Vision 2050

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शरद पवार
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MESSAGE

The scientific and technological inputs have been major drivers of growth and development in agriculture and allied sectors that have enabled us to achieve self reliant food security with a reasonable degree of resilience even in times of natural calamities, in recent years. In the present times, agricultural development is faced with several challenges relating to state of natural resources, climate change, fragmentation and diversion of agricultural land to non-agricultural uses, factor productivity, global trade and IPR regime. Some of these developments are taking place at much faster pace than ever before. In order to address these changes impacting agriculture and to remain globally competent, it is essential that our R&D institutions are able to foresee the challenges and formulate prioritised research programmes so that our agriculture is not constrained for want of technological interventions.

It is a pleasure to see that National Research Centre on Yak (NRC Yak), Dirang, a constituent institution of the Indian Council of Agricultural Research (ICAR) has prepared Vision-2050 document. The document embodies a pragmatic assessment of the agricultural production and food demand scenario by the year 2050. Taking due cognizance of the rapidly evolving national and international agriculture, the institute, has drawn up its Strategic Framework, clearly identifying Goals and Approach.

I wish NRC Yak all success in realisation of the Vision-2050.

(SHARAD PAWAR)

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FOREWORD

The Indian Council of Agricultural Research, since inception in the year 1929, is spearheading science and technology led development in agriculture in the country. This is being accomplished through agricultural research, higher education and frontline extension undertaken by a network of research institutes, agricultural universities and Krishi Vigyan Kendras. Besides developing and disseminating new technologies, ICAR has also been developing competent human resources to address the present and future requirements of agriculture in the country. Committed and dedicated efforts of ICAR have led to appreciable enhancement in productivity and production of different crops and commodities, which has enabled the country to raise food production at a faster rate than the growth in demand. This has enabled the country to become self-sufficient in food and emerge as a net food exporter. However, agriculture is now facing several challenges that are expected to become even more diverse and stiffer. Natural resources (both physical and biological) are deteriorating and getting depleted; risks associated with climate change are rising, new forms of biotic and abiotic stress are emerging, production is becoming more energy intensive, and biosafety concerns are growing. Intellectual property rights and trade regulations impacting technology acquisition and transfer, declining preference for farm work, shrinking farm size and changes in dietary preferences are formidable challenges.

These challenges call for a paradigm shift in our research approach to harness the potential of modern science, innovations in technology generation and delivery, and enabling policy and investment support. Some of the critical areas as genomics, molecular breeding, diagnostics and vaccines, nanotechnology, secondary agriculture, farm mechanization, energy efficiency, agri-incubators and technology dissemination need to be given priority. Multi-disciplinary and multi-institutional research will be of paramount importance, given the fact that technology generation is increasingly getting knowledge and capital intensive.

It is an opportune time that the formulation of 'Vision-2050' by ICAR institutions coincides with the launch of the national 12th Five Year Plan. In this Plan period, the ICAR has proposed to take several new initiatives in research, education and frontline extension. These include creation of consortia research platforms in key areas, wherein besides the ICAR institutions, other science and development organizations would be participating; short term and focused research project through scheme of extramural grants; Agri-Innovation fund; Agri-incubation fund and Agri-tech Foresight Centres (ATFC) for research and technology generation. The innovative programme of the Council, 'Farmer FIRST' (Farmer's farm, Innovations, Resources, Science and Technology) will focus on enriching knowledge and integrating technologies in the farmer's conditions through enhanced farmer-scientist interface. The 'Student READY' (Rural Entrepreneurship and Awareness Development Yojana) and 'ARYA' (Attracting and Retaining Youth in Agriculture) are aimed to make agricultural education comprehensive for enhanced entrepreneurial skills of the agricultural graduates.

I am happy to note that the Vision-2050 document of **Indian Agricultural Research Institute, New Delhi** has been prepared, based on the assessment of present situation, trends in various factors and changes in operating environment around agriculture to visualize the agricultural scenario about 40 years hence and chalk out a demand-driven research agenda for science-led development of agriculture for food, nutrition, livelihood and environmental security, with a human touch.

I am sure that the **'Vision-2050'** would be valuable in guiding our efforts in agricultural R&D to provide food and nutritional security to the billion plus population of the country for all times to come.

(S. Ayyappan)

Dated the 19th June, 2013
New Delhi

Preface

India has made a remarkable progress in agriculture sector and continues to remain essentially agrarian economy. Along with the achievements, challenges are multifold. Ever increasing population and income have raised the demand for food. The horizontal expansion of land is limited and per capita availability of land is shrinking. Share of agriculture GDP towards overall GDP has been declining over the years. Rising cost of cultivation impacts profitability and consequent out-migration from agriculture remain a concern. The rate of growth of yield of many crops has been declining, which is further aggravated by the challenges of climate change. To address these challenges, proper vision with mission mode approaches would be the right step in future.

The Indian Agricultural Research Institute (IARI), the flagship institute of the Indian Council of Agricultural Research, has served the country by developing appropriate technologies through basic, strategic and applied research leading to self sufficiency in food grains and diversification and export of agricultural commodities. During the last 107 years, IARI has responded dynamically to the needs, challenges and opportunities of the Indian agriculture by redefining its mandate, plans and programmes accordingly. The institute is not only credited with the success of the Green Revolution but also brought about a radical transformation of Indian agriculture from traditional to modern by continuously employing advanced tools and technologies to address various problems in a more effective manner. Development of the most popular Basmati rice variety Pusa Basmati 1121, as well as its BLB and blast resistant derivatives coupled with wheat, HD 2967, which have received unprecedented popularity within 2 years of their release, are some of glowing examples.

The Institute has taken the initiatives to address challenges and new opportunities that Indian agriculture is facing today and may face in future. The Vision 2050 document has been prepared keeping in mind the recent development in international agriculture and the future challenges such as sustainability, climate change, scarcity of water resource for agriculture, degraded soil and water resources which are expected to affect the cropping systems in the country. The Institute envisions that by 2050 Indian agriculture should transform itself from subsistence level of farming to commercial farming, input intensive to input responsive, carbon-negative (C^-) to carbon-positive (C^+), low-efficiency to high-efficiency, polluting to pollution-free, and climate-prone to climate-smart agriculture. This document provides a framework for visualizing new priorities, developing new programmes, adopting participatory modes of action, and making organizational adjustments for effectively addressing the challenges and tapping the opportunities before us for ushering in an ever green revolution.

The leadership of Dr. S. Ayyappan, Secretary, Department of Agricultural Research and Education and Director General, Indian Council of Agricultural Research, in guiding us this perspective planning has indeed been inspiring. The inputs of the Joint Directors, Drs K Vijayragavan and Malavika Dadlani, along with Heads of Divisions of the Institute have been extremely helpful in preparing the document.

(H. S. Gupta)
Director

Dated:

Content

1. CONTEXT

Green Revolution, emanated from the fields of the Indian Agricultural Research Institute (IARI), helped the country in attaining and maintaining self-sufficiency in food grains from early 1970s to date. Green Revolution was followed by yellow, blue and white revolutions, which are together known as Rainbow Revolution. Green revolution although made the country proud, it resulted in several second generation problems, which coupled with growing population and rising per capita income have put tremendous demand on Indian agriculture. While the population is likely to increase to more than 1.6 billion before near-stabilization by 2030, the food demand is expected to rise up to ~ 400 million tonnes (MT) by the year 2050. Hence, an agricultural growth rate of 4% per annum is necessary (as against 3.6% during the XI plan) not only to meet the demand of food, feed and fodder but to continue to have 8-9% growth in GDP to reduce poverty and support the overall economic growth of the country. Although India stands second worldwide in agricultural production, yet the economic contribution of agriculture to India's GDP has been declining steadily from 57% in Ist Plan to 14.1% by the end of XIth Plan. However, agriculture is still demographically the largest economic sector and plays a significant role in the overall socio-economic fabric of India with more than 2/3rd of its population directly or indirectly dependent on agriculture, which is facing greatest ever challenge from climate change.

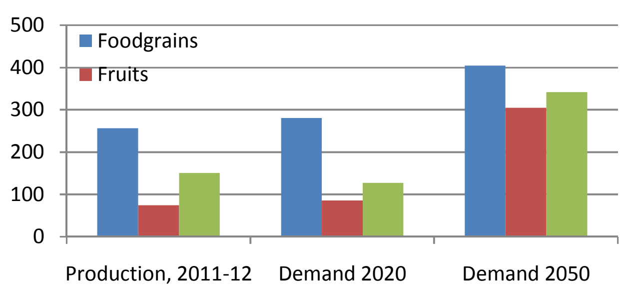

Fig 1. Production and projected demands of food grains and horticultural produce (in MT)
(Source: P Kumar and Ramesh Chand, NCAP, unpublished)

Although India attained self-suffiiency in food grains quite some time back but malnutrition continues to hang around. Today every third child born in the country is undernourished and ~45% of the children below the age of 3 years are malnourished. According to International Food Policy Research Institute, the loss due to malnutrition to the country is estimated to be around 17.3 billion US $ annually, which turns out to be 2.5% of the country's GDP. Thus, food & nutrition are of paramount importance and coupled with these concerns, water and energy securities are vital issues for India as well as the rest of the world. As regards water, most of the river basins in India and elsewhere are closing or closed and experiencing moderate to severe water shortages. Over-exploitation of ground water is a major concern. Presently, there are over 20 million wells pumping water with free power supply, provided by the Government. This has been depleting ground water, while encouraging wastage of water in many states. As a result, the water table in the country is dipping every year by 0.4 m. The irrigation potential created and utilized by the end of Xth five year plan was 102.8 Mha and 87.2 Mha, respectively. As, the potential for further utilization of created potential is hardly 5-10%; India is bound to face severe scarcity of water in the near future. It is projected that by 2050, the per capita water availability in India would further decline and hover around the scarcity level of 1,140 m^3/person/year (Table 1). It is also projected that by 2050, to feed additional population, the irrigation water demand of the country would increase to about 1,745 billion liters a day (BLD) as compared to 1658 BLD during 2000 (Table 2).

Table 1. Per capita water availability in India

Year	Population (Million)	Per capita water availability (m^3/year)
1951	361	5,177
1955	395	4,732
1991	846	2,209
2001	1,027	1,820
2025	1,394	1,341
2050	1,640	1,140

Table 2. Future Water Usage

Year	**Agriculture**	**Industry**	**Domestic**	**Total**	**Per Capita**
India	Billion Lit/Day			Lit/Day	
2000	1,658	115	93	1,866	88.9
2050	1,745	441	227	2,413	167.0
China					
2000	1,024	392	105	1,521	82.7
2050	1,151	822	219	2,192	155.4
USA					
2000	542	605	166	1,313	582.7
2050	315	665	187	1,167	484.6

Thus, projections reveal that while the consumption of water in India will increase by over 50%, the supply will increase only by 5-10% during the next 12-15 years. This will lead to water scarcity situation and most of the people, particularly those who are dependent on agriculture will suffer the most. Although, reliable data on the extent and severity of pollution is incomplete, one estimate of global wastewater production is about 1,500 km^3. Assuming that 1 litre of wastewater pollutes 8 litres of fresh water; the present burden of pollution may be up to 12,000 km^3 worldwide. Under water scarce conditions, wastewater/ low quality water is emerging as potential non-conventional source for demand management, after necessary treatment. Agricultural reuse of sewage wastewater (current: 40 billion litres a day), with an irrigation potential of 1.5 million hectare, is fast becoming popular worldwide because it closes the loop between water demand and wastewater disposal and enhances fertilizer security of resource poor farmers. However, due to the lack of proper treatment facilities and awareness in developing countries, unplanned application of raw sewage is increasing the risk of agricultural sustainability and consumer/ environmental health.

