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

Agrisearch with a human touch

# Vision 2050

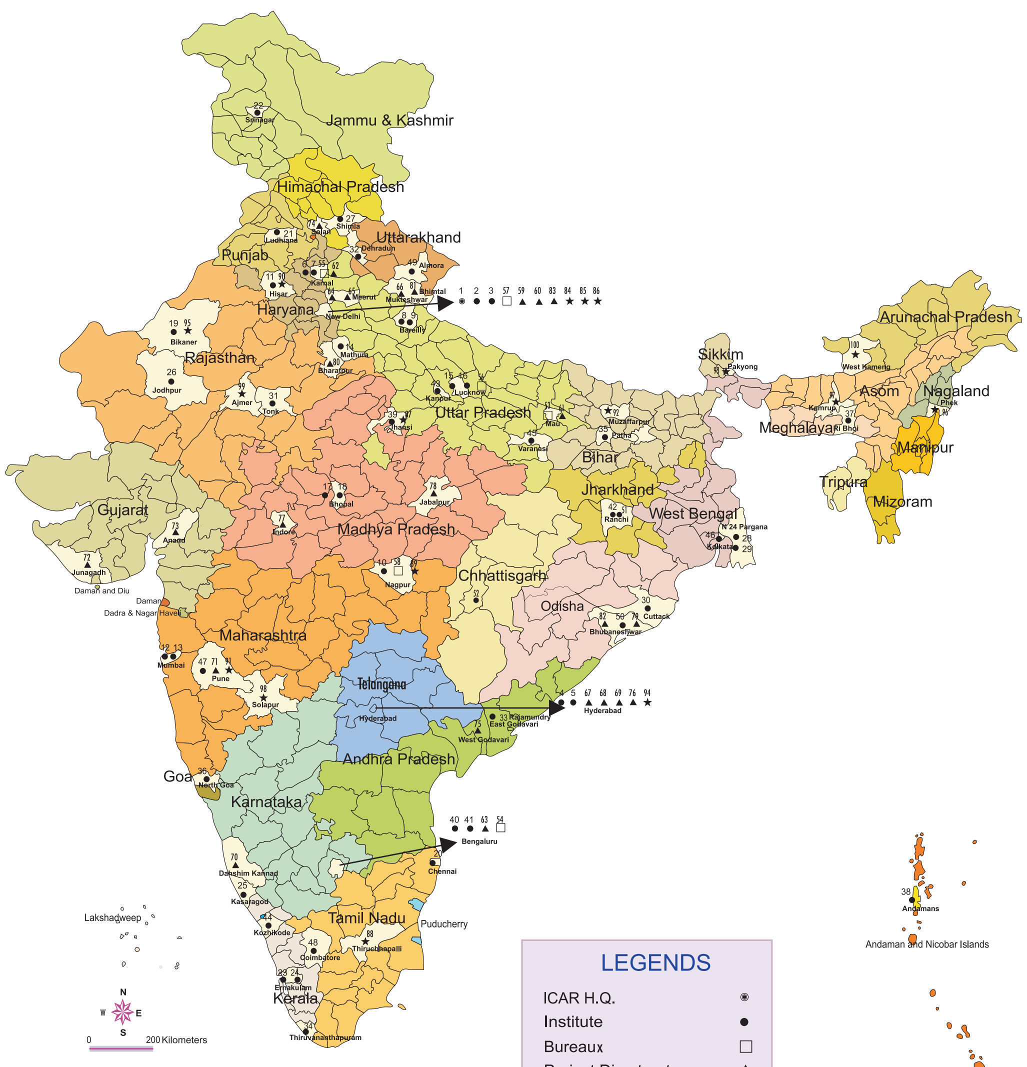

Indian Institute of Rice Research
Indian Council of Agricultural Research

भाकृअनुप
ICAR

भाचाअनुसं
IIRR

## INDIAN COUNCIL OF AGRICULTURAL RESEARCH

### Institutes, Bureaux, Directorates and National Research Centres




**LEGENDS**

- ICAR H.Q.
- Institute
- Bureaux
- Project Directorate
- National Research Centre

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

## INDIAN COUNCIL OF AGRICULTURAL RESEARCH

### Agricultural Universities


**LEGENDS**

- State Agricultural Universities
- Central Universities with Agricultural faculties
- Central Agricultural Universities
- Deemed Universities

# Vision 2050

भाचाअनुसं
IIRR

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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 insect pests 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 Institute of Rice Research (IIRR), Hyderabad 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.

