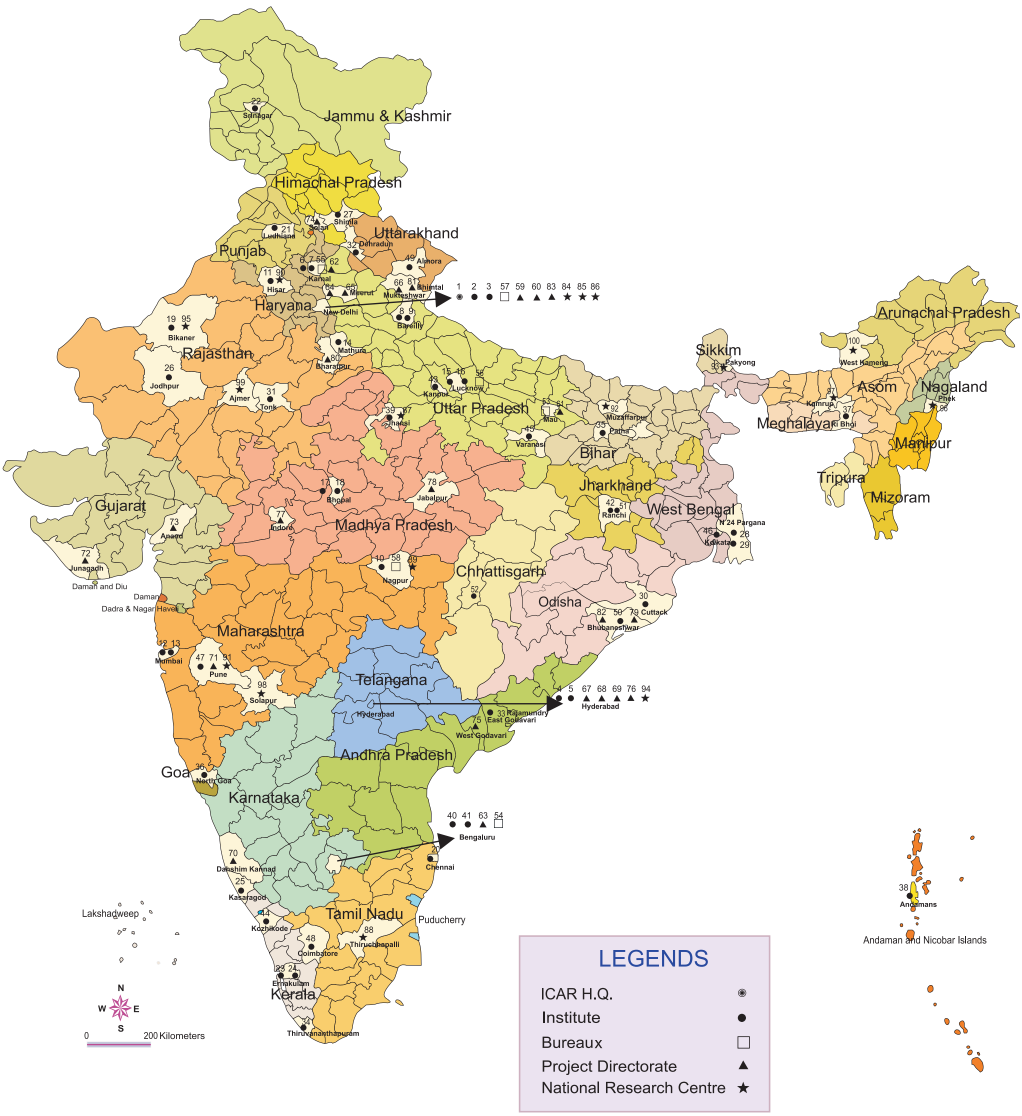
Vision 2050

Indian Agricultural Research Institute

Indian Council of Agricultural Research

INDIAN COUNCIL OF AGRICULTURAL RESEARCH

Institutes, Bureaux, Directorates and National Research Centres



• 64 Research Institutes • 6 Bureaux • 15 National Research Centres • 15 Project Directorates

Vision 2050

Indian Agricultural Research Institute
(Indian Council of Agricultural Research)
New Delhi 110 012

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संदेश

भारतीय सभ्यता कृषि विकास की एक आधार रही है और आज भी हमारे देश में एक सुदृढ़ कृषि व्यवस्था मौजूद है जिसका राष्ट्रीय सकल घरेलू उत्पाद और रोजगार में प्रमुख योगदान है। ग्रामीण युवाओं का बड़े पैमाने पर, विशेष रूप से शहरी क्षेत्रों में प्रवास होने के बावजूद, देश की लगभग दो–तिहाई आबादी के लिए आजीविका के साधन के रूप में, प्रत्यक्ष या अप्रत्यक्ष, कृषि की भूमिका में कोई बदलाव होने की उम्मीद नहीं की जाती है। अतः खाद्य, पोषण, पर्यावरण, आजीविका सुरक्षा के लिए तथा समावेशी विकास हासिल करने के लिए कृषि क्षेत्र में स्थायी विकास बहुत जरूरी है।

पिछले 50 वर्षों के दौरान हमारे कृषि अनुसंधान द्वारा सृजित की गई प्रौद्योगिकियों से भारतीय कृषि में बदलाव आया है। तथापि, भौतिक रूप से (मृदा, जल, जलवायु), बायोलोजिकल रूप से (जैव विविधता, हॉस्ट–परजीवी संबंध), अनुसंधान एवं शिक्षा में बदलाव के चलते तथा सूचना, ज्ञान और नीति एवं निवेश (जो कृषि उत्पादन को प्रभावित करने वाले कारक हैं) आज भी एक चुनौती बने हुए हैं। उत्पादन के परिवेश में बदलाव हमेशा ही होते आए हैं, परन्तु जिस गति से यह हो रहे हैं, वह एक चिंता का विषय है जो उपयुक्त प्रौद्योगिकी विकल्पों के आधार पर कृषि प्रणाली को और अधिक मजबूत करने की मांग करते हैं।

पिछली प्रवृत्तियों से सबक लेते हुए हम निश्चित रूप से भावी बेहतर कृषि परिदृश्य की कल्पना कर सकते हैं, जिसके लिए हमें विभिन्न तकनीकों और आकलनों के मॉडलों का उपयोग करना होगा तथा भविष्य के लिए एक ब्लूप्रिंट तैयार करना होगा। इसमें कोई संदेह नहीं है कि विज्ञान, प्रौद्योगिकी, सूचना, ज्ञान–जानकारी, सक्षम मानव संसाधन और निवेशों का बढ़ता प्रयोग भावी वृद्धि और विकास के प्रमुख निर्धारक होंगे।

इस संदर्भ में, भारतीय कृषि अनुसंधान परिषद के संस्थानों के लिए विजन–2050 की रूपरेखा तैयार की गई है। यह आशा की जाती है कि वर्तमान और उभरते परिदृश्य का बेहतर रूप से किया गया मूल्यांकन, मौजूदा नए अवसर और कृषि क्षेत्र की स्थायी वृद्धि और विकास के लिए आगामी दशकों हेतु प्रासंगिक अनुसंधान संबंधी मुद्दे तथा कार्यनीतिक फ्रेमवर्क काफी उपयोगी साबित होंगे।

(राधा मोहन सिंह)

केन्द्रीय कृषि मंत्री, भारत सरकार

Foreword

Indian Council of Agricultural Research, since inception in the year 1929, is spearheading national programmes on agricultural research, higher education and frontline extension through a network of Research Institutes, Agricultural Universities, All India Coordinated Research Projects and Krishi Vigyan Kendras to develop and demonstrate new technologies, as also to develop competent human resource for strengthening agriculture in all its dimensions, in the country. The science and technology-led development in agriculture has resulted in manifold enhancement in productivity and production of different crops and commodities to match the pace of growth in food demand.