The pollution of soil with heavy metals due to improper disposal of industrial effluents, use of domestic and municipal wastes and pesticides, is becoming a major concern. Though, no reliable estimates are available of the extent and degree of this type of soil degradation, it is believed that the problem is extensive and its effects are significant. Besides this, the spatio-temporal variability of soil and water resources associated with the impacts of climate change would necessitate development of technologies to manage frequent and prolonged problem of droughts in most arid and semi-arid tropics of the country. Generally, these regions suffer from drought at least twice in five years. However, during the recent past, the droughts have been prolonging beyond one year. As a result, the local people particularly the poor are unable to cope up with the traditional combat mechanisms, which they have adopted over the years. It is therefore necessary to support the local communities in these drought affected regions with modern surveillance, support and service systems.

Further, although the use of fertilisers has increased several folds, yet the overall consumption continues to be low in most parts of the country. Several studies have shown that in most of the regions there is a net negative balance of nutrients and a gradual depletion of the organic matter content of soil. It is estimated that every year, 24.29 million tonnes of the three major nutrients – nitrogen, phosphorus, and potassium are removed by growing crops but the corresponding addition through chemical fertilisers and organic manures falls short of this figure. It was determined that only 23% of the applied fertilisers is consumed by plants; the remaining 77% is mainly leached out beyond the root zone, lost by volatilisation, fixed and gets transformed into unavailable forms etc. The annual loss in production of eleven major crops in India due to depletion of nutrients as a result of unsuitable agricultural practices amounts to 0.5 to 1.3 million tonnes. The problem of maintaining the nutrient balance and hence preventing the consequent nutrient deficiencies will also be a major concern in most cultivated areas of the country. Thus, climate change coupled with consequent biotic and abiotic stresses are posing a serious threat to the agricultural production system of the country. Increasing cost of non-renewable sources of energy and inputs required for agricultural production would further add to the woes of farmers.

Biotic stresses including insects, pathogens, nematodes and weeds are the major limiting factors in realization of yield potential of crop plants. The problem will be further aggravated in view of the changing agricultural practices and environment, adoption of new technologies and more intensive cropping systems. Besides, unprecedented developments in trans-boundary trade among the countries have paved way for the introduction of newer pests across the globe. Therefore, the recent potential threat from the deadly *Ug*99 rust isolate on wheat, allexiviruses on onion and garlic, grapevine leaf roll associated virus on grape, *Helicoverpa armigera* and white fly on cotton cannot be ruled out. The crop plants over the next 37 years will be threatened by completely new as well as new strains of known pests. Preparedness for their detection and identification, and development of pest risk analysis (PRA) based prioritized pest database are of paramount importance. Tomato spotted wilt virus, moko wilt of banana, fire blight of apple and pear, soybean downy mildew, red ring nematode of coconut, cotton boll weevil are a few potential pest of quarantine significance to India.

The emphasis, therefore, has to be on enhancing resource use efficiency, developing improved futuristic varieties/hybrids having resistance to multiple stresses and thereby increasing overall productivity. The country will especially need to put in substantial efforts to become self-sufficient in pulses and oilseeds, reduce post-harvest losses and enhance quality of produce and value addition for improved agricultural exports which is currently around INR One lakh crores (nearly 166.67 million US $) .

Presently, India spends INR Fifty four thousand crores (nearly 90 million US $) of foreign exchange for importing edible oils to meet the domestic demand. In addition, we also import 2-3 million tones of pulses. Therefore, a strategy needs to be evolved to meet this deficit in conjunction with policy change. Of late, the horticultural crops have been regarded as the best option for diversification and maximizing system productivity. These have shown their potential for improved productivity and profitability, nutritional adequacy and employment generation opportunities, especially in rural and remote areas. As evident from Figure-1, the demand for horticultural produce, especially fruits and vegetables, is on an increase and is further expected to increase with growing population, urbanization and rising per capita income. It has also been observed that the demand for flowers is also increasing both in domestic and exports markets. Meeting the aforementioned challenges would, thus, require focussed national efforts in the development and implementation of suitable strategies. However, much of the solution would lie in the development and dissemination of improved technologies which can be adequately supported with agricultural policies.

During the last 107 years, IARI has played a crucial role in providing technologies, leadership and responding dynamically to the needs, challenges and opportunities of the Indian agriculture by redefining its mandate, plans and programs accordingly. The institute is not only credited with the success of the Green Revolution but also brought about a radical transformation of Indian agriculture from traditional to modern by continuously employing advanced tools and technologies to address various problems in a more effective manner. Development of the most popular Basmati rice variety Pusa Basmati 1121, as well as its BLB and blast resistant derivatives coupled with wheat, HD 2967, which have received an unprecedented popularity within few years of their release, are some of glowing examples.

HD 2967 : A high yielding breakthrough variety of wheat

IARI released a high yielding wheat variety HD 2967 for cultivation in the Northwestern Plains zone, the wheat bowl of India that is uniquely endowed with significant yield superiority over the variety PBW 343, a bench mark variety that ruled the region for over 15 years and also minor genes based resistance to the rusts which has almost wiped out PBW 343 since 2011-12. The variety has been welcomed by farmers so warmly that it has already occupied over 4 million hectares within 2 years of its release which is unprecedented spread for any variety in India of any crop.

Our current export of agricultural produce hovers around one lakh crore (17.3 billion US $ approx.), which can be increased significantly if agriculture can be made more competitive through technological advancements.

Pusa Basmati 1121 : World's most traded Basmati rice variety

Basmati rice from the Indian subcontinent is highly priced in the International as well as domestic market for its unique grain, cooking and eating quality.Basmati rice cultivation is confined to the states of Punjab, Haryana, Western U.P., Uttrakhand, parts of Himachal Pradesh and Jammu & Kashmir. Basmati rice occupies around 2 million hectares. India is the highest exporter of Basmati rice and the variety Pusa Basmati 1121 notified in 2008 is the world's longest cooked rice and the most traded basmati rice globally with outstanding basmati grain qualities. Due to its outstanding performance in the farmers' field and quick acceptance in the trade, the area under Pusa Basmati 1121 started increasing since Kharif 2007. In Punjab it increased from 23,000 ha to 6,20,000 ha. In Haryana it increased from 1,73,000 ha to 5,69,000 ha and Western U.P. from 1,45,000 ha to 4,10,000 ha. In the years 2011 and 2012, Pusa Basmati 1121 occupied 70 and 73 % of the Basmati area respectively to account for 85% of the total exports. This variety is the most preferred variety by farmers with profitability ranging from Rs 80,000 to 1,20,000 per hectare. IARI continues to lead the Basmati rice improvement programme to enhance per day productivity as well as incorporate resistance against biotic/ abiotic stresses.

IARI, since its establishment in 1905, has been striving to help in realizing the importance of agriculture as a vocational, professional and academic endeavor for those engaged in practicing agriculture. This endowed India to absorb, adopt and adapt the emerging technologies for improving agricultural productivity of different ecological situations of the country as and when the new technologies emerged. This feature has made IARI a distinct Institution enabling India to excel among the developing world. This exercise is aimed at foreseeing the agricultural scenario in 2050, assessing our strengths and weaknesses in meeting the challenges thrown out during the ensuing three decades. The document will also enlist the strategies for converting our weaknesses into opportunities that will not only help in attaining and retaining nutritional security of the nation but also make India a world power with potential to export large quantities of farm produce/processed products.

The mission of the Institute is, therefore, to explore new frontiers of science, to develop human resources and policy guidelines for creating a vibrant, responsive and resilient agriculture. In order to accomplish this mission, the Institute has been given the following mandates:

- To conduct basic and strategic research with a view to understand the processes, in all their complexity, and to undertake need-based research, leading to crop improvement and sustained agricultural productivity in harmony with the environment.
- To serve as a centre for academic excellence in the area of post-graduate education and human resources development in agricultural sciences.
- To provide national leadership in agricultural research, extension, and technology assessment and transfer by developing new concepts and approaches and serving as a national referral point for quality and standards.
- To develop information systems, add value to information and serve as a national agricultural library and database.

The vision of the Institute for 2050 will be to provide leadership for "Science-led sustainable and globally competitive agriculture for food, nutrition and livelihood security". In this endeavor, while crop improvement will continue to be our major program with thrust on the newer strategies to break yield barriers. Basic and strategic research will be further strengthened towards efficient and sustainable use of available resources. The Institute will continue to provide leadership in developing technologies for climate-smart agriculture, improved pest diagnostics and management, liquid and solid waste utilization in agriculture; besides policy research, innovative value chain models and protection of plant varieties and farmers' rights coupled with intellectual property rights. The institute will lay greater emphasis on taking the technologies to the end users in shortest possible time through inexpensive methods involving information and communication technology including mobile telephony. A mission mode approach, through partnerships will, therefore, be promoted to accomplish time bound goals through excellence in inter-disciplinary research as the new information will be available at the intersects of two or more disciplines.

2. CHALLENGES

Increasing population and income have raised the demand for food with a substantial increase in demand for the high value and quality produce like fruits/vegetables and livestock products. At the same time there has been awareness about quality of environment and standard of living. These changes have put tremendous pressure on Indian agriculture. Trend is the same for the other parts of the globe too; as evident from significant food imports in China and Africa. These challenges have to be addressed through improved technologies; without compromising the sustainability of our natural resource base. In fact, increasing demand for water from the industry and household sectors, shrinking agricultural land due to urbanization, and consequent rising energy demand in agriculture sector are likely to be the binding constraints in future. There is also a need for the agricultural and food systems to become more sustainable, whilst adapting to climate change and substantially contributing to climate change mitigation.

Thus, the major challenges before Indian agriculture are its marginal land holdings, widening production disparities between irrigated and rainfed areas (ratio of irrigated to rainfed yield lie from 1.25 to 3.30), degradation and depletion of natural resource base, climate change, increase in non-agricultural demand for land and water, inadequate mechanization, labour shortage, inefficient use of inputs, wastage of agricultural produce due to inadequate post-harvest operations, lack of awareness among farmers for modern crop production methods, ineffective extension services, inefficient financial resources for investments, high levels of consumption services (such as subsidies) resulting in wastages and above all low per-capita income for farmers. The specific areas of concern needing priority attention are as follows:

1. Increasing productivity of agricultural production system per unit of land, water, energy and other critical inputs.
2. Diversification of the production systems for household food & nutritional security and increased export of farm produce/product.
3. Sustainable management and equitable use of natural resources such as land, water and biodiversity, especially in the context of changing climate.
4. Bio-security and crop health management for higher yields and improved food quality.
5. Enhanced profitability, non-farm employment, rural livelihood, gender mainstreaming and global competitiveness in agriculture through appropriate technology development, market linkage and policy.

6. Accelerated information and technology flow to farmers and other stakeholders through efficient extension approaches.
7. Capacity building and quality human resource development in frontier areas of science and management of agricultural programs and enterprises.

