattoirs, besides in beverage factories, etc.

Robotics ease the physical handling of activities and large loads, doing it faster than humans can. The first level of smartness is derived from sensors, to start or stop an automation on its predetermined set of actions. Sensors and robotics go hand in hand, not only to actuate action, but also to monitor and stop an activity, at levels that include safety needs.

The Information Technology Research Academy (ITRA) set up by Ministry of Electronics and Information Technology), in consultation with the Indian Council of Agricultural Research (ICAR), had identified the various areas for research purpose in respect of robotics, sensors, interpretation and use of sensor data. This was carried out in 2013, and even in this short period of time, many more applications and uses can be added and innovated.

The Indian Agriculture Research Institute (IARI) has formulated a collaborative research project entitled “SENSAGRI: SENsor based Smart Agriculture” - involving six partner institutes under the ITRA Project Funding, to develop indigenous prototype for Drone based crop and soil health monitoring system using Hyperspectral Remote Sensing (HRS) sensors, so as to be integrated with satellite-based technologies for large scale applications. Such joint research efforts are recommended, to be undertaken and completed as per timelines.

7.3.6 Future uses of technologies

Possessing an amazing variety of mechanical skills, farmers have always innovated on their implements and practices over the years. Many a times, an innovation to a farm implement has died off, because further tools or parts were not easily available, or the further effort required was too time consuming. In case of various machinery used on farms, they could fall in disuse if the spare parts are hard to come across, because the model in use may be aged, could be local improvisation (no OEM exists), or if the village is not part of the spare part distribution network.

3D printing is a process for the manufacture of 3D objects made on the basis of a digital blueprint, stored as a computer file. It not only allows for rapid prototyping but is already used to produce small equipment and parts and can support experiments to innovate on existing tools. Hard to get spare parts for old valves, gears, pipe bends, plough tips, etc., can be printed for immediate use. In the years to come, such needs are set to expand. Much like how welding or electrical capabilities are common in villages, 3D printing capability may become normal for a farming operation. As 3D printing prices fall a 3D printer might become a standard tool on the farm. It is viewed that this technology may reach a point where machinery manufacturers allow farmers to purchase design files online and print spare parts or products themselves.

Mention of technologies such as 3D printing and others may seem farfetched, but the rate at which these convert into real applications with widespread uses is constantly increasing. Interactive agricultural micro-bots and robotic farm swarms, solar powered equipment, algorithmic suggested rapid iteration based selective breeding, livestock biometrics, are examples of technologies in various stages of use and development. Some could be mainstream in the coming decade.

7.4 Possible Areas of Smart Devices and Applications in Agriculture

The Department of Agriculture, Cooperation and Farmers' Welfare (DAC&FW) has desired that information generated from Sensors can be provided on the phone of farmer as SMS or via an mobile apps preloaded on their phone, and the collected data may be used for Big Data Analysis so as to create suitable Policies and Decision Support System (DSS). The Department has communicated (DAC&FW, 2016)³ on the formation of the Working Group on SMART Village and Agriculture and quotes areas related to Agriculture, where smart devices and applications can be useful, as follows:

- (i) Provide soil composition of Soil components in the field;
- (ii) Provide details of water level, humidity/moisture content and acidity/pH in the soil;
- (iii) Provide the status of growth of crop in terms of expected growth and current growth by using various parameters;
- (iv) Provide inside and outside temperature of the field in respect of crop as per its standards;
- (v) Provide temperature and also share in case of possibility of severe weather change by connecting the filed level device with district weather departments;
- (vi) Provide details of dimensions of field and classification of crop planting by analysing the total field level coordinates;
- (vii) Provide advice on crops to be sown based on NPK content and environment values and comparing with standard databases;
- (viii) Setting up of Digital Scare Crows as well as monitor any field level intrusions;
- (ix) Advise on requirement of water in the field in case of dryness increases;
- (x) Provide alert on any crop damage in case of animals destroy crops;
- (xi) Wireless communication to villages and online Knowledge-bases;
- (xii) Recommendations on the basis of crop growth, stage-wise nutrient content and required nutrients;
- (xiii) Monitoring of insects and pests incidence using sensors with various types of traps;