Agricultural production environment, being a dynamic entity, has kept evolving continuously. The present phase of changes being encountered by the agricultural sector, such as reducing availability of quality water, nutrient deficiency in soils, climate change, farm energy availability, loss of biodiversity, emergence of new pest and diseases, fragmentation of farms, rural-urban migration, coupled with new IPRs and trade regulations, are some of the new challenges.

These changes impacting agriculture call for a paradigm shift in our research approach. We have to harness the potential of modern science, encourage innovations in technology generation, and provide for an enabling policy and investment support. Some of the critical areas as genomics, molecular breeding, diagnostics and vaccines, nanotechnology, secondary agriculture, farm mechanization, energy, 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. Our institutions of agricultural research and education must attain highest levels of excellence in development of technologies and competent human resource to effectively deal with the changing scenario.

Vision-2050 document of ICAR-Indian Agricultural Research Institute (IARI), New Delhi has been prepared, based on a comprehensive assessment of past and present trends in factors that impact agriculture, to visualise scenario 35 years hence, towards science-led sustainable development of agriculture.

We are hopeful that in the years ahead, Vision-2050 would prove to be valuable in guiding our efforts in agricultural R&D and also for the young scientists who would shoulder the responsibility to generate farm technologies in future for food, nutrition, livelihood and environmental security of the billion plus population of the country, for all times to come.

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Preface

India has made a remarkable progress in agriculture sector, which is credited with making the country not only self-sufficient in food grains in early 1970s but has enabled it to export agricultural commodities worth ₹ 2.35 lakh crores during the last year. However, along with numerous accomplishments, newer challenges have come up. The ever increasing population and income have raised the demand for food but the resource base that was responsible for increasing the production has been shrinking. Rising cost of cultivation has adversely impacted the profitability; consequently, farming no longer remains an attractive option. In addition, growth rate in productivity of many crops has become stagnant. This is further compounded by the challenges of global warming. Indian agriculture, therefore, faces twin challenges of increasing production, productivity along with profitability of farming on one hand and maintaining the environmental security and sustainability on the other.

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.

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 the preparation of this perspective plan has indeed been inspiring. The inputs of the Joint Director (Research), Dr. K.V. Prabhu, former Director, Dr. H.S. Gupta, former Joint Director (Extension) and Former Acting Director, Dr. K Vijayaragavan and former Joint Director (Research), Dr. Malavika Dadlani, along with Heads of Division of the Institute have been extremely helpful in preparing the document.

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Contents

Context

Green Revolution, emanating 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. The Green Revolution, although made the country proud, resulted in several second generation problems. Coupled with this, the growing population and rising per capita income have generated increased demand for food. 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 (Fig. 1). Hence, an agricultural growth rate of 4% per annum is necessary (as against 3.6% during the XI plan) not only to meet the growing 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, the economic contribution of agriculture to India's GDP has been declining steadily from 57% in 1st five year Plan to 14.1% by the end of 11th Plan. Agriculture is, however, the largest economic sector and plays a significant role in the overall socio-economic fabric of the country with more than 55% of its population dependent on agriculture. The future requirement of food grains, vegetables and fruits in 2020 and 2050 indicate a growth rate of 1.12% for food grains, 2.41% for vegetables and 3.71% for fruits to maintain self-sufficiency.

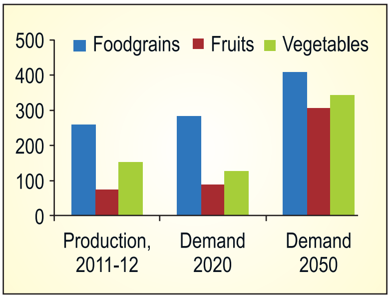

Fig. 1 Wheat Growing Zones of the Country

Although India attained self-sufficiency 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 undernourished. According to International Food Policy Research Institute, the economic loss on account of micronutrient deficiency alone (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 the country.

As regards water, most of the river basins in India and elsewhere are either closing or experiencing moderate to severe water shortages. Excessive water use for agriculture has resulted in 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 XI five year plan was 113.24 Mha and 89.94 Mha, respectively. As, the scope for further utilization of created irrigation potential is hardly 5-10%, the country 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 from an existing level of 1545 m3/capita/year (census of 2011) to a scarce level of 1140 m3/capita/year. Further, by 2050, to feed the 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 resulting in water scarcity; hence there is an urgent need to save water by adopting water use efficient technologies, to make it available for other purposes. Under water scarce conditions, waste water/ low quality water is emerging as potential non-conventional source for demand management, after necessary treatment. Agricultural reuse of sewage waste water (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 a major concern. 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. It is therefore necessary to support the local communities in these drought affected regions with modern surveillance, support and service systems.

Although the use of fertilisers has increased several folds, 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. The problem of maintaining the nutrient balance and hence preventing the consequent nutrient deficiencies will be a major concern. 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 climate change, the changing agricultural practices, environment, and more intensive cropping systems. Besides, trans-boundary trade among the countries has paved the way for the introduction of newer pests across the national boundaries. Preparedness for their detection and identification, and development of pest risk analysis (PRA) based prioritized pest database is of paramount importance. The emphasis in future, therefore, has to be on enhancing resource use efficiency, developing improved varieties/ hybrids having resistance to multiple biotic and abiotic stresses for increasing overall productivity and propelling production.

Presently the country spends ₹ 54,000 crores (approx 11 billion US $) of foreign exchange for importing edible oils to meet the domestic demand. In addition, we also import 3-4 million tonnes of pulses annually costing ₹ 11,700 crores (US $ 2 billions). In addition, reducing post-harvest losses and enhancing quality of produce and value addition for improved agricultural exports which is currently around ₹ 2.35 lakh crores (nearly 27.5 billion US $) is a dire necessity.

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.

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. 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. The unprecedented success of wheat, rice and mustard varieties in the recent past are pointers to this. The institute has served the country by developing appropriate technologies leading to self-sufficiency in food grains and diversification and export. 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.

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 feature has made IARI a distinct Institution enabling India to excel in the developing world. This exercise is aimed at foreseeing the agricultural scenario of 2050 and the likely challenges. The document also enlists the strategies to capitalise on the new opportunities for attaining food and nutritional security of the nation on its path to be a world power.