The challenges listed here would require the national efforts to develop and implement a suitable strategy. However, much of the solution would lie in development and dissemination of improved technology and human capital development, which should be adequately supported with agricultural policies. This strategy would be more relevant in the context of meeting the food requirement which is likely to increase to 280 million tonnes in 2020, which will further rise to ~400 million tonnes coupled with 650 million tonnes of fruits and vegetables in 2050. The country will also need substantial efforts to become self-sufficient in pulses and oilseeds, and also enhance agricultural exports which are hovering around 10% of AgGDP (INR one lakh crores)

IARI with its unique strength of a 'Deemed to-be University' with multi-disciplinary and multi-commodity mandate is placed to provide a leadership role for addressing the challenges in partnership with the NAREES and other stakeholders. In particular, its capacity to undertake basic and strategic research, policy and extension support and develop manpower to manage R&D, public development programs and corporate sector will go in a long way in transforming the Indian agriculture and meeting aspirations of the rural people.

The following programs are proposed to address the technological challenges in a multi-disciplinary school-mode:

I. Designing crop varieties and hybrids for higher productivity per unit resource and time, better nutrition and tolerance to biotic & abiotic stresses

It is proposed to be addressed through the following approaches:

- **Conventional breeding and its augmentation with molecular biological techniques**: Conventional breeding has already upgraded itself to the level of precision breeding utilizing molecular tools and techniques. Genomic selection (GS), marker assisted selection (MAS) technologies will be fully integrated with conventional breeding to enhance the efficiency of the breeding programmes in the Institute which has established its leadership role in rice, wheat, maize, pearl millet, mustard, chickpea and pigeonpea. In the next few decades with the rapid pace of development that is seen in the DNA/protein sequencing technologies, it should not be a tall order to completely characterize genotypic combinations for specific proteins, specific multi-protein chains in a given genotype for commercial cultivation with directed composition. IARI would like to provide leadership as in the past to facilitate environment supportive expression levels of different traits.

Building on the current levels of molecular analysis, genomic information, supported by molecular markers such as microsatellites and single nucleotide polymorphism (SNP), it is expected that the decade to follow would employ transcriptomics to identify expression variation at an allelic level for a trait and their regulatory factors for maximizing the effect of desired allele and minimizing or 'silencing' the effect of undesirable alleles of different genes controlling the trait. The plant breeding process itself will, therefore, use not only gene-specific marker system that plant breeders are already employing, but also expression-specific marker that functions under defined levels of stresses or environmental conditions. This will enable prediction of performance of a variety more precisely than the current levels. The decade following this decade, the 2030s will be in all possibility employing further advanced systems of selecting a trait along with other traits in a genotype taking into account the cross-talk between different proteins making up the expression of traits that function in sequence or in complementation or in isolation but within a phenological stage of a crop. This would mean the breeding programmes will be adapted to use of metabolomics, ionomics and other expression oriented plant components through genotypic manipulation focusing on those genomic regions/sequences and their interactive products in the cytosols and intercellular spaces as tools for selection, a progressive method over marker assisted selection (MAS), whole genome sequencing (WGS), genome wide association studies(GWAS) which mostly use existing genome sequence with reference to the trait as expressing in an environment. The use of metabolomics that further upscale proteomics beyond transcriptomics will be the approach for precision breeding to follow by the plant breeders, enabling the best possible performance potential of a variety in its cultivated area.

- **Development of novel genetic resources for exploitation of heterosis and development of hybrids in non-conventional crops:** Stabilization of productivity increment through varietal technologies is perceived as one of the major constraints for the slow paced increment in agricultural production. In order to enhance productivity to ensure food and nutritional security and profitability, heterosis exploitation needs to be focused upon. It is, therefore, necessary to develop innovative improved germplasm for broadening genetic base, explore diverse sources for cytoplasmic genetic male sterility (CMS), novel techniques such as doubled haploid technique for hastening the improvement of parental lines, use of haploid inducer stocks, instant antisense male sterility system and development of transgenic male sterility (Barnase/Barstar) system and other modified systems as an alternative where CMS is not available for exploiting heterosis. Major emphasis will be laid on the development of hybrids in vegetables, fruits, flowers, cereals, pulses and oilseed crops as well as efficient systems of hybrid seed production in vegetable crops (GMS in solanaceous; CMS in crucifers, capsicum, onion and carrot; gynoecism and parthenocarpy in cucurbits), annual flowers and field crops like wheat, mustard, and pigeon pea etc.

The fast paced development in the genomics and biotechnological application tools has set in a new hope for precision in breeding methodologies that the institute has been able to integrate in its crop breeding activities which have produced results in the form of products commercialized in rice and wheat in the area of biotic stress resistance with high yield. This would be the trend complemented with the concept of breeding "**designer crop varieties**". This would mean an end-user (consumer/processing industry/retailer/stockist) directed variety for specific purpose such as "**missy-roti-ready**" wheat (high protein, high fibre, and omega 3 edible fats), "**super-poultry growth"** maize, **"oil-only"** rice, etc. Some genetic and breeding interventions that would be put in place at IARI are as follows:

- **National networking with a self-sustainable translational platform on PPP mode for use of precision breeding methodologies and genomic resources:** IARI with its status as a national Deemed to be University in agricultural sciences would like to enable the **NARS** to be on precision breeding platform of functional plant breeding and genomic resources at least in its mandate crops covering the entire country. For effecting this, there is a requirement to develop a full-fledged translational platform and training centre. As a novel initiative, it would be a model to be set up where the private establishment and companies with services and supplies to participate in the exercise including maintenance of the centre. There would be heavy rebate to be given to the NARS on a cost-to-pay basis of usage time and consumable, supplies of consumables for laboratory work, with commercial operations with rest of the user base. This would liberate those programmes and systems which get restricted with latest technologies being made available competitively by the vendors at the translational platform to be named "**Innovation and Translational Centre (ITC)**". The responsibility of IARI would be to keep the support systems for the vendors to function, facilitate services and communication on a commercial basis.

Pre-breeding: Over the last three decades the crop breeding priorities revolved around the major priority of increasing productivity of crop plants to feed newer varieties into the national seed chain and ensure their use in crop production by adoption of the new varieties by farmers. To a large extent this goal has been achieved in the country which witnessed record production of food grains as well as horticultural produce on a continuum since the year 2002 fundamentally through genetic enhancement using the available genetic resources. This prioritization led to a poor attention for the scheme of developing genetic resource with novel combination of traits through novel genes or alleles as well as novel traits which would add value to a cultivated species. The research programs for strategic research to explore the wild species or other genera that can be made to hybridize through assisted crossability or through the involvement of a bridge species that are required to introgress novel genes and traits have to be executed by institutions like IARI. This, however, requires a renewed interest and research in the science of cytogenetics on an equal priority as plant breeding programs themselves. IARI has the expertise and systems in place to encourage such research programs. Stable

Transfer of rust resistance from wild species like *Triticum militinae* (2n=28, AAGG) introgression lines with novel genes, alleles or traits will serve as genetic stocks for plant breeders to exploit in their breeding programs and also to basic scientists to pick out new genes, characterize their products and functions. Breeding programs, therefore, will be with a completely different mode of functionality and priorities with active involvement of molecular cytogenetics, eugenics, expression genomics and classical plant breeding to target futuristic targets that are required to be provided in crop species that will be novel in its usage for farmers and consumers benefits.

- **Super hybrids as vehicle to fast-pace productivity increment in crops:** The public-bred hybrids have reached the farmers of India only in sorghum, maize, rice, pearl millet, tomato and brinjal. Private enterprises have been using their marketing power and network to promote their hybrids in maize, rice, pearl millet, sorghum, tomato, brinjal, cauliflower, cabbage, carrot and cucurbits not necessarily with the best hybrids in the respective crops, while public hybrid development programmes, despite their potential with high heterosis, have not crossed the institutional evaluation mechanisms unlike the private sector who have been using farmers' fields as sites for popularizing their hybrids, sector-wise. A partial success achieved in rice cannot be sustained without most desirable diversification in the CMS sources which has been the major constraint so far. The varietal technologies seem to have got locked in a slow paced increment below 2-3% growth rate. IARI's vision, therefore, is to take up this enormous problem and solve it through perfecting the hybrid technologies on priority. The imminent consequence is productivity increase provided there is replacement of the existing varieties with the hybrids. It is this area where public sector based research institutions is ineffective because, together, these crops occupy about 100 million hectares in India and therefore under fast information exchange, the potential yield increment is likely to generate demand for hybrid seed far beyond their capacity. The only means to realize this vision is on a Public-Private partnership mode can easily do the same. Within two years of release, the PPP can affect 50% seed replacement to make India produce nearly 300 million tons of these crops.

The enhancement can also be achieved by exploring diverse sources for male sterility as well as restoration of male fertility. The well documented resources such as cytoplasmic-genetic male sterility (CGMS, three line system) and thermo genetic male sterility (TGMS, two-line system) or a potential and promising system of apomixes (one-line system) need to be employed on a much larger scale than at the current level. The success of Barnase/Barstar system of inducing pollen sterility and restoration by transformation using recombinant DNA induced transgenic hybrid production system in some crops provides scope for enlarging the hybrid base to those crops where within genome male sterility systems are not available. The HSP system of transgenic hybrid seed production where the parental lines are transgenic and the commercial product is non-transgenic (Non-GMO) will be a most useful and easily acceptable GMO for release in the environment. IARI would focus on exploring this as a priority product of plant breeding in cereals, pulses and oilseeds. One of the requirements to enable major adoption of this technology will be through the doubled haploid line development which is now possible to be explored involving the haploidy inducer lines as has been established in maize.

- **Ushering seed-security through public-farmer-private partnership:** The success of crop production depends to a great extent on its seed programme, which can facilitate the supply of quality seed of improved varieties and hybrids as per the needs of the farmers at affordable prices. Realizing the significance of and impact the quality seeds make, IARI initiated, the concept of seed village in 1960s, a systematic seed production programme at its head quarters and regional stations at Karnal, Katrain,

Fig. 2. Seed production of PRH-10- a popular fine grain aromatic rice hybrid of IARI

Indore and Pusa (Bihar). The major objectives of this programme is to produce high quality nucleus, breeder and labelled seed of improved IARI varieties of field crops, vegetables and flowers as well as developing location-specific hybrid seed production technologies.

In addition to the Institutional programmes, the seed production of IARI varieties were also being undertaken in a big way through farmers' participation, which helped increase the seed production of field crops by 250-300% during the last 5 years.

To expand the scope of this initiative, IARI launched a farmer producer company 'BeejIndia" in 2012 with a mission to develop farmer-led sustainable seed enterprises in different parts of the country taking advantage of its regional stations and other voluntary partners. IARI will also continue to strengthen its partnership with private sector for commercialization of high-value hybrids, which require more organizational support, infra-structure and technical skill. Yet another potential area is quality seed production for export, which is <1% of global seed export. This can be raised to 10% by 2020 and 20% by 2050 through capacity building, development of world class infrastructure and aggressive marketing. There is an enormous potential in exporting quality seeds of several of our varieties to OECD, SAARC and African countries. The Institute will continue to develop more precise, rapid and cost-effective protocols for seed-quality assessment including seed health, genetic purity and GM-testing, and provide a national facility for referral testing. Research on seed quality enhancement will be taken up to upscale into designer seed treatment technologies in partnership with the private sector.