³ DAC&FW (2016): Communication of the Department of Agriculture and Cooperation (Ministry of Agriculture & Farmers' Welfare) - vide No. Z-11015/1/2015-IT-Part(I) dated 7-Jan-2016, to TEC which has formed the Working Group on SMART Village and Agriculture set up by the Telecom Engineering Centre (TEC), Ministry of Communications

- (xiv) Digital view of field from home /remote location;
- (xv) Information on real time moisture and temperature variations in grain storage to undertake corrective measures to prevent pest infestation;
- (xvi) Provide information on protected cultivation in green Houses;
- (xvii) Controlling the micro sprinklers quantity, direction etc;
- (xviii) Monitoring animals body temperature to ensure proper health and information on food quantity consumed from their food drum beds;
- (xix) Quality evaluation of honey bees and honey bed growth using IR or UV radiations analysis;
- (xx) Precision Livestock Farming (PLF) sensors for monitoring and early detection of reproduction events and health disorders in animals;
- (xxi) Identification of Fish Density Zones (FDZs) in the Sea and informing and guiding Fishermen about FDZs;
- (xxii) Temperature regulator in fisheries to produce different varieties of fishes in different zones like greenhouses;
- (xxiii) Use of bio sensors matrix and analysing the weeds and insects in the field;
- (xxiv) IR sensors for monitoring growth and development in urban horticulture;
- (xxv) Monitoring the soil density and nutrition values after a particular crop;
- (xxvi) Ontology based CDN Systems to assist the sensors for capturing data and analysing with standard data sets for a specific crop domain dynamically;
- (xxvii) Maintaining temperature/humidity for perishable goods;
- (xxviii) Environment control and weather sensors in poultry farms.

The ICAR – ITRA Joint Research Programme is also required to look into the areas identified by the DAC&FW for possible areas of IOT based smart devices and applications in agriculture, and also to get associated with the TEC Working Group on M2M Domain: Smart Village and Agriculture (set up by 2015), so as to enrich ICAR-ITRA Outreach Programme, based on the standards published by TEC Working Group.

7.5 Digitalised technologies in Farming

All current and upcoming technologies hold the potential of boosting innovations in organisation that leads to improvement of agricultural models. By adopting Data Science and an analytical approach, various solution can be found to erstwhile insurmountable challenges, to minimise risk and maximise profit of the farmers. Smart systems have been brought into use in India's Dairy Sector by private sector organisations, for improving agri-supply chain parameters, including milk production, milk procurement, cold-chain, animal insurance and farmer payments. The introduction of smart technology into farming practices provides a new way for farmers to manage natural resources and hence, the economic profitability of the farm. Smart Farming uses modern automation and IT to increase the productivity and efficiency of modern farming in a sustainable way with minimal impact on the environment. The current

array of technologies would include the integrating of Internet of Things (IoTs), Satellite Monitoring, Mobile devices, Soil / Plant Sensors, Smart Zone Seeding, Autonomous Robotics, Weather Modelling, Fertilizer Modelling, Smart Micro-Irrigation. The systems would require to be standardised and inter-compatibility to be most relevant.

Business models are changing and trying to develop software platforms that will act as farm-management systems, which will collect data from individual farms and process them, allowing for the farm's history, the known behaviour of individual crops strains and the local weather forecast, and then make recommendations to the farmer. Information, when combined with geo-mapped land, creates a yield map that shows which bits of land are more or less productive, and thus in turn be fed into the following season's planting pattern. Farming solutions are facilitated by using technologies such as, Big Data (e.g. Agriculture Statistical System - Scientific Disease Monitoring and solutions), for subsequent analysis and use in Artificial Intelligence applications. The solutions they lead to can be such as, remotely controlled irrigation water management, site-specific farming (variable rate) for adaptation of the cultivation to the heterogeneity within the field (soil testing, landscape, microclimate), maximise yield potential and improve crop quality, reduce amount of inputs and environmental impact, etc. The technology and applications are suggestive of the scope and scale possible. The impact on analytics in rationalising priorities and expediting the policy making process is yet to be fully realised.