VISION

'To provide national leadership for evolving science-led environment-friendly and globally competitive Indian agriculture with a view to assuring sustained food, nutrition and livelihood security for all'.

MISSION

'To explore new frontiers of science for farmers and for developing technologies and human resources supported by policy guidelines for creating a vibrant, responsive and resilient Indian agriculture'.

APPROACH

'Partnership-based agricultural research, education and frontline extension for development of Indian farmers and consumers'

MANDATE

In order to accomplish the above, the Institute has set the following mandates:

(i) To explore new frontiers of sciences for basic, strategic, and need-based research in agriculture and allied sciences;

(ii) To develop human resources by imparting globally competitive higher education in basic and frontier areas of agricultural sciences for meeting the needs of agricultural research, extension, and management systems; and

(iii) To evolve innovative concepts and approaches for technology assessment & transfer, priority setting, policy analysis, monitoring & evaluation and quality standards at all levels of R & D system.

"Take it to farmers"

In the decades to come, IARI aims to anchoring crop improvement and natural resource management as the major drivers of change with strategies to breaking the yield barriers with the help of efficient and sustainable use of available natural and input resources for farmers of the country to adopt. The Institute will focus on developing technologies of 'direct use by farmer' for climate-smart agriculture; improved pest- diagnostics and management; liquid and solid waste utilization 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 innovative approaches and partnerships, involving information and communication technology

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Challenges

Increasing population and income have changed the demand for food with a substantial increase in demand for fruits/vegetables and livestock and quality products. In addition, concern for environment protection and globalisation has put tremendous pressure on Indian agriculture. In fact, increasing demand for water 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.

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 range 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. These challenges have to be addressed through improved technologies; without compromising the sustainability of our natural resource base.

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 farm production systems with better storage and processing technologies for domestic 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, generating 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. Quality human resource development in frontier areas of science and management of agricultural programs and enterprises

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

Programmes Proposed

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

- **Integration of conventional breeding with genome resource tools for enhancing crop yield and quality:** Advanced precision breeding tools such as Genomic selection (GS), marker assisted recurrent selection (MARS) technologies will be fully integrated with conventional breeding to enhance the efficiency of the breeding programmes. Complete characterization of genotypic combinations for specific proteins, specific multi-protein chains and micronutrients in a given crop will facilitate development of value added product for direct selection for predictable commercial cultivation by farmers in different agro-ecologies. IARI would provide leadership as in the past through high throughput phenomics facilities to facilitate environment supportive expression levels of different traits.

  Plant breeding shall employ transcriptomics led proteomics in a routine fashion to identify expression variation for maximizing the effect of desired allele and minimizing or 'silencing' the effect of undesirable alleles of different genes controlling the trait.

  The elite genotypes will be targeted to facilitate and complement breeding of **"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.

- **Exploitation of heterosis and development of hybrids:** Efforts will be directed to develop innovative improved germplasm for broadening genetic base, explore diverse sources for cytoplasmic genetic male sterility, use of novel techniques such as anther culture and haploid inducer stocks for instant production of doubled haploid lines for use as parents in hybrid development, development of transgenic male sterility etc., to enhance the productivity of cereals, pulses and oilseeds.
- **National networking with a self-sustainable translational platform on PPP mode for use of precision breeding methodologies and genomic resources:** IARI in partnership with private sector and industry would develop precision breeding platform utilizing high throughput genomic and phenomic resoures, which can serve as full-fledged translational platform and training centre to be named "Innivation and Translational Centre", which can be effectively utilized by NARS partners. This would liberate those programmes and systems which get restricted with latest technologies being made available competitively by the vendors.
- **Pre-breeding:** The 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 are best and crucial tools to introgress novel genes and traits into a cultivated species. Breeding programs, therefore, will be with a completely different mode of functionality and priorities with active involvement of molecular cytogenetics, epigenetics, expression genomics and classical plant breeding.
- **Development of "Super Hybrids" as vehicle to fast-pace productivity increment in crops:** IARI's vision, is to perfect the

Fig. 2 Seed production of PRH-10-a popular fine grain aromatic rice hybrid at IARI Regional Station, Karnal

hybrid technologies on priority. The only means to realize this vision is on a public-private partnership mode. The enhancement can be achieved by exploring diverse sources for male sterility and fertility restoration system. The Hybrid Seed Production system for transgenic hybrids where the parental lines are transgenic and the commercial product is non-transgenic (Non-GMO) will be most useful and easily acceptable for release in the environment.

- **Ushering seed-security through public-private partnership:** Realizing the significance of and impact the quality seeds, the systematic seed production programme of IARI at its head quarters and regional stations at Karnal, Katrain, Indore and Pusa (Bihar) will continue on professionalized principle through direct (Fig. 2) and collaborative participation of farmers and industries.
- **Establishment of genomic resources, and integration of bioinformatics and systems biology in functional genomics:** With genome sequencing becoming affordable and available to public institutional mechanisms, the emphasis would be on targeting the physical distance between marker and genes or quantitative trait loci (QTLs) for agronomic adaptation, nutrient use efficiency, water use efficiency, abiotic stress tolerance and biotic stress tolerance. This will be complemented with characterization and functional validation of the component genes and alleles. The transgenic crops with multiple stress tolerance using RNAi technology will be developed. Long-term collaborations shall be established with other leading national / international groups based on systems such as *graminae* group, *vigna* group, *cruciferae* group, *solanaceae* group, etc. This information will be 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, drought and frost during their phenological cycles.
- **Bioinformatics:** It will receive top priority in view of the important role bioinformatics plays for converting the information that is getting generated through molecular technologies, system biological inputs, digitization of environmental and natural resources for crop improvement and natural resource management.
- **Genetic improvement of cropping systems for enhanced stability to changing climate regimes:** 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 keeping

the crop rotations in a given agro-ecology in view for a total system based genetic gain exploration.

Climate change and its consequential changes in water regimes, ground and air temperature patterns are projected to severely dent production in varying intensities. Therefore, modern tools of biotechnology (genomics insights for exploring all genomic resources, mobilizing the same and adoption of wide-spread rapid throughput molecular marker technologies) for improvement of physiological trait and introgression of novel alleles from wild and related genetic resources, protein and metabolome engineering for enhancing and metabolic stability and thus yield stability under stresses will be attempted.

- **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, 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.
- Phenomics and genomics assisted development of climate-smart crop varieties: 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 unfavorable, fluctuating and stress environments.
- **Development of functionalized and futuristic crops:** Biofortification and plant derived biomolecules (for vaccines) are important technologies to achieve the Millennium Development Goals. Protein malnutrition, micronutrient deficiency such as iron and zinc, and vitamin A deficiency affect more than two billion people in developing countries. Biofortification of these essential nutrients is important to alleviate these problems. Golden Rice biofortified with provitamin A, potato with protein and provitamin A, banana with

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.