- **Genomic resources and functional genomics:** With sequencing becoming affordable and available to public institutional mechanisms, the emphasis would be on converting the information to resources through aligning the different genes along the sequence within linkage groups supported by genetic linkage mapping to develop closely linked marker systems for targeting the physical distance between genes for tagging genes or quantitative trait loci (QTLs). All mandate crops will be explored through molecular mapping, allele mining, bioprospecting, isolation, characterization and subsequent functional validation of the new loci/alleles available in the diversity of the crop species. The area will be further utilized for picking up novel alleles, genes and tissue specific promoters for their use in transgenic development across species depending on the traits targeted. The traits under focus will be for agronomic adaptation, nutrient use efficiency, water use efficiency, abiotic stress tolerance and biotic stress tolerance which will enable both genetic potential enhancement and consolidation of the enhanced potential in a crop plant.

- **System biology in collaboration with basic science institutions:** Molecular biological insights into various system biological features of the agriculturally important taxon will be explored through the basic scientific studies using the available and advanced tools for biological system based studies to understand the different levels of tissue-based expression analysis, tissue specialization and adaptation that create species- specific trait composition and expression. The transgenic crops with multiple stress tolerance using RNAi technology will be developed. Risk assessment studies would also receive priority. Besides, understanding of innate immunity in host and nonhost plant would pave way for the development of more acceptable and safe genetically altered cisgenic or intragenic plants against biotic stresses. The transgenic root stocks with resistance to biotic stresses such as wilts and abiotic stresses like salinity will be developed in horticultural crops so as to extend their cultivation in problem soils. Shelf life enhancement in perishable crops, especially vegetables will also be addressed through transgenesis to reduce post-harvest losses and enhance availability. This will be facilitated by exploring the strengths in the area with different institutions in the country along with those abroad with expertise in system-biology and insights into the area for their applications in agriculture. Long-term collaborations shall be established based on systems such as *graminae* group, *vigna* group, *cruciferae* group, *solanaceae* group, etc. This information will be most useful in targeting system based improvement in the physiology of a crop species especially for those which are coexisting with extreme environmental situations such as freezing conditions (winter type adaptation) to high temperature conditions during their phenological cycles. Such understanding will help in targeting characters and biological modifications to adapt to the diverse environments for their subsequent mobilization across crop species which lack these systems.

- **Bioinformatics:** An area that needs to be strengthened immediately within next five years for its adoption as the order of advancement to be practiced in the next two decades is bioinformatics a crucial link in converting the information that is getting generated through molecular technologies, system biological inputs and digitization of environmental and natural resources management factors. The national human resource development strategy needs to get this on priority as was done in the case of information technology in graduation and post-graduation education system. The earlier this is achieved, earlier would be the proper use of the enormous information bank that is getting developed with modern tools. IARI with its Post-graduate School would not only be creating a bioinformatics specialization in post-graduation, but will also like to integrate bioinformatics in genomic resources and its utilization in crop improvement as well as natural resource management options for a predictable results in productivity improvement with high degree of efficiency.

- **Genetic improvement under cropping systems exposed to changing climate regimes:** The system biological insights are important in tackling specific agricultural problem of particular importance to Indian agriculture where the average cropping intensity is more than 1.4. The inter-season crop adaptations between two crops in rotation are crucial for the success of the rotations and improving total agricultural productivity improvement per unit area and unit input in a year. In view of the anticipated effects of global climate change (GCC) on crop based system productivity; our research program will be oriented towards mitigating these effects. The focus would be on cold, heat and drought tolerance.

Climate change and its consequential changing water regimes, ground and air temperature patterns are projected to severely dent production in varying intensities. Genetic improvement of cereal and horticultural crop varieties which are water use efficient, temperature tolerant, drought resistant and nutrient use efficient is a top priority objective that has to see the use of modern tools of biotechnology (genomics insights for exploring all genomic resources, mobilizing the same and adoption of wide-spread rapid throughput molecular marker technologies) coupled with physiological manifestations, introgression from wild and related genetic resources, etc. Since certain physiological traits and their QTLs are associated with genetic gains under drought these can be applied in breeding programmes in India. However, before these QTLs can be accumulated in breeding materials, it is important that the capacity to accurately phenotype WUE and heat stress tolerance is established at key Indian locations. A number of putative QTLs of variable significance have been identified in a range of different environments in crops like rice, wheat, maize and chick pea.

Quantitative improvement of productivity of crop plants, especially the self pollinating crops and vegetables by targeting upwards of 20% yield increment, IARI would aim to provide the farming community a means to have a basic yield potential level increase over the currently stagnating yields of low-seed replaced crops. This is planned by **molecular breeding** for simply inherited traits and an accumulative approach of **"cumulative quantitative breeding (CQB)"** for quantitative traits where the methodology would stack and pyramid the **"quantitative trait loci (QTLs)"** for component traits associated with yield. The components will not only be the direct yield component traits but also will include QTLs related to higher nutrient and water use efficiency. This is visualized as a realizable goal in three phases which involve the first five years of work to map and tag the QTLs on a network mode using multilocation based phenotyping of the reference mapping populations in different crops.

- **Crop improvement for conservation agricultural practices:** The increased emphasis on improving soils can be achieved to a large extent by adopting conservation agriculture practices which uses a combination of minimum tillage, residues incorporation and its management over a period of time (such as once in four years for incorporation and soil rotation), multi-crop facilitation with modified planting systems, alternate water-nutrient-chemicals management, etc. This aim could be achieved by developing varieties of field and horticultural crops that are suitable to adapt to conservation agriculture practices while being both nutrient and water use efficient. A new approach needs to be worked out on priority looking at the global changing scenario of consumer preference, purchasing power and awareness through organic agriculture. Currently, only existing high yielding varieties are being fitted into conservation agriculture cropping practices.

Due to increased cropping intensity, improper nutrient and water management regimes, and increased level of soil salinity; the soil quality in the broad Indo-Gangetic Plains stretching from the fertile north western Himalayan foothill region to the delta region following the vast highly variable north eastern plains zone is degrading rapidly. A number of resource conservation technologies have been suggested including reduced tillage, surface retention of crop residues and sustainable use of water.

Innovative solutions, which increase the yield, protect the environment including natural resources and enhance the economic viability of farmers and rural livelihood, are the need of the hour. These solutions should incorporate conservation agriculture practices which regenerate natural processes, such as nitrogen fixation, nutrient recycling, maintenance of soil structure and fertility, and protection of natural enemies of insect pests, weeds and diseases, into agricultural practices. The key features of CA that may be applied in all situations include,

- Minimum disturbance of soil,
- Maintenance of mulch (live or dead crop cover)
- Sound crop rotations
- Need based and sound IPM practices

In a consortium mode, a large multi-disciplinary programme with objectives to address the problems of small land holders/ farmers, it will be appropriate to develop a project on wheat improvement for conservation agriculture with the following strategic initiatives:

- Understanding the crop response under different agronomic manipulation for conservation agriculture and designing the agronomy to maximum production under climate change
- Genetic adaptation to agronomic manipulation for conservation agriculture
- Understanding host- pest vis- a- vis pest- predator dynamics under conservation agriculture
- Deciphering the impact of resource conserving technologies on soil health

- **Development of functionalized and futuristic crops:** Biofortification and plant derived biomolecules (for vaccines) are important technologies to achieve the Millennium Development Goals. Protein malnutrition and micronutrient deficiency such as iron, zinc and also vitamin A affect more than two billion people in developing countries. Genetic biofortification of these essential nutrients is important to alleviate these problems. Golden Rice biofortified with provitamin A, potato with protein and provitamin A, and banana with iron and provitamin A are such examples. Biofortification of staple food crops such as wheat, maize, rice, millets and important vegetables, fruits and flowers with higher nutrients and end-user target compositions in harvested products through conventional breeding/biotechnological approaches will be undertaken to address malnutrition problem.

The specific extrinsic (colour, texture, shape, size, etc.) and intrinsic (carotenoids, β-carotene, lycopene, lutein, ascorbic acid, anthocyanin, mineral micronutrient, and other bioactive compounds) traits using conventional and biotechnological approaches will be adopted in agri-horticultural crops to develop functionalized foods and nutraceuticals. Pusa Asita black carrot is one such example of IARI varieties which is richest source of most stable acylated anthocyanins. For biofarming, crops suitable as industrial raw material such as biochemicals and biofuels will be developed.

Edible Vaccines will be developed for treating the important human diseases. These vaccines will be cost effective and easily accessible.

Golden Rice and Orange Cauliflower

Keeping in view the acute malnutrition problem in India, especially that of Vitamin A, IARI is working towards development of Vitamin A Rich varieties across crops. In this endeavor, popular varieties of Rice and Cauliflower, extensively cultivated and consumed, are being introgressed with genes enhancing β-carotene to address this issue of national importance to usher in nutritional security.

- **Genetic enhancement of photosynthetic efficiency in C3 crops:** Two approaches will be pursued to achieve this goal

i) Engineering C3 pathway to enhance photosynthesis: Enhancing the RuBP regeneration through Calvin cycle, which may lead to increase in photosynthetic efficiency and biomass production under both optimal and stress environments will be under taken. Rubisco enzyme that fixes CO_2 in photosynthesis also fixes molecular oxygen (O_2) through photorespiration, which leads to significant loss of previously fixed carbon and nitrogen. The photorespiration losses increase further under abiotic stresses such as drought and high temperature. Therefore, C3 crops with enhanced of RuBP regeneration and reduced in photorespiratory carbon and nitrogen loss will be developed to improve the productivity of C3 plants both under normal and stress environments.

ii) Conversion of C3 to C4 pathway for higher productivity and yield stability: By 2050, rice yield needs to be increased by 60% in Asia. In rice, yield potential is limited by low photosynthetic capacity, fresh water scarcity and global climate change. Hence, systems biology and modern molecular tools will be deployed to develop rice cultivars with single/ two-celled C4 photosynthetic pathway for quantum jump in rice productivity.

- **Transformation of cereals with biological nitrogen fixation pathway:** Nitrogen is a major nutrient that determines plant growth and yield. Most of the Indian soils are deficient in nitrogen. The major cereal crops such as rice, maize and wheat production requires huge amount of N fertilizers. Legumes and few non-legume plants fix atmospheric nitrogen in symbiosis with N-fixing Rhizobia, acetobacter and other bacteria in a process called biological nitrogen fixation (BNF). Hence, incorporation of BNF in major cereal crops is envisaged to enhance profitability and reduce production cost as well as environmental cost.

- **Phenomics and genomics assisted development of climate-smart crop varieties:** Yield is characterized by a low heritability and high genotype × environment (G × E) interaction, therefore further yield improvement requires breeding approach based on an understanding of the crop at physiological and molecular levels. Unravelling the molecular basis and pyramiding of the component physiological traits such as radiation use efficiency, water use efficiency, nutrient use efficiency, and tolerance to biotic and abiotic stresses may help in developing high yielding, resource efficient and climate resilient crops. Combination of knowledge on the physiological basis of yield limitation and pyramiding of component physiological traits with modern phenomics will accelerate the rate of genetic progress in yield under unfavourable, fluctuating and stress environments.

II. Ensuring bio-security and integrated plant health management

The following issues will be addressed enabling our capabilities in managing future risk:

- **Genomics, improved diagnostics and biosystematics:** Genomics will become a cornerstone of plant protection research. Complete genome sequence data of several nationally important pests and their exploitation for diagnostics and management has not yet been done in our country. Through interactive genomic and transcriptomic approaches, there is a need for better understanding of pest-host-vector- environment interactions, so as to map the resident flora of crop plant and decipher mechanism involved in innate immunity in host and non-host plants. This would yield an array of molecules for future pest management strategies through conventional and unconventional methods. Besides, development of synthetic media for culturing fastidious bacteria and other non-culturing obligate bio-trophic pests will also be feasible.