7.5.1 Challenges in Digital Technologies

There has been a lack of interoperability, because currently ICT components of multiple vendors do not operate as one integrated farm information system. This impacts especially where database is expected to be used across applications. Further, the farming community would also need to be supported in building capacity for using such technologies. This work is to be actively promoted through extensions services. A SWOT Analysis was undertaken by (Moni & Saurabh Sharma, 2017) drawing on various stakeholders (farmers at block level, NGOs, academic & research institutions, public sector and private sector, etc.). The findings from this study are listed in the Annexures.

During the last 22 years, agricultural sector has been witnessing ICT growth in a very systematic manner. As the connectivity over BharatNet / RailTel / Cable TV etc., systems strengthen in reach, they will also require to be strengthened with specialised content. Local innovation cells, including farmers can be supported to create media for knowledge sharing.

7.6 Annotation

For many, the bringing in of digital technologies into Indian farming system may seem far-fetched, especially from the perspective of doubling farmers' income in a short time-period. However, the importance of moving towards such system integration, of the physical and digital worlds, is important to sustain income growth in the long run.

Lack of standards, a perceived poor transparency around data use and ownership, and the difficulty of gathering and sharing data have led to a situation where AI algorithm developers in Agriculture are still starved for data.

SMART Farming uses modern automation and IT to increase the productivity and efficiency of farming in a sustainable way with minimal impact on the environment, which will be “Future Farming”. There is a school of thought that both digital technologies and precision farming merge to form “decision farming” which is termed as “future farming” and “smart farming. This will amount to “Informatics led Agricultural development”.

Digitalisation of Agriculture makes imperative that the Agricultural Science Curriculum of the Graduate level needs to include Digital Technology disciplines so as to develop human resources having competency in both Agricultural Science, Technology and Engineering, and also Computer Science, Technology and Engineering, in their 4-Year Curriculum. This discipline is also termed as “Agricultural Informatics Engineering”.

Agriculture Skill Development, under the PMGDSA (Prime Minister Gramin Digital Saksharta Abhiyan) scheme of the MeitY, should also consider “targets” to be achieved by 2022. All Farmer Friends should be trained under PMGDSA. This Committee has recommended that the current practice of one Farmer Friend per two villages be revised to have one Farmer Friend per village and that at least 50 per cent of Farmer Friends be women.

As Agriculture is complex, and it involves multiplicity of both schemes and institutions, there have been issues related to “institutional accountability” and “benefits reaching the needed farmers”. It is suggested to operationalise a “Farmer Welfare DBT Portal” as the MetaPortal (System of Systems) - in 22 constitutionally recognised Indian languages, linking farming community and the Central and State government institutions..

The DNF sub-Informatics Networks viz., AGRISNET (and its subset DACNET), ARISNET, AGMARKNET, PPIN, SEEDNET and HORTNET are operational more than a decade and need further strengthening. Networks viz., FISHNET, FERTNET and Weather NET are at different stages of development, whereas the Networks viz., CoopNET, APHNET, LISNET (AgRIS), AFPINET and ARINET are yet to get into synergy. The NeGP-AMMP was expected to be “VISTARNET of DNF.

Digital Technologies in Agriculture (DTA) and Digital Networks for Farmers (DNF) are essential components for empowering farmers, reducing cost of cultivation, increasing their income, and enhancing agriculture productivity.

Key Extracts

- All Farmer Friends be trained in use of digital technologies.
- All PACs to be networked and computerised using block chain systems.