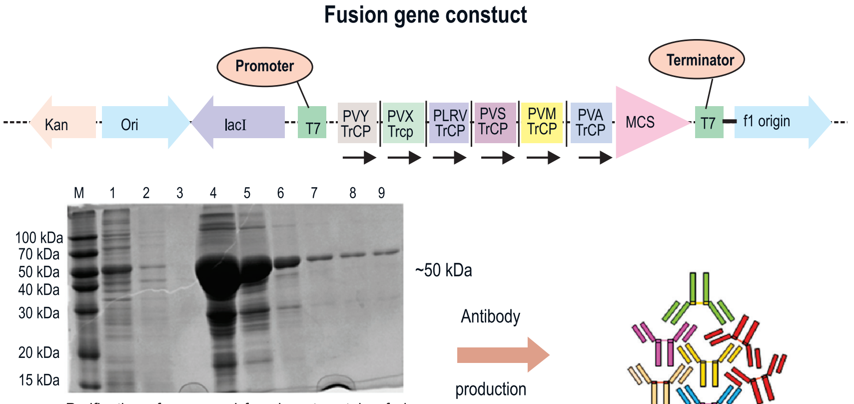
iron and provitamin A and cauliflower with provitamin A (Fig. 3) are such examples.

- **Genetic enhancement of photosynthetic efficiency in C_3 crops:** Two approaches will be pursued to achieve this goal
  i) *Engineering C_3 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.
  ii) *Conversion of C_3 to C_4 pathway for higher productivity and yield stability:* By 2050, rice yield needs to be increased by 60% in Asia. Hence, systems biology and modern molecular tools will be deployed to develop rice cultivars with single/ two-celled C_4 photosynthetic pathway for quantum jump in rice productivity.
- Transformation of cereals with biological nitrogen fixation (BNF) 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. Hence, incorporation of BNF in major cereal crops is envisaged to enhance profitability and reduce production cost as well as environmental cost.

II. Ensuring bio-security and integrated plant health management

- 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 will receive priority. Through interactive genomic and transcriptomic approaches, better understanding of pest-host-vector- environment interactions will be attempted, 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 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.



Purification of expressed fused coat protein of six potato viruses, lane 1: flow through, lane 2-3-wash, lane 4-9: eluted fractions-3rd, 5th, 9th, 13th, 17th and 25th fraction, M=Protein Maker.

Fig. 4 Multiplex detection of potato viruses using cocktail of antibodies generated through recombinant DNA technology

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. 4).

Biosystematics based on digitized keys will receive priority. The existing repositories of the fungi, bacteria, insects and nematodes will be enriched by collection and conservation of these organisms. Digitized database of the species will be developed;

Restructuring the repositories for achieving national/ international repository status in accordance with National Biodiversity Act and other biodiversity regimes will be a priority.

- **Molecular approaches to multiple stress tolerance:** Transgenic crops with multiple stress tolerance using RNAi and Genome Editing Based technologies based on Transcription activator-like effect or 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 10.8 mha 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 expensive and is 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. 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:** Search for novel molecules from natural resources especially plants and microbes through chemical profiling, genome mining and genome wide identification will 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.. Fruits and vegetables being highly perishable need specific chemicals/products for post-harvest management of diseases in order to enhance their shelf life. In addition research will focus on anti-sprouting agents and chemicals for ripening.

  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 carried out 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.
- **Info-chemicals:** Infochemicals play a key role in insect-insect and insect plant interactions. Decoding these infochemicals will lead to the identification of novel sex /aggregation pheromones, kairomones which could be utilized for developing lures and traps to improve the efficiency of IPM strategies for major pests of crops.

- **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. Integrated crop health management solutions need to be developed for different cropping systems including protected cultivation, conservation agriculture and organic farming.
  Principles of nanotechnology will be used for developing nanomaterials for crop protection and increasing the efficiency of agri-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 strict monitoring of 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 for developing a sustainable management strategy.
- **Precision farming system:** This system coupled with crop pest monitoring and their management 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.
  Potential of space technology for mapping and monitoring pest and development of weather based forewarning in GIS environment will be given priority. Robust forecasting model for economically important pests will be developed for reliable pest advisory.
- **Molecular Farming:** Pests as useful genetic resource need to be exploited. Several plant RNA 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. The virus induced gene silencing (VIGS) mechanism 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 impart resistance in plants need to be identified.
- **Genomics aided pest control:** Insects are the largest group of animals having a robust genomics data base, Genomics approaches will be utilized for identification of novel targets for insecticidal molecules, pheromones and other infochemicals and also for

understanding the mechanism of detoxification of xenobiotics in key pests which could be utilized for developing insecticide resistance management strategies and for developing novel plant protection chemicals.

III. Natural resource management

Efficient management of water, soil and energy will remain important and vital for Indian agriculture. Most of the river basins in India are experiencing moderate to severe water shortages. Over-exploitation of ground water is a major concern. Likewise, widespread multi-nutrient deficiencies owing to indiscriminate and unbalanced use of fertilizers, depletion of soil organic matter content, and sub-soil compaction have emerged as major soil health problems. 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 and climate-prone to climate-smart agriculture. In this connection, following areas will receive priority:

- **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 increasing the efficiency of 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 and exploring alternative sources of nutrients viz. rocks, minerals and town refuse. Nano-formulations for slow release and commodity specific-nutrients and chemicals will be developed. Efficiency of biofertilizers using microbial consortia and natural processes on nitrogen fixation and nutrient cycling will be enhanced. Next generation sensor-based technology will be developed for precision applications of agri-inputs.
- **Managing vulnerability to climate change in 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 a pre-requisite for developing and disseminating the climate-smart

technologies. A study by IARI showed that the eastern indo-gangetic plain (IGP) is highly vulnerable to climatic variability with low adaptive capacity to recover (Fig. 5). 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 agricultural technologies and strategies for the country.

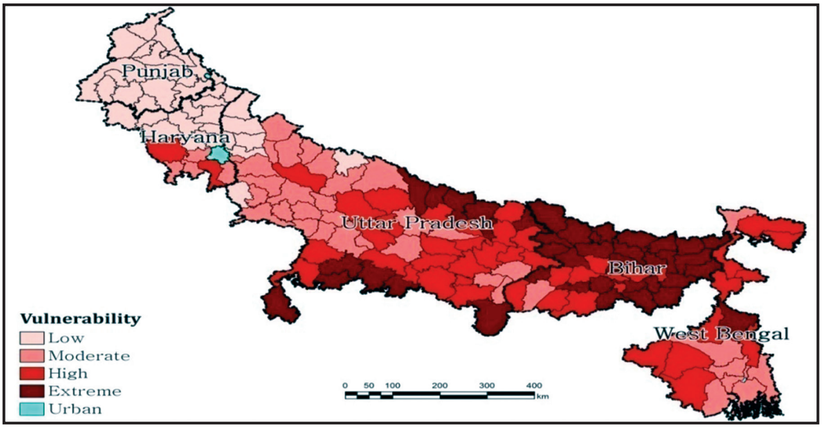


Fig. 5 Vulnerability of agriculture to climatic changes in the various districts of the Indo-Gangetic plains