Advances in genomics coupled with robotics, and nanotechnology will dramatically increase the capability of diagnostic laboratories though ultra-sensitive diagnostics, which would culminate in developing technologies termed as "**Lab-on-the-Chip".** Improved diagnostics developed by the *Referral Centre for Virus Testing of Tissue Culture Raised Plants* of the Institute will facilitate the production of virus free planting material, particularly in vegetatively propagated crops. It is expected that the diagnostic capacity for plant pests will match with human pathogens in future in accuracy and speed. Worldwide ***Network*** among plant disease clinics will be in place, as international trade and travel necessitate the sharing and leveraging of expertise to combat exotic pathogens. Advancement in web enabled antibody designing (synthetic peptide) and raising antibodies through recombinant DNA technology will be given due emphasis. Indigenous broad spectrum diagnostic reagents should be easily available (Fig.3)

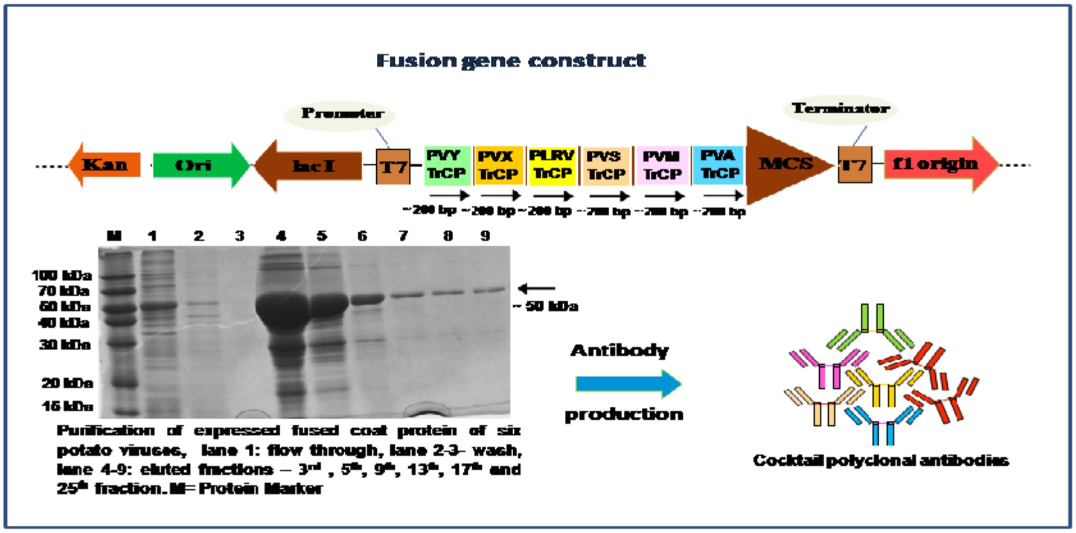

Fig. 3. Multiplex detection of potato viruses using cocktail of antibodies generated through recombinant DNA technology

Biosystematics based on digitized keys should receive priority. There is a need to enrich the existing repositories of the fungi, bacteria, insects and nematodes by collection and conservation of these organisms; to develop a digitized database of the species and genetic diversity of the fungi, bacteria, insects and nematodes through making the existing ones comprehensive and sustainable; restructuring the repositories to achieve a sustainable reference collection integrated with informatics, provide infrastructure support and develop/ generate the logistics for the same, with an aim to achieve national/ international repository status in accordance with National Biodiversity Act and other biodiversity regimes and to create and strengthen human resources and capacity building in biosystematics.

- **Molecular approaches to multiple stress tolerance:** Pest tolerance crop derived through conventional or nonconventional approaches will continue to receive attention in the future. Without undermining the importance of conventional breeding, transgenic crops with multiple stress tolerance using **RNAi** and **Genome Editing Based technologies** based on Transcription activator-like effector nuclease (TALENs) will be developed. Transgenic approach would be followed particularly in those crops where natural host resistance is lacking. Though, presently the total area under transgenic crop (Bt-cotton) is 10.8mh in India, the area is likely to increase with transgenic crops having tolerance to other biotic stress including weeds. For example, there is a need to develop transgenic cotton against leaf curl disease, rice against sheath blight, papaya against ring spot and leaf curl etc. Besides, understanding of innate immunity in host and non-host plants against major pests would pave way for the development of acceptable and safe genetically altered **Cisgenic or Intragenic** plants against biotic stresses.

- **Weed dynamics and management in cropped and non-cropped situations:** Studies on weed dynamics under changing climate, development of composite weed-crop interference model for prediction of yield reduction and economic threshold levels will be the priority areas of research.

In this direction, herbicide tolerance as an introduced trait in the crop to target weeds with minimum application of herbicide at one time without the sensitivities of pre-emergent, post-emergent, broad leaved versus narrow leaved, grassy versus leguminous weeds, etc., that require multiple sprays of multiple chemicals in today's agriculture where manual weeding is the most expensive and is increasingly becoming unavailable. The available technology of glyphosate and glufosinate tolerances are to be introduced in maize and soybean to enable fast adaptation of these crops in the water depleting zones of Punjab, Haryana and western Uttar Pradesh primarily to increase their adoption by mechanized agriculture. Thus, development of integrated weed management options for emerging cropping systems with more emphasis on selective stimulation for competitive ability of crops against weeds, use of bio-herbicides and herbicides tolerant crops in various cropping systems, soil/ herbicides plant interaction and assessment of slow release formulations of new low dose herbicides molecules in the changing weed scenario would be addressed in a holistic manner.

- **Novel agrochemicals:** Potential of microbial, plant and marine wealth has remained underutilized. Search for novel molecules from natural resources especially plants and microbes through chemical profiling, genome mining and genome wide identification will have to be pursued. This would yield novel molecules that can be exploited as plant protection chemicals and health benefiting products. Pests are developing resistance to pesticides, therefore, research will be required to find replacement with synthetic/natural products having high potency, new chemistry and different mode of action synthetic fungicides, nematicides, insecticides and herbicides.

As there is concern about adverse effect of pesticides, research need to be carried out on resistance inducing chemicals (SAR) to reduce the use of pesticides. After the ban on methyl bromide which was used for pest control especially for export commodities, there is a need to develop safer fumigants. Further the fruits and vegetables play an important role in nutritional security. However they being highly perishable need specific chemicals/products for post-harvest management of diseases in order to enhance their shelf life. Besides judicious management of diseases, there will be a need for anti-sprouting agents and chemicals for ripening. As seeds are very important and costly input in agriculture, while the seed viability decreases with time and therefore chemicals/products will be required for enhancing seed germination and plant vigor and disease management.

The use of health benefiting chemicals or nutraceuticals is increasing day by day worldwide. The fruits and vegetable are very good source of nutraceuticals. Therefore, to meet the demand, research will be required for developing processes for isolation of nutraceuticals which can be taken up as value addition in agriculture.

To make the agriculture more productive and profitable, there is a need to increase the use efficiency of agro-inputs like water, nutrients (fertilizers) and pesticides. In order to achieve this, research will be carried out to develop chemicals/products like hydrogel, nitrification inhibitors and control release formulations.

Nanotechnology is being widely used in drug delivery. Research efforts will be required to use principles of nanotechnology for developing nanomaterials for increasing the efficiency of these agro-inputs. Influence of chemicals on various metabolic pathways in target organisms and crop plants also need to be worked out. For promoting global trade of agricultural commodities and for ensuring safety of consumers, there is a need for monitoring food commodities including processed food for contaminants like pesticides, mycotoxins, heavy metals, etc. Besides, long term effects of pesticides and other contaminants on soil and water needs to be investigated.

- **Integrated crop health management solutions:** In order to minimize the annual losses of crop produce (about 25%) in India, knowledge based farmer-driven crop health management solutions have been developed for a few field and horticultural crops. These solutions are limited to small scale and need implementation on a large scale. Like for pulses, integrated crop health management solutions need to be developed for different cropping systems including protected cultivation, conservation agriculture and organic farming. Shrinking land and changing climatic conditions forces us to develop protected system of cultivation of crop plants especially in high value horticultural crops. The solutions for this system need to be developed and greater emphasis has to be laid. Precision farming system coupled with crop monitoring including pests need to be developed for protected cultivation of crops. Crop health clinics with adequate technical capacity and infrastructure for rendering diagnostic and electronic surveillance services need to be established.

The vision 2050 envisages exploring potential of space technology for mapping and monitoring pest and development of weather based forewarning in GIS environment. Robust forecasting model for economically important pests need to be developed for reliable pest advisory. Mapping of pest hot spots and free areas should receive priority.

- **Molecular Farming:** Pests as useful genetic resource need to be exploited. Several RNA plant viruses have been found promising in expression of high level of foreign proteins including vaccines in plant. Plants are now recognized as attractive bio-reactor for producing not only vaccines but also heath benefitting biopharmaceuticals. Virus derived molecules could also be used in expression of plant genes. This mechanism virus induced gene silencing (VIGS) can be used to provide new insights in to the roles of specific genes in plant development and plant defense. Besides, pathogen derived molecules which can impart resistance in plants need to be identified.

III. Combating degradation/depletion of natural resources under changing climate

Water, food and energy securities are emerging as important and vital issues for India and the world under changing climatic conditions. Most of the river basins in India and elsewhere are closing or closed and experiencing moderate to severe water shortages. Over-exploitation of ground water is a major concern. Presently, there are over 20 million wells pumping water using free power supply (provided by the Government). India is bound to face severe scarcity of water in the near future. It is projected that by 2050, the per capita water availability in India would further decline and hover around the scarcity level of 1140 m^3/person/year. It is also projected that by 2050, to feed additional population, the irrigation water demand of the country would increase to about 1,745 billion liters a day (BLD) as compared to 1,658 BLD during 2000.

It has also been observed that during the last two decades or so, the use of fertilisers has although increased several folds yet the overall consumption continues to be low in most parts of the country. Several studies have shown that in most of the regions there is a net negative balance of nutrients and a gradual depletion of the organic matter content of soil. The estimated annual loss in production of eleven major crops in India due to depletion of nutrient as a result of unsuitable agricultural practices amounts to 0.5 to 1.3 million tonnes. Thus, the Institute envisions that by 2050 Indian agriculture should transform itself from input intensive to input responsive, carbon-negative (C^-) to carbon-positive (C^+), low-efficiency to high-efficiency, polluting to pollution-free, and climate-prone to climate-smart agriculture. In this connection, following priority areas are proposed to gain more emphasis:

- **Enhancing efficiency of agri-inputs:** To enhance the efficiency of agri-inputs (water, nutrients, energy); novel products, precision-agriculture technologies and management practices suitable for both open fields and greenhouse conditions will be invented and explored. Improvements in nutrient-use efficiency and soil health sustainability will be achieved by the development of low-cost indigenous nitrification inhibitors and coating materials for developing more efficient nitrogenous fertilizers; agro-ecosystems based plant and micro-organisms mediated nutrient management strategies; SSNM encouraging the development and promotion of secondary and micronutrient fortified customized fertilizers; use of water-soluble nutrients to increase the nutrient and water productivity under different agro-ecosystems; improving quality of fertilizer materials through the establishment of reliable referral laboratories and exploring alternative sources of nutrients *viz.* rocks, minerals and town refuse. Nano-formulations for smart, slow release and commodity specific-nutrients and chemicals will be developed. Biofertilizers using microbial consortia and natural processes on nitrogen fixation and nutrient cycling will be enhanced for higher efficiency. Next generation sensor based machinery will required to be developed for precision applications of agri-inputs on spatial sensitive mode.