--To be added--

Chapter 8

Digitalisation across the Agri-Value System

Digitising the information flow and data analysis across the entire “Agricultural Value System” brings extended benefits. Using digitised information to technologically engage and address specific needs is digitalisation. Such intervention brings innovation, both structural and from perspective of governance, which is needed to capture greater value from agriculture and for sustained income growth of farmers.

--To be added--

Chapter 9

Road Map for Modernising Agriculture

Scientific interventions must have clear outcomes that will modernise the agricultural sector. Scientific practices and technologies are required to be translated into associated enterprise level utilities and models. A technology should preferably be simple to use, replicable by many and easily serviceable. These factors are key to economic viability and long term relevance to the scientific intervention.

--To be added--

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Annexures

Table-A.1: Mapping of the Ministries for Goals and Targets (as of August, 2017)
(<http://www.niti.in>)

SDG #	SDG Description	SDG Targets	Ministries / Departments concerned
2	<i>End hunger, achieve food security and improved nutrition and promote sustainable agriculture</i>	2.3 : By 2030, double the agricultural productivity and the incomes of small-scale food producers, particularly women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets, and opportunities for value addition and non-farm employment;	<ul style="list-style-type: none"> • Agriculture, Cooperation & Farmers' Welfare • Chemicals & Fertilizers • Tribal Affairs
		2.4: By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters, and that progressively improve land and soil quality;	<ul style="list-style-type: none"> • Agriculture, Cooperation & Farmers' Welfare
		2.5: By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed;	<ul style="list-style-type: none"> • Agriculture, Cooperation & Farmers' Welfare • Tribal Affairs
		2.c: Adopt measures to ensure the proper functioning of food commodity markets and their derivatives and facilitate timely access to market information , including on food reserves, in order to help limit extreme food price volatility;	<ul style="list-style-type: none"> • Agriculture, Cooperation & Farmers' Welfare
6	<i>Ensure availability and sustainable management of water and sanitation for all</i>	6.5: By 2030, implement integrated water resources management at all levels, including through trans-boundary cooperation as appropriate;	<ul style="list-style-type: none"> • Ministry of Water Resources • Ministry of Rural Development & Panchayat Raj • Agriculture, Cooperation & Farmers' Welfare • Department of Land Resources

SDG #	SDG Description	SDG Targets	Ministries / Departments concerned
14	Conserve and sustainably use the oceans, seas and marine resources for sustainable development	14.4: By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans , in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics;	<ul style="list-style-type: none"> • Dept. of Animal Husbandry, Dairying & Fisheries (DADF)
		14.5: By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information ;	<ul style="list-style-type: none"> • MoEF &CC • Ministry of Science & Technology, • Department of Animal Husbandry, Dairying & Fisheries (DADF)
		14.6 : By 2020, prohibit certain forms of fisheries subsidies which contribute to overcapacity and overfishing, eliminate subsidies that contribute to illegal, unreported and unregulated fishing and refrain from introducing new such subsidies , recognizing that appropriate and effective special and differential treatment for developing and least developed countries should be an integral part of the World Trade Organization fisheries subsidies negotiation;	<ul style="list-style-type: none"> • Department of Animal Husbandry, Dairying & Fisheries (DADF)
		14.7 By 2030, increase the economic benefits to small island developing States and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism ;	<ul style="list-style-type: none"> • Department of Animal Husbandry, Dairying & Fisheries (DADF), • Ministry of Tourism
		14.b: Provide access for small-scale artisanal fishers to marine resources and markets ;	<ul style="list-style-type: none"> • Department of Animal Husbandry, Dairying & Fisheries (DADF)
15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss;	15.3 By 2020, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land-degradation-neutral world ;	<ul style="list-style-type: none"> • Agriculture, Cooperation & Farmers' Welfare • Land Resources