- **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. Besides, appropriate wastewater management guidelines for their effective disposal in food/non-food crops; 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 - the conservation agriculture (CA) technologies such as direct- seeded rice, brown manuring, zero tillage, residue retention, bed planting and crop diversification will be promoted at large 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; carbon sequestration; and thereby improving soil physical, chemical and biological properties; and for reclamation of degraded lands and sustaining agro biodiversity. Studies in relation to CA practices on genotype-environment interactions in the changing climate; nutrient dynamics and input-use efficiency; weed and pest dynamics and management; moderation of heat and cold stress to crop; root growth and rhizosphere soil parameters influencing health of soil will be given emphasis. Modeling crop response under CA would be another dimension.
- **Crop Residue Management:** In India, approximately 500-550 million tons of crop residues are produced every year of which ~ 70% are contributed by cereals (Fig. 6). While a substantial quantity of these residues are used for animal feed, soil mulching, manuring, roof thatching and fuel purposes, a large 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 technologies are available for residue use in conservation agriculture, lack of

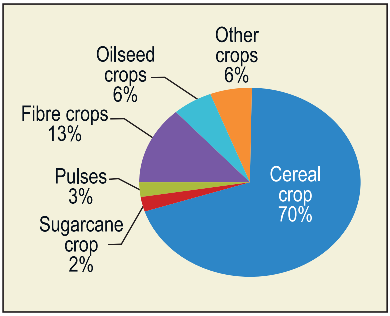


Fig. 6 Residue generation by different crops in India (MNRE, 2009)

affordable and suitable mechanization remains a constraint. Efforts will be made 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, improving fertilizer-use efficiency and incentives to retain crop residues. The following areas of research will be given immediate attention:

  - Development of region-specific crop residue 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-farm 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. 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. 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 inoculants: Microbe-based technologies including** identification 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:** In order to combat droughts, enhance input use efficiency, farm income, and round the year on-farm employment, 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; silvi-pasture 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 dry land 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 provide sustainable livelihood to the rural community. Selection of short duration intercrops, use of organic manure and various water saving devices will also enhance the success of the system. Focus will also be on reduction in fertilizer 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 systems will be developed in resonance with other existing farm enterprises or new/modified enterprises for generating more productive integrated farming system 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.

IV. Policy Research for efficient, sustainable and inclusive agricultural growth

Indian agriculture currently contributes 14.1% to the national 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 dominate the agrarian structure. The overall productivity is also rising moderately, and the growth has accelerated to 3.6% during the XI Plan. The future direction of Indian agriculture will be driven by rising demand for high value products, which shall facilitate commercialization and diversification of agriculture. A moderate growth in food grain production shall be adequate, but production of pulses and oilseeds must be increased to meet the demand. Similarly, a growth of 4-5% may be needed for horticultural and livestock products to meet their demand. Social science research will assess these trends and future development pathways to provide input for policy making, so that the transition to productive, inclusive and globally competitive agriculture is attained in a short period.

These developments on the production side should be supported with participation of private sector in agricultural markets and trade, and an incentive system to promote market-led agricultural production. The production to consumption system should witness value creation with use of post-harvest technology. This can be done when infrastructure is in place and necessary manpower to manage them are available. Thus, development of agri-preneurs and encouraging rural youth to take up income generating primary and secondary agriculture will be essential. In addition, the other specific areas of policy research for making agriculture an economically viable professional option are as follows:

- **Government support for agriculture:** The role of government in agricultural development will remain critical, but the nature and degree of interventions need to be re-examined. Higher investment and efficiency of P-P-P interventions for higher and inclusive agricultural growth shall continue to be an important issue. Assessment of the investment priorities and institutional mechanism to ensure efficiency of the investments and relevance of government interventions through peoples' participation, decentralization, partnerships, etc. will need greater attention.
- **Promoting sustainable systems:** The role of technology, no doubt, to conserve the resources is important, but incentives and appropriate

institutions can help accelerate the conservation process and promote sustainable and equitable use. Research work in this area will assess the causes and economic losses due 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 studies for sustainable use of natural resources and reducing the externalities. Alternate sources of energy, their efficiency and economic viability must be worked out. This work should be complemented with policy actions to promote use of alternate energy sources, both on small scale agriculture and commercial secondary agriculture.

- **Markets and trade:** Agricultural markets and trade will undergo a considerable change during the next couple of decades. A number of modernised and integrated chains will emerge with participation of private sector. Also, the domestic markets will be linked with international markets and there will be greater emphasis on product quality and safety aspects. The 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 and participation of small farmers in value chains and global trade will be analysed.

  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 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 financially-viable insurance products, and information system. The models for timely dissemination of agricultural information to a variety of stakeholders will also be needed.
- **R&D policy research:** This theme shall focus on assessment of changing research priorities to enhance the role of R&D in agricultural development. Agricultural R&D regulations are also expected to 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 public and private investment in R&D.

V. Models for effective technology transfer

Future technology will be more capital, knowledge, and skill intensive and therefore design and capacity of technology transfer systems should adjust to these changing needs. Research work in this area will 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.

- **Application of IT:** Research for 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.
- **Farmer participatory and community extension:** Development of decentralized, market-led and farmer participatory extension approach in the public-private and public-public partnership mode will be the focus of efficient extension and delivery mechanisms. Special attention will be paid to development of these models for integrated farming systems for sustainable rural livelihoods, high value products and export of farm produce. Community-led extension system for climate change adaptation, grassroots innovations and revival of ITKs for climate resilient agriculture shall be promoted.
- **Gender mainstreaming:** 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 strategy for gender mainstreaming and empowerment of farm and other rural women.
- **Private extension:** Next shall witness higher participation of private sector in delivery of inputs and services to farmers and development of their skills and entrepreneurship. This development can fill gap arising due to weakening of public extension system. Research work will assess these trends and suggest the ways to accelerate the participation of private sector, foster partnership with the public systems and promote market-led extension. The role of venture capital and government regulations will also examined in this context.

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

IARI is the mother institute in providing skilled human resources to national agricultural research system in India. IARI alumni, today, are heading and directing agricultural research, education and extension programmes in several key organizations in India and abroad. 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 new challenges ahead. IARI will focus on developing highly trained personnel in large numbers for areas like crop improvement, protection, production, resource management and social and basic sciences through interdisciplinary and multi-commodity mode. The Institute will also focus on strengthening higher agricultural education 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 recruitment and development of competent faculty members through national and international level scouting and 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, would represent state-of-the art infrastructure, amenities and resources needed for evolving globally competitive programmes.
- **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 in near future which will help in developing strong international linkages through post-graduate teaching and research and building competence in the host country for higher growth in agricultural sector. Suitable modules will also be developed for introducing e-learning programmes.

Fig. 7 A Ph.D student receiving his degree certificate from Hon'ble Prime Minister of India, Dr. Manmohan Singh at the Golden Jubilee Convocation held on February 20, 2012.

- **Centre for International Agriculture:** In order to address the problems faced by other countries in Asia and Africa, IARI will establish an independent centre which will build human resource for meeting the challenges of food and nutritional security in those countries.
- **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.
- **Capacity and skill 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.