- **Managing vulnerability to climate change in Indian agriculture:** Climate variability and changes are among the major challenges faced by Indian agriculture. For ensuring country's food security and making agriculture climate-resilient, appropriate adaptation and mitigation strategies have to be developed. Assessing vulnerability of agriculture to climate change is the pre-requisite for developing and disseminating the climate-smart technologies as some regions are more vulnerable than the others. For example, we recently assessed vulnerability of agriculture to climate change in the Indo-Gangetic Plains (IGP), which is one of the most populous and productive agricultural ecosystems in the world. The study showed that the Eastern IGP is highly vulnerable to climatic variability with low adaptive capacity to recover from the climatic stresses (Fig. 4). Technologies and strategies, therefore, need to be developed for adaptation of crop production systems of the vulnerable regions to the current and future climatic changes. Since climate change poses complex challenges of multiple abiotic and biotic stresses on crops, integrated and multi-disciplinary approaches will be required for developing climate-smart agriculture for the country.

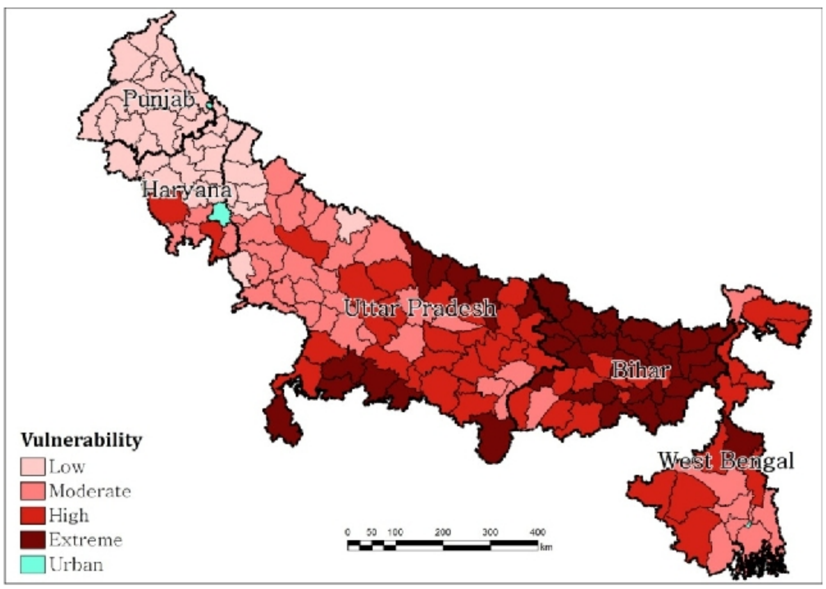

Fig. 4. Vulnerability of agriculture to climatic changes in the various districts of the Indo-Gangetic plains

- **Wastewater management and use in agriculture**: To manage huge volumes of wastewaters generated (Global: 1500 Trillion Liters; Indian: 40 BLD (current) and 83.3 to 166.6 BLD: Projected for 2020 to 2050), to create an alternative source of water (coupled with effective water management) and to mitigate its long term negative impacts on soil quality, biological diversity, ground water contamination, food contamination and consumer health hazard; sustainable phyto-remedial measures (such as engineered wetlands involving single/ multiple- emergent/submergent/floating - plants and different reactive/ non-reactive soil/gravel media/ bio-filters) and/or microbial consortia for degradation of metals/polyaromatic compounds/oily sludge/pesticides/ colour/odour need to be explored and standardized for treating and reusing wastewaters, with different pollutants and pollution levels. Besides, appropriate wastewater / management guidelines for their effective disposal in edible/ non-edible agriculture/ forestry systems; development of suitable business models (such as particle board/ handicrafts/ bio-coal/ fish meal, etc.) for technology sustenance and decision support systems for proposing appropriate adaptation strategies for small/ marginal farmers, under diverse peri-urban/ rural settings, needs to be developed and standardized. Options for their easy integration with existing wastewater treatment and water/ energy conserving technologies also needs to be explored and widely demonstrated /disseminated.

- **Promoting conservation agriculture:** To improve soil health and environment and to enhance resource use efficiency, productivity and profitability - conservation agriculture (CA) technologies such as zero tillage, residue retention and crop diversification will be promoted in irrigated as well as rainfed agro-ecologies. This activity will be integrated with the breeding programmes of the institute under major cropping systems. Technologies will be developed to enhance soil organic matter; agro-biodiversity; carbon sequestration; and thereby improving soil physical, chemical and biological properties; and reclamation of degraded lands. Studies in relation to CA practices on genotype x environment interactions in the changing climate; nutrients dynamics and input-use efficiency; weed and pest dynamics and management; moderation of heat and cold stress to crop; root growth and rhizosphere soil parameter influencing health of soil will be given emphasis. Modeling crop response under CA practices would be another dimension.

- **Crop Residues Management:** In India, approximately 500-550 million tons of crop residues are produced every year of which ~ 70% are contributed by cereals. While a substantial quantity of these residues are used for animal feeding, soil mulching, manuring, roof thatching and fuel purposes, a large remaining portion is burnt on-farm for timely clearance of fields for sowing of the next crop. Burning of crop residues not only causes environmental pollution adding to global warming but also results in depletion of valuable nutrients like N,P,K and S. With the poor availability of labour and increasing cropping intensities in the coming years, the problem is expected to assume greater dimensions. Hence, efficient management of crop residues is vital for long term sustainability of Indian Agriculture. Though several technologies are available for residue use in conservation agriculture, lack of affordable and suitable mechanization remains a constraint. Efforts are required to quantify the economic, social and environmental benefits of residue management practices under different situations. These can then form a basis for policy decisions in relation to carbon sequestration, erosion control, fertilizer-use efficiency and incentives to retain crop residues. The following areas of research will be given immediate attention:

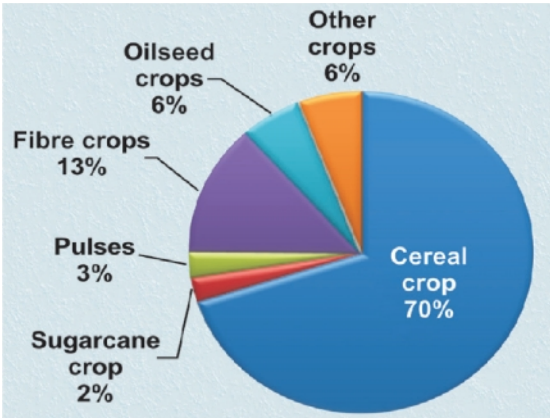

Fig. 5. Residue generation by different crops in India (MNRE, 2009)

- Development of region-specific crop residues inventories, including total production from different crops, their quality, utilization and amount burnt on-farm, for evolving management strategies. Satellite imageries will be used to estimate the amount of residues burnt on-farm.
- Assessing the quality of various crop residues and their suitability for off-farm (e.g. animal feed, composting, energy, biogas, biochar and biofuel production) and on-farm purposes and analysing the benefit: cost ratio, socio-economic impact and technical feasibility of off and on-farm uses of crop residues .
- Enhancing decomposition rate of residues for *in-situ* incorporation using efficient microbial strains.

- Quantifying the permissible amount of residues of different crops which can be incorporated/ retained, depending on the cropping systems, soil characteristics and climate without creating operational problems for the next crop or chemical and biological imbalance.

- **Farm mechanization, protected and precision agriculture**: Multi-task precision farm machinery allowing selective automation for crop production would be developed to make farming more energy and labour efficient, gender and ergonomically responsive. Power-machinery management protocols will be developed as a linkage between manufacturer, service provider and user for different level of farming. Appropriate power-machinery system should be made available for small, peri-urban/urban agriculture. Energy harnessing equipment and technologies for efficient home users of renewable energy will be developed.

Low cost polyhouse for cultivation of high value crops in small farms will be developed. Due emphasis will be given for the development of remote sensing and GIS integrated approach for crop (biotic and abiotic) stress monitoring, soil moisture, fertility and quality assessment for precision agriculture.

Fig. 6. Tomato grown under low cost polyhouse

To enhance resource-use efficiency as well as crop productivity and to reduce environmental foot-prints of agriculture, precision farming research and technology development for field scaled application shall be emphasized. Estimating optimum sowing densities, fertilizers, irrigation water, herbicides, insecticides, fungicides requirements and schedules and developing efficient and scale neutral application devices for accurately applying these inputs as per crop needs will be focused on. Use of sensor-based technologies for quickly assessing the variability in growing environment, crop requirements and synchronizing the supply of inputs with crop demand will be given thrust. Although limited work has been done in the area of precision farming in India but there exists a scope for its improvement through trials in institute farm and development of indigenous tools for its subsequent up-scaling to the farmer’s fields. Standardization of guidance system for fertilizers and pesticides applications; validation of crop growth models for simulating and evaluating the effects of climate will also be important components of precision agriculture. Technologies will be developed for standardizing and promoting soil-less, hydroponics, aeroponics and vertical agriculture for feeding commercial enterprises.

- **Exploring renewable energy sources:** Solar –wind energy based cost effective models for powering farm equipment/sensors/ pumps and generating heat under both open field and protected farming conditions would be tested and standardized; R&D on cost effective transformation of bio-residues (derived from varied agro-ecologic settings) into bio-coal/ biogas/ biogas slurry/ compost, etc and their fuel efficiency/ impact under varying weather/ environmental conditions needs strengthening for promoting their wide scale direct/ indirect agricultural applications and combating air pollution. Microbial diversity and molecular pathways involved in the energy generation processes (such as production of methane, ethanol and other fuels, biodiesel, and electricity); optimization of energy generation processes by microbiological and technological interventions and evaluation/ integration of microbial energy generation technologies with various biomasses will also be given emphasis.
- **Developing biotic/ abiotic stress tolerant microbial inoculations:** Microbe-based technologies including **i**dentification of microbes tolerant to various abiotic (drought, high temperature, salinity) and biotic (plant pathogenic fungi, bacteria and insects) stresses; studies on plant-microbe interactions under selected abiotic/biotic stresses; performance evaluation of promising strains in nutrient budgeting; and development of microbial inoculants for enhancing crop yields, soil health and water quality in stressed habitats needs strengthening.