Table-A.2: SWOT Analysis was undertaken by (Moni & Saurabh Sharma, 2017)⁴

The Small and Marginal farmers, constituting about 85 per cent of the operational holdings of size (< 2 Ha.), are equipped with (a) progressively Mobile Communication Technology - Feature Phones and Smart phones; (b) Traditional (Tacit) farming methods (knowledge); (c) taking farm level decision based on past experience; (d) access to Extension only through neighbourhood Farmers; (e) Watch out for effective Information Service delivery on Agro-met Advisory Services, Soil and Water Sample Analysis (Farm Health) and Advisory Services on Management Salt affected Soils, etc. However, they have the following problems/issues on hand:

1. **Limited access** to information on Improved Agricultural Technologies;
2. **High level Dependency** on ineffective Public Sector Extension System on large scale;
3. **Highly Susceptible** to Advisory Services from Un-Authorised Sources;
4. **Hesitant** to exploit emerging Technologies / New Generation Technologies;
5. **Lack of Information Content** in local languages;
6. **Digital Literacy Issues;**
7. **Problem of Internet Access;**
8. **Lack of innovation and motivation to innovate;**
9. **Adoption of Traditional methods of Farming;**
10. **Moving out of Farming** by Rural Youths;
11. **Non-existing Marketing Entrepreneurship:** Value-addition through Processing based on Consumer needs and adequate Investment Resources for Commerce and Trade (National and International);
12. **Questionable Utility / Performance based Government Subsidies;**
13. **Conservative Family Values and Outlook;**
14. **No-Ease of Doing Business / Getting Service**

The **Large Scale Farmers**, who constitute about < 1 per cent of Operational Holding Ownership, have shown their progressive farming operational strengths in adoption of technology and access to Extension System on demand, as follows: -

1. Favourable to Acquisition and Adoption of Technology;
2. More inclined to Investment in Farm Automation;
3. Amenable for ICT Integration in Agriculture Value Chain (sectoral supply chain);
4. High Capacity to cope with Market-led Agriculture;
5. Have capacity to undertake RISKS and Independent Decision;
6. Amenable for adopting Good Agricultural Practices (GAP);
7. Have access to assured Irrigation Potential;
8. Access to Mobile Computing facility (Smart Phone) & Internet Access;
9. Wider access to Extension Services through Radio, TV, Internet, Mobile, Tablets etc.):
 - a. Agro-advisory services;
 - b. Soil and Water Sample Analysis;
 - c. Reclamation of Salt Affected Soils;

⁴ Moni. M and Saurabh Sharma (2017): “**Situational Analysis on the needs of Farming Community – ICT enabled Services**” (unpublished), Centre for Agricultural Informatics & e-Governance Research Studies (CARIS), Shobhit University, Meerut, Uttar Pradesh.

- d. Progressive Farmers (Trainer of Training);
10. Have resources and willingness to experiment New Generation Technologies (NGTs) and promote farm Automation;
11. Have high Investing Capacity on Resources, as they are economically affluent
12. Undertake Agriculture as Business Venture;
13. Understand the short term and long term benefits of ICT/NGT;
14. Have motivational interest in Precision Farming methods; and
15. Mostly Innovative.

The Semi-Medium and Medium Scale Farmers, who constitute about 14 per cent of Operational Holding Ownership, are having problems more or less same as Small and Marginal Scale Farmers. The Challenges faced by the 99 per cent of the Farming Community (both Marginal, Small, Semi-medium and Medium Scale farmers) are enumerated under categories viz., Investment & Risk Management; Citizen Charter; Technology Solution; Capacity Building & Competency Development; Accessibility, Authentication, Availability and Affordability Issues; and Information Security Issues, as given below:

A. Investment & Risk Management

1. **Community Risk Management System** through micro-finance and micro-insurance delivery systems;
2. **Coping** with Farm Risk and its Management;
3. **Credible** Agricultural Commodities Value-Chain: end-to-end information service (e.g. **AMUL's Dairy Value Chain** in Gujarat);
4. **Investment** for Establishing ICTs Infrastructure for Farm Automation;
5. **Making** "Farming as a Business" from Traditional farming practices;
6. **Dealing with** Tenant Farming & Absentee Owners;