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Operating Environment

IARI is a multi-crop, multi-disciplinary institute of ICAR charged with all the three the responsibilities of agricultural research, education and frontline extension. The institute was the first institution in the country to be given the status of 'deemed-to-be' University way back in 1958. IARI is fully funded by the Government of India through the Department of Agricultural Research and Education. During the last 108 years of its existence, it has evolved into a vibrant institution, that has helped the nation in not only attaining and maintaining country's self-sufficiency in food grains but has enabled the country to be a net exporter of many agricultural commodities. With its national character built on well-established network in the entire country covering the major cropping system ecologies of the country, advanced education at post-graduation level, international linkages through peer recognition and partnerships, This unique progressive research orientation enables IARI to effectively provide leadership and mentoring to the growing NAREES. Thus, in a growing agricultural set up under the changed circumstances, IARI continues to play its dynamic role of a national institute providing technical backstopping to the NAREES. The highly skilled and system-motivated scientific strength has evolved on the foundation of advanced research orientation and scientific temperament. This professionally driven research environment can be compared to any advanced research institution globally where the motivated workforce enjoys a freedom to operate, demonstrate skills and develop into leaders.

The declining investment in agricultural R&D coupled with reduction in human resources during the last several Five-Year Plans has affected the institute's growth potential which has happened despite its outstanding contribution to GDP of the nation. As for example, earnings from the export of a single commodity like Basmati rice, the contribution of which is estimated to be around 80% of total INR 14,500 crores (nearly 2.3 billion US $) and domestic wheat production at an estimated INR 38,000 crores during the year 2012-13. There are numerous such contributions of IARI which have resulted in huge financial gain to the nation. Thus, the return on the investment made in agricultural R&D in general and IARI in particular has been very high.

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New Opportunities

IARI has unique strength in terms of being the largest agricultural research establishment in Asia. It is further supported by 10 regional stations and two off season nurseries that are used in shuttle breeding. IARI provides intensified research outputs that are aimed at solving problems which require multi-dimensional, multi-regional and multi-disciplinary system-oriented research by keeping the concerned NARS institutions in the loop of operation and execution of the experimentation, validation and demonstration of the results. Therefore, in the present circumstances, IARI engages itself in addressing the basic and strategic issues/problems of national priority, the results of which are shared by the SAUs as well as commodity institutes of ICAR. Such research driven nationally important results when demonstrated through the national systems provide the leads for policy development and insights for implementation of developmental activities for growth in agricultural sector and economic development of the farmers, directly influencing the agricultural production scenario of the country. IARI therefore provides the think-tank option to the core-strength of national policy making set ups as well as international development goals to which the Government of India is committed.

Fast paced developments in the molecular biology technologies, next generation IT infrastructure, communication technology, societal resilience to changing culture and environment are inevitable and need to be coped up with if India has to compete in the open world trade and growth. In the area of agricultural system, these will have to be seen as opportunities up for adoption for the innovative and sensitized research establishments. India has already shown signs of keeping each citizen as a population unit having nearly complete information about the person which may get accomplished by about 2015. This opens a great opportunity for an agricultural research enterprise like IARI aiming towards an all-inclusive growth to divide Indian agricultural production system based on stratification through functional modes of economy, productivity, natural resources, ecology and cropping systems.

IARI would like to take a lead in utilizing these opportunities for gainful activity to its broad mandate of **"Agriculture-India".** IARI would take the role of a national curator, assessor and impact inducer for maximized economic growth in farming sector, against global competition which is more likely to happen with international presence in a liberalized economic investment opportunity. Through a system on programme mode of linking agricultural production enterprises with processing and marketing enterprises, IARI has the extension-backed resources to organize a business model for each participating unit under one umbrella of production-processing-marketing linkage (PPML), which would be an integration of farmer-private and public enterprises in a FPPP activity. It is expected with **"ADHAAR"** based unique identity system along with **Kisan-credit card** and population management unit, there would be a near-perfect orientation to target farm unit by unit on each of the strata mentioned above. With such likely to be a routinely accessible data points, IARI can link each individual farm enterprise in its contact with a particular technology, social set up, e-agri education option to build on the private and unorganized agri-businesses through multi-cornered networks.

Having made signal contribution in the field of agricultural research, education as well as extension, IARI is called upon to help in revamping Agricultural R&D in not only the neighbouring Asian countries like, Nepal, Myanmar and Afghanistan but in the distant African nations owing to similarity in agro-climatic conditions coupled proven track record over the past several decades. Therefore, we propose to set up a 'Centre for International Agriculture' with a view to having better understanding about the needs of different developing nations in Asia and Africa.

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.

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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 presented in the following Table will help achieve these targets. These programmes will be pursued in participatory mode and organizational collaboration for their effective implementation. 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 which will help in their realization.

In order to address the challenges described in section 2, the institute will adopt various approaches in short as well as long term. These approaches along with time frame are presented in Table 1:

Table 1 Challenges, Approaches and short & long-term goals

Challenge I. Designing crop varieties for higher productivity & input use efficiency, resistance / tolerance to stresses and quality traits for different agro-ecosystems, integrating conventional and genome resource- based tools		
Approach	**Short Term Goal**	**Long Term Goal**
Genomic resources and functional genomics	• Sequence for functional allelic resources • Analysis of mutants for functional validation for target traits.	• Use of novel alleles, genes and tissue specific promoters for their use development of transgenics across species depending on the targeted traits
System biology based interventions for crop improvement	• Decipher expression within specific tissue and across taxon • Establishment of system-biological processes for crop designing	• Development of safe cisgenic or intragenic plants against biotic and abiotic stresses. • Long-term collaborations for exploration of genetic gain options from *graminae, vigna, cruciferae* & *solanaceae* groups.
Bioinformatics	• Collation of sequence information with digitized system through databanking	• Integration of bioinformatics with genomic resources data
Development of novel genetic resources for exploitation of heterosis	• Pre-breeding and haploidy • new male sterility/restoration systems. • PPP translational platform	• *Development of parental materials* “designer crop varieties
Designing crop varieties/ hybrids for input use efficiency, nutrition and tolerance to biotic / abiotic stresses	• Transcriptomics and integrated plant breeding through genomics	Development of crop varieties/hybrids by using: • Advanced systems for selection-metabolomics ionomics and expression genomics
Super hybrids as vehicle to fast-pace productivity increment in crops	• Heterotic parental pairs in field and horticultural crops for climate resilience	• Apomixes for hybrids and their maintenance • Super hybrids in pipeline assembly
Development of Novel cereal crops capable of C_4 photosynthesis and biological nitrogen fixation	• Develop C_4-like C_3 crops • Cloning of genes for BNF mechanisms	• C_4 rice • Incorporation of BNF in major cereal crops
Development of climate resilient varieties / hybrids through phenomics and genomics assisted breeding	• Unravel the genetic and functional basis of component physiological traits • Varieties for input use efficiency and stress tolerance	• Aim to provide yield potential increase • Genomics assisted cumulative quantitative breeding (GACQB)
Crop improvement for conservation agricultural practices	• Varieties with adaptability for conservation agriculture practices.	• Innovative conservation agriculture practices which regenerate natural phenomena in biomass
Development of functionalized and futuristic crops	• Identification of genomic resources for intrinsic and extrinsic quality traits	• Extrinsic traits adoption for functionalized foods