**(S. AYYAPPAN)**
Secretary, Department of Agricultural Research & Education (DARE)
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# Preface

Indian Institute of Rice Research (IIRR) has mandate to coordinate research on rice across the country and conduct strategic and applied research on irrigated rice to enhance and sustain production, productivity and profitability while preserving environmental quality.

India had an all-time high rice production of 106.54 million tonnes during 2013-14. The rice varieties released for commercial cultivation have crossed 1088 mark. Over 20 rice hybrids are now being aggressively marketed by the private sector. First batch of products of marker technology have been accepted by the farmers and are spreading rapidly. System of Rice Intensification, aerobic rice, direct seeding and AWD methods of cultivation are effectively addressing production constraints like water and labour shortages. In view of the changing scenario, emerging challenges and opportunities, it is desirable to make a mid-course evaluation of the Vision 2030 and prepare a revised document "Vision 2050" to abreast the challenging scenario.

New threats like climate change, acute water and labour shortages for rice production, escalating input costs and non-commensurate procurement prices are proving deterrent to rice farmers forcing some of them to declare crop holidays. But new opportunities are being opened up through rapid progress in cutting edge sciences of biotechnology, space and nanoscience. IIRR is poised to face these challenges and march ahead to meet the future goals and expectations of the nation in achieving food and nutritional security. I sincerely hope the current document will serve as a guiding principle towards meeting the future challenges in more meaningful ways.

We are grateful to Dr. S. Ayyappan, Secretary, Department of Agricultural Research and Education and Director General, Indian Council of Agricultural Research for being the constant source of inspiration and driving force behind our efforts in bringing this thoughtful and futuristic document. We are also extremely thankful to Dr. Swapan Kumar Datta, former Deputy Director General (Crop Science) and Dr. J. S. Sandhu, Deputy Director General (Crop Science), ICAR, for their keen interest in rice and constant endeavour to improve the rice research programmes at different levels. We place on record our sincere thanks to Dr. R.P. Dua, former ADG (FFC) and Dr. I.S.

Solanki, ADG (FFC) for their guidance and support in preparing this important document.

This document is the product of long stretches of brain storming, incisive discussions, argumentative points of view of my senior colleagues from time to time. Participation of several of my colleagues in IIRR and in the Council in shaping the document and bringing uniformity across those being prepared by other Institutes is also acknowledged.

(V. Ravindra Babu)
Director
IIRR, Hydrabad

# Contents

# Context

The paradigm shift from subsistence agriculture to technology driven intensive farming has taken the country from the days of food deficit to an era of self-sufficiency which is a golden chapter in the history of post-independent India. The food grain production rose from 50.82 million tonnes (MT) in 1950-51 to 265.04 MT in 2013-14 and the productivity registered a similar upward trend from 522 kg/ha to 1824 kg/ha during the same period. Rice, wheat, maize, pearl millet and sorghum among cereals registered maximum production and productivity enhancement, with rice per se which is the staple food for more than two thirds of Indian population contributing to 40.88% to the total food grain production thereby, occupying a pivotal role in the food and livelihood security of the people.

Globally rice is planted in about 150 million ha and 497 million tonnes of produce is harvested annually (FAO, 2014). Of this, Asia accounts for 90% of the production and consumption of rice. Only about 31 million tonnes of rice is traded through international market. Leading rice exporting countries are Thailand, Vietnam, USA, India and Pakistan. However, during 2012, India has surpassed Thailand to become the first among the rice exporting countries with the export of more than 10 million tonnes for the first time in recent years.

India has the world's largest area under rice with 42.5 million ha and is the second largest producer (106.65 million tonnes in 2013-14) next only to China. It contributes 21 percent of global rice production. Within the country, rice occupies one-quarter of the total cropped area, contributes about 40 to 43 per cent of total food grain production and continues to play a key role in the national food and livelihood security system. Rice export contributes to nearly 25% of total agricultural exports from the country. However, productivity of rice is only 2.54 tonnes/ha of milled rice as against the global average productivity of 3.28 tonnes/ha (FAO, 2010).