- **Developing unified soil quality index:** Unified soil quality indices will be developed by integrating soil chemical, physical and biological properties, which would serve as a robust tool for soil quality assessment at micro as well as macro scale. For this, thresholds, particularly for important physical and biological properties will be established under diverse agro-ecologies.
- **Decision Support Systems and ICTs for Climate Resilient Agriculture:** To enhance efficient spatial and temporal natural resource (such as soil, water, air, energy) characterization, utilization, allocation, impact/ vulnerability assessment, early warning, contingent planning, agronomic manipulation and agro-advisory services, suitable decision support systems and information and communication technologies (ICTs), based on modern geo-spatial (GIS and Remote sensing) and modeling techniques will be developed and applied at field, farm and regional scales to enhance resilience of Indian agriculture to climatic/ environmental risks - particularly in rainfed regions, to propose appropriate adaptation measures/ strategies.
- **Farming system and watershed based models:** To combat droughts and to enhance input use efficiency, farm income, round the year income sources, multiple enterprise resource use and food crop integration with horticultural, vegetable and tree crops farming system and watershed based production system models (including developing suitable rainwater/ sewage water harvesting/ treatment systems as decentralized ensured water sources; soil-water-nutrient conserving technologies/ production systems; post harvest storage/food processing units; fodder/ grain/ seed banks along with fodder processing/ feed units; silvipasture interventions on village/ watershed common lands; suitable livelihood improvement and business/ marketing/ industry models, etc) for small, marginal and large farmers needs emphasis. Diversification of existing inefficient cropping systems with intervention of legumes, vegetables, fruits, flowers, medicinal plants and spices and integrated use of resources in the promising cropping systems needs to be emphasized especially in areas where the agricultural crops fail due to erratic monsoon. Establishment of dryland horticulture and medicinal plants as the main crop with traditional agricultural crops as intercrops has good potential to overcome the adverse impact of drought and to provide sustainable livelihood to the rural community. Selection of short duration intercrops,

use of organic manure and use of various water saving devices will also enhance the success of the system. Focus will also be on reduction in fertilizer nutrient requirement through recycling of crop residue other than cereals and other locally available organic sources to sustain the soil health, productivity and environment. The climate resilient diversified cropping system will be developed in resonance with other existing farm enterprises or new/modified enterprises for generating more productive integrated farming systems modules for different land holdings and water availability/ drought conditions. Both horizontal and vertical diversification will find due consideration for generating more income and employment. Eco-tourism models will also be developed to supplement farm income.

- **Postharvest and storage system models:** Parallel to the concept of rural health care and milk cooperative systems in India, post harvest systems for fresh horticultural and arable produce can be evolved on the basis of "*Wheel and Spoke Model*". A Community Post-harvest Centre (CPC) as a hub can be connected to several Primary Post-harvest Centers (PPC) spread across the given area.

A paradigm shift in the socio-economic system in the country will stimulate the growth of food processing sector. The definition of food will transform from "Food for Calories" to the "Food for health and wellness". The scientific evidences in favour of roles of phytochemicals in diet for controlling and preventing several chronic diseases are accruing rapidly. Development of functional or fusion foods by using functional ingredients such as plant-derived carotenoids (lutein, lycopene, β-carotene, capsanthin etc.), phenolics (quercetin, reservatrol, genestein etc.) and peptides.

Fig.7. Fibre and natural anti-oxidant enriched bread for nutritional security

High fiber foods enriched with (β-glucan, cellulose, resistant starch, and fructose-oligosaccharides) with enhanced mineral and protein bioavailability to combat mineral and protein deficiency, respectively. Gluten free products for celiac population, texturized foods and probiotics/ prebiotics, foods for gut health will receive adequate attention. Processing of nutri-cereals (millets, soyabean and corn), for weaning foods, breakfast and snack foods will be frontline products with proven health claims. Production of these high value added foods would be accomplished through high tech-engineered technologies, such as enzymatic liquefaction, extrusion, micro-fluidization, micro-encapsulation, bio-fermentation, supercritical carbon-dioxide extraction, ultrasonication and microwave processing. Production of safe and quality foods will receive further impetus by developing infrastructure and optimized processing technologies for non-thermal processing methods such as Pulsed Electric Field (PEF), Ultraviolet (UV), and ozonation to yield products with more 'fresh-like' flavor than those produced by traditional thermal processes coupled with smart packaging solutions based on nano-composites, and, sensors based systems to detect adulterants and monitor changes during storage conditions. Food safety and traceability will emerge as the major challenges as the food value chains undergo modifications in the near future. The role and need for scientific support to the regulatory and food trade organizations will increase several folds. The development of rapid diagnostic procedures / tools for contaminants/toxins, and pathogens will remain the focus. The increasing consumer awareness and recent upsurge in the fresh and processed food imports will be the driving forces to strengthen the concept of food traceability.

The storage systems will have to be less energy intensive and cost effective to have minimal impact on the environment. The bio-energy from farm and post harvest centre's waste could be another preposition which could be exploited for power generation in the remote areas for meeting energy requirements. It is also envisaged that advanced storage technologies such as controlled atmosphere, dynamic controlled atmospheres, ultra-low oxygen storage, hypobaric storage etc. will be fully commercialized on mega scale in the Indian markets. Special emphasis has to be on low cost processing machinery, primary processing and storage at PPCs. Future trends have to emerge in the direction of usage of clean and renewable energy. The advancement of photovoltaic cells technology may bring revolution in the storage and rural transport systems which can be solar powered. Integrated post harvest management of horticultural crops for loss reduction will continue to receive attention.

- **Enhancing post harvest shelf-life, nutritional quality and food safety:** The future will be for designer food crops, modified suitably to accommodate the most desirable traits. The regulation of ethylene biosynthesis pathway through silencing of regulatory enzymes, RNAi silencing and virus induced gene silencing (VIGS) can be employed to interfere with ethylene pathway. Metabolomics and chemometric profiling is a promising area which can be employed to understand the metabolic shifts associated with postharvest deterioration of fruits and vegetables. These guidelines have to focus on how to produce, pack, transport, retail and consume the food safely. The concept of 'Traceability' has to emerge out significantly without which food safety pillars can't stand. The detection of genetically modified organisms (GMOs) at very low levels is crucial to ensuring responsible release of transgenic crops to build consumer confidence, developing GM product safety standards and analytical methods for detection and traceability of GM in food handling and processing. Development of functional foods/designer foods, including valorization of by-products for fortification/enrichment (wealth from waste). Green, fermentation, encapsulation of food, non-destructive quality evaluation and extrusion based processes for developing fusion foods for health will be given emphasis. Gender specific processing for women entrepreneurs and farm women will be given adequate importance.

IV. Policy Research for achieving higher, sustainable and inclusive growth in agriculture

Indian agriculture currently contributes less than 15% of the gross domestic product and provides employment to nearly half of the work force. Average size of holding continues to shrink (1.16 ha) and small farmers dominates the agrarian structure. The overall productivity is also rising moderately. The growth has accelerated recently to 3.6% and it is likely to sustain. The future direction of Indian agriculture will be towards commercialization, diversification and value addition. There will be pressure to make small holding viable and competitive globally. Surplus labour should move out of agriculture and rural non-farm employment and service sector.

Social science research will assess the future development pathways and provide input for policy making to guide the transition to productive and globally competitive agriculture.

The specific research thrust areas are as follows:

R&D policy research will focus on priorities to enhance the role of R&D in agricultural development. This work will be guided by agricultural development and changing consumer preference, advancements in science, technology generation and economic environment. The studies on impact assessment in newer areas like environmental benefits, nutrition, poverty reduction etc. will provide feedback for research targeting. Agricultural R&D regulations need to also change considerably and the work in this area will analyse effectiveness of various regulations in enhancing technology flow to farmers. There will also be emphasis on role of IPRs in promoting investment and innovations, research partnerships and knowledge sharing, and increased public and private investment in R&D.

Shrinking and degradation of natural resources and environmental externalities are intensifying to the extent that threaten sustainability of agriculture production system. Incentives and institutions have important role in reversing this process. Research work in this area will assess the causes and economic losses to these undesirable changes in natural resource base. Since these are cumulative effects of a number of forces which are dynamic in nature, their solutions using a mix of policy, institutional and technological measures will be studied for sustainable use of natural resources and reducing the externalities.

The role of government in agricultural development will remain critical but the nature and degree of interventions will change. Efficiency of public interventions for higher and inclusive agricultural growth would be an important issue. Institutional mechanism to ensure efficiency and relevance of government interventions through peoples' participation, decentralization, partnerships etc. will need greater attention.

Agricultural markets and trade will undergo a considerable change during the next couple of decades. Research work in this area will assess the direction of these changes, evolving value chains and developments in secondary agriculture. The strategy to enhance corporate investment in the value chains, participation of small farmers in value chains and global trade will be analysed.

Future technology will be more capital, knowledge and skill intensive, and therefore, design and capacity of technology transfer system should adjust to these changing needs. There is need to assess institutional arrangements and resource (financial and manpower) needs to take new technologies to farmers, suggest ways of aggregation of small-scale production and linking farmers with the markets. Development of innovative business models, and skills and entrepreneurship of farmers and rural youth would be of great relevance.

The multiplicity of backhand service and input providers, and value chains in agriculture will provide more choices to farmers and an opportunity to increase their higher income. But at the same time, multiplicity of the actors and options may make decision making difficult. This coupled with higher climatic and market risks would require financial viable insurance products and information system. The models for timely dissemination of agricultural information to a variety of stakeholders will also be needed. Research will focus on increasing the use of modern information, communication and mobile technology to enhance extension efficiency through encapsulation of agricultural knowledge for ICT-enabled advisory system and developing the location specific decision support tools and portals as well as "what-to do" and "how-to do" community participatory videos for use at village level. Development and deployment of weather based advisory services through ICTs and Information Portals and Kiosks for NRM based production strategies will also be followed.

Development of decentralized, market-led and farmer participatory extension approach will be adopted in the public-private and public-public partnership mode for efficient extension and delivery mechanisms. Special attention will be paid to development of these models for integrated farming system for sustainable rural livelihoods, high value products and export of farm produce. Networking of famers association with federal structure and inclusive strategy of international linkages for profitable trade of agricultural produce will also be examined. Community-led extension system for climate change adaptation, grassroots innovations and revival of ITKs for climate resilient agriculture would be promoted. Emphasis will be given on promotion of educational campaign for awareness about farmers' rights, patenting of farmers' innovations, benefit sharing mechanism in commercialization of indigenous knowledge and community resources.

Gender mainstreaming and development of skill and entrepreneurship of farm women will remain an important agenda for inclusive growth. Policy, technological and social awareness will be critical to address this challenge. The research shall draw from the experiences so far in this area and suggest the strategies for gender mainstreaming and empowerment of farm and other rural women.

V. Building globally competitive human resource in frontier areas of agricultural science, technology and management

IARI has served as a mother institute in providing human resources to national agricultural research system. The contribution of IARI towards human resources development for the national and international agricultural research and education systems is unparalleled. IARI alumni, today, are heading and directing agricultural research, education and extension programmes in several key organizations, not only in India, but also in other countries. The forward looking academic environment at the Institute attracts the most talented students available for agricultural sciences in the country and abroad.

The Institute is committed to develop a new breed of trained manpower to face the toughest challenges ahead, including those related to research management in the changing national and international arenas which is a pre-requisite for up-grading research programmes, developing technologies and evolving institutional mechanisms. IARI will focus on developing highly trained personnel in large numbers for areas like crop improvement, protection, production, resource management and social sciences through interdisciplinary and multi-commodity mode. The Institute will also focus on strengthening and streamlining higher education in agricultural sciences to meet the future challenges and develop a band of agricultural scientists, who must also be familiar with IPR/PBR/SPS/PVP regimes, and various international conventions and their implications. To meet the challenges of development of globally competitive quality human resource through PG education in basic and advanced areas of agricultural sciences, efforts will be made to develop world class infrastructure and amenities. Attention will be paid for development of competent faculty members through national and international level training.

The specific thrust areas will be:

- **Imparting globally competitive PG education in basic and frontier areas of agricultural sciences:** Keeping pace with the global standards the Institute would strengthen post graduate education in diverse disciplines in agriculture laying greater focus on science and processes and through experiential learning and problem solving approach. The Institute, through partnerships with industry and academia, would develop state-of-the art infrastructure, amenities and resources needed for evolving globally competitive innovations. It will also encourage overseas exposures and attachment of its faculty with the top academic institutions of the world to continuously upgrading their knowledge.