	• Targeted bio-fortification of crops	• Varieties, transgenics and hybrids rich in phyto-nutrients, nutraceuticals and processing traits
Ushering seed-security through public- private partnership	• Seed production technologies with seed-quality, health and purity • Farmer-led sustainable seed enterprises	• Up scaling seed enhancement into designer seed treatment technologies.
Challenge II. Ensuring bio-security and integrated plant health management		
Strategy	**Short Term Goal**	**Long Term Goal**
Genomics, improved diagnostics and biosystematics	• Enrichment of repositories of fungi, bacteria, insects and nematodes • Sequencing of nationally important pests. • Deciphering the mechanism of host and non-host innate immunity • Standardized broad spectrum diagnostic kits, database through DNA fingerprints	• Interactive omics approaches • Development of crop based chips for diagnostics • Establishment of worldwide network • Preparedness for exotic pests to ensure crop bio-security and export promotion • Media for culturing fastidious bacteria and other non-culturing obligate bio-trophic pathogens
Molecular approaches to multiple stress tolerance	• Isolation of stress resistance genes for transgenics/ cisgenics • RNAi constructs for stress resistance • Development/validation of transgenics	• Transgenic / Cisgenic crops using RNAi and Genome Editing Based technologies • Understanding of innate immunity in host and non-host plants against major pests • viruses as vectors for expression of heterologous proteins including vaccines in plants
Weed dynamics and management in cropped and non-cropped situations	• Identification mechanisms of HT • Development of HT transgenics	• Development of bio-herbicides for eco-friendly management of weed
Novel agrochemicals	• Genome enabled discovery of molecules • Processes for isolation of nutraceuticals • Input-use efficiency enhancer chemicals • Molecules for seed health and vigour • Molecules to prevent post harvest losses	• Microbial biomolecules for devising novel pest/ disease/ nematode management strategies • Nanotechnology for increasing the efficiency of agro-inputs and managing biotic stress • High throughput metabolomics for rapid identification of important biomolecules
Integrated crop health management solutions	• Integrated crop health solutions • Precision in protected cultivation • Technologies against post harvest losses • Crop health clinics for diagnostics and e-surveillance	• Space technology for mapping and monitoring pest population and development of weather based forewarning in GIS environment • Development of High Throughput technologies for food/produce safety analysis

Engineering plants with immunity to pest and diseases	• Development of virus induced gene silencing (VIGS) technologies for functional analysis of plant defense	• Exploitation of plant viruses as suitable vectors for expression of heterologous proteins including vaccines in plants
Challenge III. Combating degradation/ depletion of natural resources under changing climate		
Enhancing efficiency of agri-inputs	• Site-specific nutrient management • Low-cost nitrification inhibitors and coating materials • Novel nutrient careers and nano-formulations Efficient microbial consortia based bio-fertilizers	• High yielding and resource efficient varieties • Agro-ecosystem based plant and nutrient management Low cost, low-energy sensor-technology based agri-input management.
Alternative horticulture production systems for resource poor and marginal farmers	• Standardized conservation/ precision/organic and other farming systems Site- and cropping system-specific IWM, INM and IPM strategies	• Improved production and propagation technologies Area-specific agri-horti-silvi-pastoral systems
Managing vulnerability to climate change in Indian agriculture	• Refined methodologies for climate change vulnerability • Surface/ groundwater vulnerability assessments and adaptation measures • Low-carbon technologies for GHG mitigation • Agro-technologies and contingency planning for extreme weather events	• Low cost, energy-efficient conservation and precision agriculture • New cropping/farming systems for variable agro-climatic and socio-economic conditions • Climate resilient varieties for multiple stress tolerance
Wastewater management and use in agriculture	• Improved irrigation methods and agricultural practices for safe use of wastewaters • Comparative pollutant reduction efficiency assessment of various bio-remediation measures/ nano-bio molecules • Low-cost wastewater treatment technologies	• Indigenous models and decision support systems for water pollution control/ management • Suitable PPP based agri-business models for resource recovery and reuse • National guidelines for safe use of wastewaters
Conservation agriculture (CA)	• Enhanced soil physical, chemical and biological heath • Genotype-environment interactions, nutrient/weed/ pest dynamics, and input-use efficiency assessments	• CA-specific plant breeding • CA technologies for varied agro-ecologies
Crop residue management	• Quality of crop residues and their suitability for off-farm and on-farm purposes • Microbial consortia for in situ residue management	• Long-term sustainable crop residue management strategies& policy interventions for improved carbon sequestration, erosion control, fertilizer-use efficiency

Farm mechanization for protected and precision agriculture	• Soil-less and vertical agriculture • Low cost, scale neutral and ergonomic precision machinery • Soil/plant sensor-integrated simulation models/ decision support systems	• Low cost, energy-efficient protected agriculture technologies and novel products for year round production of vegetables/ flowers, and quality planting material/seeds • GIS and Remote Sensing framework-integrated guidance systems for large scale irrigation, fertilizer and pesticide applications and crop condition/yield mapping
Exploring renewable energy sources	• Solar/wind energy based models for powering farm equipment/ sensors/pumps • Efficient transformation of bio-residues into bio-coal/biogas/ biogas slurry/compost • Microbial pathways for energy generation	• Renewable energy sources for open-field and protected farming • Cost effective transformation of bio-residues into the energy-rich products • Green technologies for sustainable production
Developing biotic/ abiotic stress tolerant microbial inoculations	• Plant-microbe interactions under abiotic and biotic stresses	• Biotic/abiotic stress tolerant microbial inoculants for improving soil health and water quality
Decision Support Systems and ICTs for Climate Smart Agriculture	• DSSs and ICTs for efficient natural resource characterization and impact/ vulnerability assessment • Indices for extreme weather monitoring	• Real-time crop monitoring systems and contingency advisory services • Early warning systems and advisory services
Farming system and watershed-based models	• Sustainable cropping system models for small and marginal farmers • Carbon foot printing and input cost quantification	• Efficient models for year-round income and employment • Capacity building of state and ICAR extension functionaries
Challenge IV. Policy Research for achieving higher, sustainable and inclusive growth in agriculture		
Technology, market linkages and policy for higher profitability and rural livelihood	• Technologies for raising farm income • Business models to link farmers with markets (national and global) • Assessment of rural non-farm sector opportunities for rural workers	• Policy options and institutional arrangements to link farmers with markets • Promote rural non-farm employment through infrastructure, skill and entrepreneurship
Agricultural growth and rural livelihoods	• Acceleration and sustainability of agricultural growth in farm and non-farm activities	• Policy for sustainable and inclusive growth
Accelerated information and technology flow to farmers and empowerment of women	• Development and testing of models for technology transfer and dissemination • Need assessment and testing of modules for skill and entrepreneurship	• Institutionalization of innovative extension models • Mainstreaming gender issues in agricultural development programmes