At the current rate of population growth (1.98%) Indian population is expected to touch 1.63 billion by 2050. Of these, about 52% will be the urban population. Considering three divergent scenarios of economic growth under 'Business as Usual' (BAU); 'Maintain Momentum' (MM) or 'Upside Scenario' (US), GDP growth rate may vary from 5.43, 6.0 to 8.0%, respectively (Ramesh Chand, 2012). Per capita demand for food has been estimated to be about 140 kg cereal/year or about 384 g/day. Based on the assumption that about 60% of the cereal requirement will be fulfilled by rice, the requirement of rice can be estimated to be 230 g/day or 84 kg/year/person. Therefore, the rice requirement for an expected population of 162 million by the year 2050 would be about 136 million tonnes for consumption purpose alone.

Till date 24,163 elite lines developed by different cooperating centres were tested in multi-location trials across the country under the umbrella of All India Coordinated Rice Improvement Programme (AICRIP) at funded, voluntary centres and in partnership with private sector for hybrid rice following ICAR guidelines for varietal testing. Every year about 2000 experiments/trials are laid out in rice. The dynamic time tested multilocation three tier testing programme involving one year of Initial Varietal Trial (IVT) and two years of Advance Varietal Trial (AVT-1 and AVT-2) as well as screening of elite breeding lines at hot spot locations for generating information on their pest/disease resistance/tolerance, grain quality attributes and agronomic performance has led to release of varieties including hybrids suitable for all the ecosystems.

Rice production systems are also likely to undergo major changes in view of production constraints. Water and labour would be the main inputs in short supply. Thus we need to take stock of the available technologies and evaluate if these could deliver desired results. If not, examine the other emerging technologies and increase the pace of harnessing these technologies for getting breakthrough in enhancing productivity.

IIRR has been in effective service of the country for the past 50 years. It was established in 1965 as All India Coordinated Rice Improvement Project (AICRIP) with 12 main centers and thereafter elevated to Directorate status in 1983 and to a full-fledged Institute in 2015. Now there are 45 funded centres participating in AICRIP and over 60 voluntary centres. IIRR has a sanctioned scientific cadre strength of 71 scientists. Over the years, the institute has strengthened its infrastructure and human resources and is well prepared to face the domestic and global challenges. It is committed to maintain its leadership and is responsive, vibrant and sensitive to the changing scenario and needs of its stakeholders. The Institute with its vision and mission works under ICAR as per the system indicated in the Organogram (Figure 1).

## VISION

Welfare of the present and future generations of Indian rice farmers and consumers by ensuring food, nutritional and livelihood security.

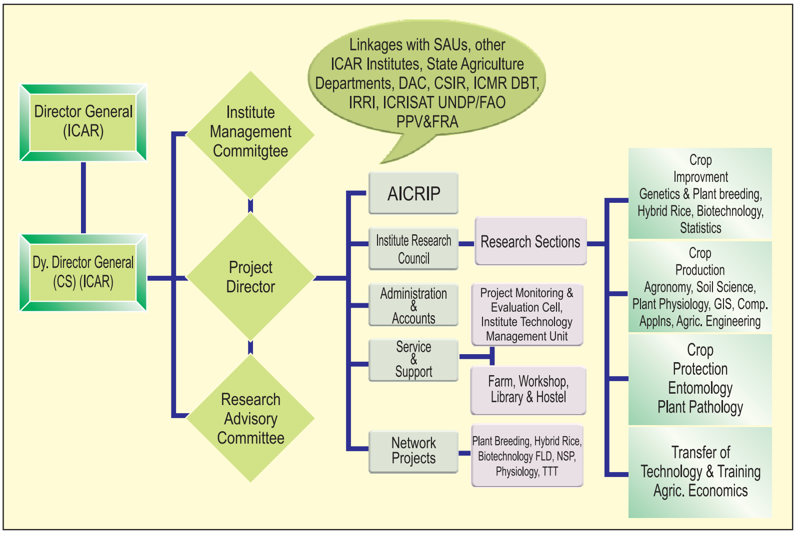


**Fig. 1** Organogram of IIRR

## MISSION

Develop technologies to enhance rice productivity, resource and input use efficiency and profitability of rice cultivation without adverse affects on environment.

## MANDATE

- To organize, coordinate and monitor multi-location testing at national level to identify appropriate varietal and management technologies for all the rice ecosystems.
- To conduct basic, strategic and anticipatory research in the major thrust areas of irrigated rice aimed at enhancement of production, productivity and profitability while preserving environmental quality.
- To develop, organize, coordinate and monitor research networks relating to problems of national and regional importance.
- To serve as major centre for exchange of research material and information.
- To accelerate the pace of technology transfer through development and adoption of innovative extension training models, self-learning modules and through organizing formal training courses, frontline demonstrations, exhibitions, farmers' day etc.
- To develop linkages with national, international and private organizations for collaborative research programmes.
- To provide consultancy services and undertake contractual research.