B. Citizen Charter

1. **Public Grievances Redressal and ICT enablement** among farming community (through Electronics Service Delivery Act 2011);
2. **Identification** of Vulnerable Farmers based on certain ground-level happening criteria;
3. **Action Plan** (Short-Term, Medium-Term and Long-Term) for ICT for Agriculture (ICT4Ag);
4. **Development** of Farm Level Decision Support System;
5. **Trust worthy Input Dealers** (fertiliser, seeds and Agro-chemicals etc.)
6. **Site-Specific** Quality Information service delivery in local languages
7. **Overcoming** Affordability, Digital Illiteracy, Language Barrier and Wages issues;
8. **"Unverified & Biased Information"** Information Delivery in the form of Advisories;
9. **Trust worthy and targeted** Extension System – both Public and Private Extension Systems;
10. **Market Linkages: Credible** Value-Chain: end-to-end information service so as to remove intermediaries;
11. **Linkages** with Agriculture & Food Processing Industries;
12. **Compulsory Formation** of FPOs / FPCs etc;
13. **Crop Diversification.**

C. Technology Solution

1. **Identification, access and integration with niche markets** for achieving sustainability;
2. **Leveraging** existing ICT in Agriculture (IT4Ag) by National Agricultural Research System (NARS) – ICAR, Agricultural Universities/Colleges, KVKs, ATMAs, Agricultural Technology Application Research Institutes (ATARIs), Public Sector Banks, PACS, CSCs, etc.;
3. Appropriate ICT infrastructure at grassroots level;
4. **Provision of ICT enabled** (predictive, preventive and reactive) **Solutions / Services** to farmers;
5. **Service Providers** for the benefit of Farming Community and their empanelment;
6. **Multiple Platforms** based One-Stop-Solution for Farming Community, including Mobile Phones; One-Stop-Solution for Farmers
7. SMART Farming – SMART Irrigation, SMART Farm Health, etc;
8. **Networking** of Multiple Institutions for converged Village Level Service Delivery for better ROI;
9. **IT eco-system** at local level for information exchange;
10. **Operational efficiency** for large scalability for Farming Community;
11. **Access to electricity** to power ICT devices (e.g. Mobile phones);
12. **Operating Efficiency** of Telecom Network Services (e.g. weak signal strength, call drop issues, etc.)
13. **Operational efficiency** of Extension System built for MASSes (Scalability Issues)
14. **Technical Support** - Farm Mechanisation, Integrated devices to recommend site specific technologies with weather, soil moisture and water demand sensors; and Space technologies like Remote Sensing and GIS;
15. Farm Health Management through Application of Technologies (e.g. Drones(UAVs) to identify abiotic and biotic stresses of Plants)
16. **Farm Automation - FARM ERP and Adoption of Precision farming:** SMART Water, SMART Weather, SMART Health, SMART Carbon, SMART Nutrient, SMART Knowledge etc.

D. Capacity Building & Competency Development

1. **Providing Capacity Building and Competency Development** among RURAL YOUTHS in respect of “technology enabled Agricultural farming”;
2. **Providing Capacity Building to Farmers** on Advanced Farm Technologies, ICTs and NGTs;
2. **Undertaking** e-literacy Programme;
3. **Availability of Experts** for networking to provide site-specific solutions to Farmers;
4. **Integrated Land Use Planning System** for Sustainable Agricultural and Rural Development;

E. Accessibility, Authentication, Availability and Affordability Issues

1. **Access** to Quality Information on Agricultural Inputs;