Improvement of government interventions for agricultural development	• Assessment of agri R&D efforts • Measures for increasing efficiency of public farm services • Models for evaluation of environmental externalities	• Policy to increase role and effectiveness of R&D in agricultural development • Reforms to enhance efficiency and effectiveness of public services in sustainable development
Challenge V. Building globally competitive human resource in frontier areas of agricultural science, technology and management		
Imparting globally competitive Post-Graduate education for capacity building	• Improvising teaching/learning processes and methods for PG education • Rigorous evaluation and upgradation of course curricula, faculty competence • Capacity enhancement	• IARI as an autonomous and international level university attracting huge investments in higher education • Development of international level infrastructure for education, research, hostel amenities etc., through public-private partnerships
Strengthening Post Graduate education through National and International Collaboration	• Strategic partnerships with relevant R&D institutions/ ICAR institutes • Dual degree/ integrated Ph.D. • Post-doctoral Fellows in frontier areas • International level courses • National/global faculty/student exchange	• Establishment of IARI off-shore campus at selected countries of South Asia and Africa
Enhancing the content and quality of educational programmes	• State-of-the-art advanced centres for higher learning in agriculture • Effective integration of ICT, GIS, RS technologies different cources • Designing short-, medium- and long-term entrepreneurial training programmes on different farming technologies. • National Centre on Innovative Learning and Teaching in agricultural sciences	• Establishment of virtual centre of excellence in teaching and learning to reach the unreached • Developing strong linkages between traditional and agricultural universities and agro-industries for creation of 'Technology Parks' etc. • Development of a modern library and information centre with international standards • Development of International Centre on Innovative Learning and Teaching in agricultural sciences

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Way Forward

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. The Vision 2050 outlines a strategy to leverage the strength of advances in each of these disciplines via integrated approaches to increase the productivity potential genetically and per unit area by 50-60% in food grains and doubling that of fruits and vegetables while conserving the environment. Basic, strategic and anticipatory research would be pusued in a translational mode to sustainably increase land and water productivity on one hand and successfully face the challenges of climate change on the other.

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. This additional food will have to be produced on existing agricultural land and resources. 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 also 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. Genomic and phenomic tools will be further simplified for affordable application in the next two decades for crop improvement purposes, in which IARI has strong foundations.

World class research in agriculture is possible only through quality education and training. IARI would take on this mantle of being the backbone of the NAREES in higher education. The Institute's aim is to strive to set a standard in imparting world class agricultural education, that should attract students from India and developing as well as developed world. In this endeavour, IARI proposes to establish a Centre for International Agriculture (CIA) in its main campus as well as overseas collaborations in Asia-Oceania and Africa for affordable quality education. The CIA will help developing quality human resource designed to address the challenges likely to be faced by these countries.

Public sector funding is expected to decline with passage of time, to cope with which IARI would manage its IPR to generation revenue and leapfrog technology commercialization and dissemination competitively through public and private investments. Therefore, in the coming decades, IARI will expand and strengthen its Technology Management and Business Development programmes in a corporate mode, wherein the industry partners will collaborate in technology development, validation, scale up and finally its commercialisation in an integral manner. Promoting such partnerships, nationally as well as internationally, will be pursued vigorously to realize the dreams of success.

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NOTES

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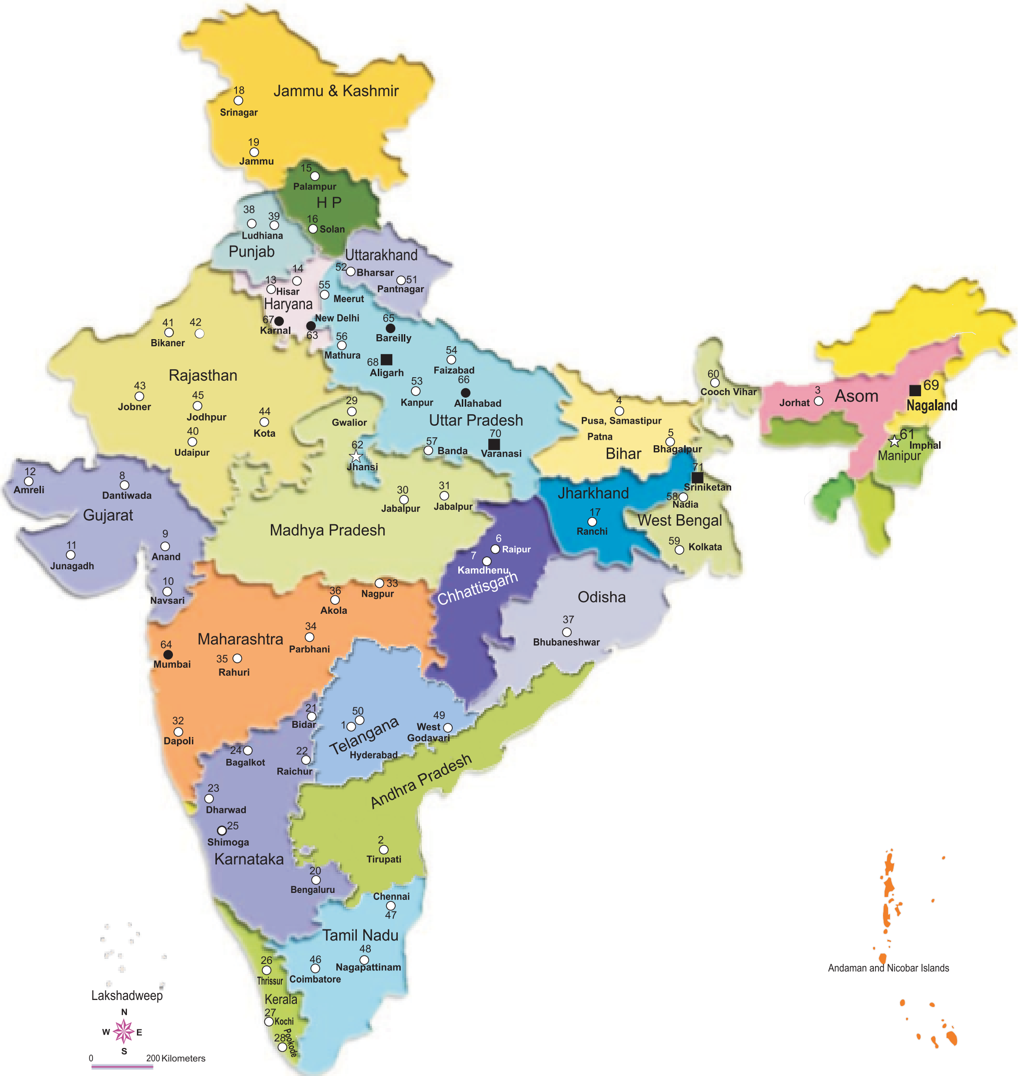
INDIAN COUNCIL OF AGRICULTURAL RESEARCH

Agricultural Universities



LEGENDS

- State Agricultural Universities ○
- Central Universities with Agricultural faculties ■
- Central Agricultural Universities ☆
- Deemed Universities ●

हर कदम, हर डगर
किसानों का हमसफर
भारतीय कृषि अनुसंधान परिषद

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