Since its inception in 1965, the All India Coordinated Rice Improvement Project was instrumental in testing and release of 1088 varieties including 72 hybrids till 2014. Among these, 130 varieties and 45 hybrids were released through Central Sub Committee on Crop Standards, Notification and Release of Varieties (CSCS & NRV) while the State Variety Release Committees released 886 varieties and 27 hybrids. Of these varieties, 503 are for irrigated areas, 133 for rainfed uplands, 194 for rainfed low lands, 44 for semi deep and 18 for deep water situation, 51 for high altitudes, 42 for saline and alkaline areas, 10 for aerobic, 19 for boro and 74 aromatic long and short grain varieties were released. Having realized the scope and potential of quality rices for export, special thrust was given for genetic enhancement of quality rices in the country which lead to the release of 30 export quality basmati and short grain rice varieties. Many of these varieties possess tolerance/ resistance to major insect pests and diseases.

In the last decade effective deployment of biotechnological tools such as molecular marker assisted breeding has resulted in development of land mark varieties such as Improved Samba Mahsuri and Improved Pusa Basmati 1 which involved introgressing BLB resistant genes into the genetic background of Samba Mahsuri, the most sought after rice variety for its grain and cooking quality and Pusa Basmati 1, the important long grain Basmati variety which has a major share in export markets. The two landmark varieties are developed by IIRR, Hyderabad and IARI, New Delhi, respectively, tested and released through AICRIP as central releases. Similarly, efforts made at IRRI to introgress the major QTL 'Sub 1', for inducing submergence tolerance into popular variety Swarna, were highly successful with the development of Swarna Sub 1 which was tested in the NIL- Submergence trials of AICRIP and released in Odisha and Uttar Pradesh. The recent releases include drought resistant DRR Dhan 42 and High Zinc line DRR Dhan 45.

Unique genetic stocks developed by IIRR were granted soft registration by NBPGR, New Delhi. These include six restorer lines viz., RPHR 2, RPHR 12, RPHR 517, RPHR 619, RPHR 1005 and RPHR 1096, four CMS lines viz., IIRR 4A, IIRR 5A, IIRR 9A and IIRR 10A, nine biotic stress resistant lines viz., RP 4518-2-6, RP 4621-1842, RP 4621-1845, RP 4639-110, RP 4642-669, AGGANI, ARC 15831, INRC 3021, INRC 202, BLB pyramided line – IET 19045, Basmati line- IET 15833 and low phosphorous tolerant line – IET 9691, were registered with NBPGR, New Delhi.

Development of first medium slender hybrid "DRRH 3" which is similar to Samba Mahsuri with 25-30% higher yield has already proven its merit by being most sought after hybrid. It is already commercialized by forging MoAs with 11 private companies. As these MoAs are made in the last couple of years, once the companies make strong effort in up scaling the seed production and delivery mechanism, the technology which has a tremendous potential would have a positive impact in increasing the area under hybrid rice. The other IIRR releases, Varadhan, Sampada, Akshyadhan, DRR Dhan 39, DRR Dhan 40, DRR Dhan 41, DRR Dhan 42, DRR Dhan 44 are gaining popularity with the farming community.

Marker-based purity assessment of rice hybrids and CMS lines: IIRR has developed a rapid and reliable assay for assessment of purity of seed-lots of rice hybrids and CMS lines. Functional markers have been developed for the major blast resistance gene Pi54 and the major QTL controlling grain length, Gs3. These markers have accelerated MAS programs significantly in terms of efficient foreground selection.

Under Biofortification programme, some of the high zinc lines with high yield and good grain quality were identified and are at advanced stages of testing under AICRIP. These can be available to the farmers in a couple of years. Varieties such as BPT 5204, Sampada and Lalat have been identified as low glycemic index (GI) rices and work is also under progress to develop rice varieties with high protein and high bran oil content. Using the transgenics approach, Bt transgenic rice with Cry1A proteins has been developed in the genetic background of IR64. Five selected lines are being promoted to Biosafety Research Level. The transgenic event related to Golden rice, GR2R has been introgressed into the genetic background of Improved Samba Mahsuri and MTU1010 through MABB. The improved breeding lines possess 20-25 ppm of total carotenoids in their endosperm.