2. “Information Currency” on Agriculture related Portals (e.g. AGMARKNET for Agricultural Produces Wholesale Market Prices);
3. **Non-Convergence** in Content and Carriage;
4. **Access to Real Time data** for updating and verifying information, innovations, competition, market variables, alternatives and opportunity exploitation options;
5. **Selection** of “right” information from numerous sources and **transform** it into useful knowledge;
6. **Availability** of “actionable Information” for Farmers;
7. **Access to information** (ICT Infrastructure) and **Information to Access** (Content) in local languages;
8. **Access to** Computerised Land Record System and **Geo-tagging** of Land Parcels used for agricultural purposes (Farming);
9. **Access to** Agricultural Credit and Financial Services;
10. **Integration** of Rural India with Urban India for Access to Alternative Inputs & Outputs;
11. **e-Learning Materials** on Food Processing, Products Development and market-led extension;
12. **Limited Access to electricity** to power Mobile Phone devices and **Telecom Signal Loss** for Smart Phones;
13. **Access to** Farmer Service Centres (FSCs) at grassroots level (if any);
14. **Access to Logistics** and Infrastructure Facilities (e.g. Transportation, Marketing, cold storage etc.);

F. Information Security Issues

1. **Susceptible** for misuse and cheating through uncontrolled social media networks viz. WhatsApp, LinkedIn, Facebook etc.
2. Data Security and Cyber Security issues;
3. Data Accessibility, Acceptability and Adaptability **issues**;
4. **Source & data credibility** – accessible over Social Media Networks;

G. StartUps

1. **Need** for StartUps in Farm Management Services;
2. **Mostly** into information sharing and e-Commerce Services;
3. **Need for customised information service to Farmers**;
4. **Need** to make awareness and operationalise Government Schemes which are spread across the entire agri-supply Chain;

This survey also listed out **possible opportunities on “Use of ICT, Extension, NGT”** for mitigating the Farmers' Distress as given below:

1. **Formation of Farmer Producers Companies (FPCs) / Farmer Producers Organisations (FPOs)** - Groups of Small & Marginal Farmers – rather than Small and Marginal farmers individually struggle:
 - i. Establishing ICT enabled Process to overcome in-situ hurdles;
 - ii. Promoting Market Linkages and Agribusiness;
 - iii. Staying Competitive by adopting IOTs, Big Data Analytics and Digitalisation to achieve maximum Resource Use Efficiency (RUE);

2. **Operationalisation of Smart Village and Smart Farming** – Micro level Planning (Sansad Adarsh Gram Yojana and Rashtriya Krishi Vikas Yojana)
 - i. SMART Water
 - ii. SMART Weather
 - iii. SMART Health
 - iv. SMART Carbon
 - v. SMART Nutrient
 - vi. SMART Knowledge
 - vii. SMART Energy
 - viii. **Site-Specific Technologies** using Crop Modelling, Climate Change Modelling and Economic Modelling, to increase farm outputs;
 - ix. **e-Farmer**

3. **Establishment of BharatNet – eHighways** to about 2.25 lakhs Gram Panchayats and further up to 6.35 Lakh villages under Digital India Programme;

4. **Capacity Building and Competency Development**
 - i. Adoption of Scientific methods and Good Agricultural Practices (GAPs).
 - ii. Adoption of Farm Mechanisation;
 - iii. Strengthening of Extension mechanism through ICTs;
 - iv. e-Learning Courses for Capacity Building of Extension Workers and Farmers;
 - v. Adoption of Smart Phones directly linked to literacy – L3F Distance education;
 - vi. Promotion of “Farm Fit Technologies” (FFT)s;
 - vii. Adoption of Technology Intensive Farming – Protected Horticulture, Hydroponics, aeroponics etc;
 - viii. Adoption of Digital Technologies for Farm Management;
 - ix. Marketing knowledge and On-line Marketing (Networking Markets at e-NAM Platform);