Fig. 8. Prime Minister of India - the Chief Guest at the Golden Jubilee Convocation

- **Establishment of off-shore campus of IARI at selected countries of South Asia and Africa and creating e-learning opportunities:** The institute plans to establish off-shore campuses which will help in developing strong international linkages through post-graduate teaching and research and building competence at these countries for higher growth in agricultural sector. Suitable modules will also be developed for introducing e-learning programmes.

- **Introducing dual degree programmes with universities overseas:** Through international collaborations sandwitch degree / dual degree programmes will be introduced, particularly in the emerging disciplines in agriculture and allied sciences.

- **Promoting post-doctoral programmes in different disciplines:** This is an ideal system for developing competence in young scientists. Institute will undertake the task of imparting post-doctoral training in emerging areas of agricultural sciences through various projects, schemes and funding sources.

- **Regular up-gradation of faculty competence in frontier research areas.:** The Institute lays great importance to up-gradation of its faculty through training and visits to various laboratories and centres of advanced studies in different parts of the world, so that the world agriculture get the benefit of its highly trained, dedicated and motivated faculty.

- **Capacity development of master trainers, entrepreneurs and farmers through training at the national and international level:** Through organisation of refresher, short- and long-term training courses in specific areas of agricultural Sciences. These would be very fruitful in providing new ideas and knowledge as well as for developing linkages and international collaboration.

3. OPERATING ENVIRONMENT

The growth of Indian agriculture, since Independence, has been closely linked with the contributions of IARI in agriculture research, education and technology transfer. Development of high yielding and abiotic/ biotic stress tolerant varieties / hybrids of all major crops for different agro ecosystems; development of efficient production technologies and integrated crop management practices (including plant health and nutrient management), several novel chemicals, resource management strategies/ indigenous decision support systems as well as working prototypes; and concepts and models based on socio-economic analyses have been the hallmarks of the Institute's research. The Institute has moved upstream, integrating basic and frontier science with strategic and applied research. Keeping abreast with the advancements in cutting edge research, the Institute has served the cause of science and society with distinction through first-rate research, appropriate technology development and generation of globally competitive human resource. Today, the Institute has a core strength in several key areas, such as conventional and molecular breeding, genomics, molecular diagnostics, climate research, functionalised foods, precision agriculture, wastewater management, nano-chemicals, extension models, impact analysis and policy research.

The Institute's has reorganised its various Centres, Divisions and Units within six Schools. These are 1) Field Crop Improvement; 2) Horticultural Sciences; 3) Crop Protection; 4) Natural Resource Management; 5) Basic Sciences and 6) Social Sciences. The current programmes on crop improvement are focused towards exploiting heterosis in crop plants, trait-specific breeding using molecular tools and techniques, such as MAS, MAB, MARS, mining and identification of new genes and alleles for resistance/tolerance to biotic and abiotic stresses and creation of pre-breeding stocks combining multiple resistances and other desirable attributes which are taken up as integral components of crop breeding. IARI will continue its leadership in basic, strategic and anticipatory research in frontier areas of agricultural sciences, focussing on bio-nano-technology, application of space and nuclear sciences in agriculture and also exploring newer areas like ocean farming for food production.

IARI has geared itself to generate productivity enhancing technologies fitting the diverse agroclimatic conditions prevailing across the country to make Indian agriculture more efficient, vibrant and internationally competitive. The future research will focus more on rainfed agriculture, particularly in the eastern and central India. The programmes will also address the issues emerging from the dramatic changes in the consumption patterns of the people and will generate technologies for high-value agriculture, suitable for large, small as well as marginal farmers for enhancing the profitability through crop diversification and value addition. The Institute is ready to deal with the problems related to declining natural resources and deteriorating environment, which at present plague Indian agriculture, by developing new technologies in the context of water scarcity, water and land degradation and climate change. The extension services will be strengthened with new programmes and models to improve access to productivity enhancing technologies by the farmers including those living in less favoured or remote areas. Special attention will be given to empower the farm women, who are expected to play more important role in agriculture as a large proportion of men folk will not be available for farming after 2-3 decades.

The institute places high priority on making small and marginal farms viable by raising their productivity in sustainable and environment-friendly manner by reducing cost of inputs through the use of biofertilizers on one hand and diversification in conjunction with value addition and market linkage on the other. Input and natural resources management through human interventions are recognized as the operating blocks for the improved technologies to function and realize the potential of the latter. IARI would be working towards the best use of natural resources through adoption of resource conservation technologies, enhanced water and input use efficiency and harnessing of non-conventional water sources for sustained and improved productivity. There would be emphasis on using social networks, ICTs and promoting public-private partnerships in extension and agri-business.

The Institute has taken new initiatives in strengthening agricultural research and higher education in some of the developing countries such as Myanmar, Afghanistan and in Africa, which will help in their capacity building programme as well as for increasing agricultural productivities, which will, in turn, impart global food security.

4. NEW OPPORTUNITIES

Advancements in science and technology will be harnessed for enhancing judicious use of inputs, development of ICT, deployment of decision support system and biosensors. These will also include advancements in the fields of system biology, bio-informatics, space technology and simulation modelling etc. Bilateral/ multilateral cooperation will be encouraged with other countries, particularly in African continents keeping in view the global demands in various commodities. The institute envisions its role in finding technological solutions to region- specific problems and providing technological backstopping. The CGIAR system is strengthening its partnership role with the national programmes, which will be leveraged to establish new collaborations. Likewise, several national agricultural research systems, both in developed and developing countries are keen to establish collaboration with IARI. This provides an excellent opportunity for the Institute to strengthen its partnership not only with CGIAR institutions but with other international institutes/universities as well.

By having its centres in different agro-ecological regions of the country, IARI has the opportunity to have its technologies assessed and refined in different agro-ecological settings of the country and thus serve truly as a national Institute. In this way, the Institute is able to address both local and regional problems in a synergistic manner. The regional stations also help in popularizing IARI technologies. Further, collaborations with other ICAR institutes and their centres in other regions will be set up to develop temperate vegetable, fruit and flower varieties and their seed production opportunities to save valuable foreign exchange spent on their import. . The institute also looks forward to venture new centres in other parts of the world especially in central African and South Asian countries to provide scientific support and technological backstopping.

The issue of commercialisation of technologies developed by the institute will need greater attention at the national as well as international levels. The Institute has a well established system of Technology Management and Business Promotion through its ITM/ ZTM and BPD Units which will be expanded in a corporate mode to generate sufficient revenue for financing the research programmes of the institute. A centre of Agri- Business Management and Economics is proposed to develop pilot scale commercial modules. For better utilisation of research outputs, a consortium approach will be adopted to link with the industry partners promoting joint ventures for technology development and commercialisation.

5. GOALS/ TARGETS

Ensuring food and nutritional security, improving rural livelihood along with environmental security in a sustainable manner, will remain the major goals of the agricultural development planning. IARI will strive to help achieve these goals through development of improved agricultural technologies along with their efficient and effective modes of dissemination. It is estimated that the annual growth in the productivity of food grains should be more than 1.5% and that of horticultural crops more than 3% to meet this goal. This will essentially require development of improved varieties of field and horticultural crops with desirable traits under the changing environmental scenario. At the same time, technology will also be needed to increase the input use efficiency to reduce the cost of production. and enhanced value addition to make Indian agriculture profitable, competitive and attractive to rural youth. In addition, value addition through processing will help in reducing colossal losses on one hand and increase the income of the farmers on the other. The Institute is ready to take up the proposed research programs keeping in mind the recent developments in the field of science, agriculture and economic environment and accelerate the growth in total factor productivity (TFP) thereby contributing to technology-led growth. The priorities and programmes spelt out in this document will help in achieving these targets. These programmes undertaken in participatory mode and organizational adjustments for their effective implementation will be pursued. The Institute plans to address these challenges, in a holistic manner, through different schools and a proper mix of basic, strategic, anticipatory and applied research with strong outreach programmes and linkages will help in their realization.

6. WAY FORWARD

Establishment of Agricultural Universities in the 19th century coupled with deployment of science and technology helped in ushering an era of prosperity and affluence in the country. The IARI, a flagship Institute of the ICAR, played a vital role in developing agricultural production technology that has helped in meeting the food and feed requirements of the country before and after independence. IARI was later instrumental in ushering 'Green Revolution' in India (in early 1970s) that helped the country not only in attaining self-sufficiency in food grains but has been in the forefront in increasing productivity of cereals, pulses, oilseed, fruits and vegetables that has enabled the country to become an exporter of nearly INR one lakh crores (nearly 166.67 million US $) annually. However, despite these spectacular gains in crop and livestock productivity, nutritional security could not be attained, which will, therefore, receive overriding importance. Currently, we are facing the problem of colossal waste due to low level of post harvest processing and value chain. In addition, the agricultural education, which helped in producing high class researchers as well as teachers, has suffered a setback because of diminishing resources and poor quality of scientific manpower in the National Agricultural Research, Education and Extension System (NAREES).

IARI has unique advantage of being a multi-crop and multi-disciplinary Institute encompassing crop improvement, natural resource management, crop production, crop protection as well as basic and social sciences, which enable our scientists to handle the researchable issues in a holistic manner. Advances in crop breeding in the past five decades have lead to substantial increases in crop productivity. However, the population of the country is expected to stabilise at around 1.6 billions by the year 2030, making food and nutritional security the most important issue. Therefore, food grain production needs to be increased by 50% whereas that of vegetable and fruit production will have to be doubled to meet the needs of this population. This additional food will have to be produced on existing agricultural land that will be around 140 million ha with dwindling soil and water resources coupled with uncertainties of climate change. In addition, crop losses due to insect pests and diseases have to be controlled in an eco-friendly manner. The challenges of malnutrition, low productivity and crop diversification can be met by better resource management and breeding more productive, more nutritious and at the same time less resource input demanding crops. The crop commodities, thus produced, need to be saved from post-harvest losses through innovation in food processing technologies. In addition to this, value addition chain will be given high priority. This will call for harnessing the powerful tools of modern technology including bio- and nanotechnology in agriculture. Modern biology that flourished during 1970s has made spectacular strides and commendable successes have been reported in the field of agriculture. Transgenic crops are the order of the day and are now grown globally in about 170 million hectare area in 28 countries with significant social, economic and environmental benefits to the farmers in developing as well as developed countries. Molecular marker assisted precision crop breeding has given new varieties with enhanced value in terms of pest resistance, abiotic stress tolerance and improved quality, which have become immensely popular. Genomics have opened a new era in crop improvement and when coupled with large scale phenotyping will lead to significantly increase the pace of varietal development with desirable traits.

Along with world class research, high quality agricultural education is a key to the development of the country with special reference to rural India. IARI, a deemed university, has contributed significantly in imparting quality education by producing world class trained manpower, who form today the backbone of the NAREES. The Institute will, therefore, continue to excel in imparting world class agricultural education, which will attract students not only from India but also from the other parts of the world especially middle east, south Asia and Africa. In this endeavour, IARI proposes to establish overseas campuses in Africa as well as south Asia to impart quality education at reasonable cost.

Public sector funding is expected to decline with passage of time, therefore, we will pursue protection and management of IPR for revenue generation on one hand and increasing collaboration with private sector for attracting investment in agricultural R&D on the other. Public-Private partnership in R&D will help in harnessing the benefits of advancements made in generation as well as dissemination of new technology that have enormous potential as evidenced by gains made recently. Therefore, promoting such partnerships, nationally as well as internationally, will be pursued vigorously to realize the dreams of success.