5. **Farm Knowledge Connectivity**
 - i. **Knowledge Hubs** in Villages – PPP Model – NARS and NGOs;
 - ii. **Operationalization** of Village Knowledge Centre (VKC) of CAPART (Ministry of Rural Development) / Village Resource Centres (VRC) of ISRO/DOS / ATMA & KVK of MOA&FW, Union Adarsh Gram Project of Union Bank of India, MSSRF VKC-VRC Project); NASSCOM Knowledge Centre; CABI e-Plant Clinic in J&k etc;
 - iii. **Delivery of the latest information** on Agriculture Value Chain (AVC) through lab-land, land-lab, lab-lab and land-land approaches;

6. **ICT enabled Empowerment of Farmers**
 - i. Bi-directional Information Exchange using ICTs (Smart Phones and Tablets)
 - ii. Knowledge Dissemination through Websites and Portals;

- iii. **Enhanced and Sustained Use** of ICT and NGT through and NGOs and Farm Cooperatives;
 - iv. “Farm-Fit” Agro Advisory Services (AAS) in local languages;
 - v. Mobile Apps on Expert Systems / Warning Systems;
 - vi. Operationalisation of ICT enabled Farm Health Management System – Plant Health, Soil Health (including salt affected soils), Water Health and Animal Health;
 - vii. **Creation of Site Specific** Agriculture Technology Information Base;
 - viii. **Agricultural Value Systems** for each Commodity / Service (about 400 agricultural Commodities);
 - ix. **Cost of Cultivation** Calculator (CCC) for Farm Management;
 - x. **Digitalisation of Farm / Farmers and Villages** – Smart Village & Smart Farming;
 - xi. **Interoperable Web services** enabled Portal;
 - xii. **Digitalised Access** to Agricultural Credit and Financial Services;
 - xiii. **Converged Agricultural Schemes** Delivery System;
 - xiv. **Traceability** in Agriculture Value Chain (e.g. Participatory Guarantee System (PGS) for India – Decentralised Organic Farming Certification System);
 - xv. **Extension Outreach and Adoption of GAP** for producing quality Farm produces
 - xvi. **Market led Farm production** (Demand – Supply) achieving economy of scale and sustainability for farmers;
 - xvii. **Result oriented ICT Platform** to build trust with farmers;
 - xviii. **Speech Recognition** based Information retrieval to overcome digital illiteracy issues;
7. **Digital SMEs: Development of ICT enabled Value-Chain** for Village Level Entrepreneurs (VLEs). Online Value addition of agricultural produces to promote more income and more market (Village Entrepreneurship);
 8. **CSR Programmes: Adoption of Villages by Corporate Houses** for market linkage, retail marketing and branding, as the large rural population is a big business opportunity for Corporates to explore;
 9. **Hotbed for StartUps** in ICT4Ag Sector, as Farming is a Knowledge System; Knowledge plays a key role in information revolution; **Creation** of “Use Case of Technology” and making it available to ICT StartUps in Agriculture;
 10. **Creating Database** on data collected on Cost and Margin Studies through different channels sanctioning Case studies **projects; issues related** to price Support Schemes & its implementation at village level; **problems faced** by Small and Marginal farmers in absence of such government support;
 11. **Information on Quality Assurance**, Agencies involved in implementation of quality assurance programme at producer’s level;
 12. **Formulation and Regulatory Support** for National Agricultural Informatics Development Plan, State Agricultural Informatics Development Plan, District Informatics Development Plan and Village Agricultural Informatics Plan;

This Survey has highlighted that ICT enabled Extension measures may face serious “threats” viz., (a) Unsuitable ICT equipment, Outdated Infrastructure and short comings in Capacity Building and (b) Misappropriation of ICT development funds and disruption of innovation priorities. There has been a strong requirement to bridge the widening gap of human resources among rural youths to promote Digital India Programme in Agricultural Sector which necessitates:

- **Establish Centre for Agricultural Informatics** dedicated to ICT Application in Agriculture/farming in Research and Extension Institutions (e.g. ICAR Institutes/State Agricultural universities/Extension education Institutes (EElS), etc.), facilitating India farming community in using ICTs for their livelihoods.