Identification of sources of resistance and resistant lines against major pest & diseases; production constraints identified through POS and course corrections suggested; new molecules for management of pest & diseases identified and incorporated in integrated pest management practices for irrigated rice. Planting of one row of Pusa Basmati 1 (PB1), an aromatic cultivar highly susceptible to yellow stem borer, for every 9 rows of any main crop reduced stem borer damage considerably giving additional income from PB1 crop.

Studies on SRI proved that it is genotypic specific and hybrids perform better than the varieties and the cost of cultivation too drastically reduced in case of hybrids. Adoption of SRI at proper locations with suitable genotypes has a scope for area increase, enormous saving on seed and 36% saving on water, additional yield of 1.0 to 1.5 t/ha which will add 4-6 million tonnes to our food basket.

Frontline demonstrations have proved the merit of the technologies generated and how up scaling the innovations will make a major effect on rice production and productivity enhancement through technological interventions. During the last five years, a total of 201 technologies were displayed in about 4125 FLDs in 14-24 states. Recently another major initiative was undertaken as Rice Knowledge Management Portal (RKMP) serving as an information highway for sharing the Rice Knowledge across the country. This extension semantic portal was launched by our Honourable Prime Minister Sri. Manmohan Singh on 16th July, 2011. Now IIRR is reaching out to all the stakeholders through effective management of Institute Technology Management Unit and harnessing the ICT tools for managing the Rice Knowledge Management Portal (RKMP).

However, under the existing scenario more rice needs to be produced in less area with declining and deteriorating resources. The major challenges ahead including climate change are to be tackled through advances in frontier sciences like biotechnology, nanotechnology, information technology and space technology which can provide new tools to effectively address existing and impending problems.

Thus, IIRR needs to revisit its earlier Vision 2030 document to provide new thrust for its future research and extension agenda under this document " VISION 2050".

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# Challenges

- Setting up of few centers of excellence with adequate infrastructure for high- end basic and strategic research in addition to many well equipped centers for technology validation.
- Rapid urbanization is leading to decrease in area under rice and labour availability is becoming a great challenge for rice cultivation. This will require emphasis on productivity per unit area and mechanization of field operations.
- Climate change in terms of frequent droughts, cyclones, floods, enhanced temperature and $CO_2$ is a serious concern which needs to be addressed on priority.
- Declining water availability would be a major threat for rice cultivation as some area may be diverted to other crops due to water shortages.
- Cost of cultivation due to escalating input cost is proving disincentive to rice farmers. Hence, development of input use efficient cultivars and resource conservation techniques will need major thrust in future.
- Deteriorating soil health and declining factor productivity would be a major concern. This would require attention and search for diversification of cropping systems.
- Rapid change in pest composition and population dynamics is threatening pre-harvest and post-harvest losses. This would require a strong programme on survey and surveillance of pest and diseases and identify the environment friendly control measures.

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# Operating Environment

The research programmes will have to be carried out keeping in mind the existing as well as future challenges expected to be encountered. Following situations are likely to be faced for which solutions are required to be sought through development of suitable technologies with the help of available scientific knowledge.

**Physical Environment**

Productivity of rice is now increasing at a slower rate than during the height of the Green Revolution. Yield stagnation in many Asian countries, limited possibilities for arable land expansion, and fewer water resources for expanding rice planted areas are the main constraints to expanding production. Other concerns are related to environmental degradation, genetic erosion and nutritional quality of rice. The current approaches to intensification of rice production have caused considerable damage to the environment and related natural resources, including the building up of salinity/alkalinity, water pollution and health hazards caused by excessive use of agro-chemicals and emission of important greenhouse gases. Climate change is driving significant alterations to the physical and biological systems in all continents and most oceans resulting in major challenges to the natural systems. All these changes are mostly due to the increase in global temperatures. The best estimates of global warming are in the range of 1.8 to 4°C by 2100, mainly based on the future scenario of greenhouse gas emissions used for simulations by the models. The combination of generally increasing temperatures and shifting rainfall amounts and patterns will clearly have impacts on agriculture. By the 2050s, freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is projected to decrease as a result of climate change. Climate change will not only affect the water availability but also affect crop water use. Plants are sensitive to high temperatures during critical stages such as flowering and seed development. With the increase in daily maximum temperature averaged over flowering period above about 36$^{o}$ C, rice yield generally declined because of spikelet sterility induced by high temperatures. Climatic factors especially temperature and relative humidity are the key factors influencing development of any insect pest and disease of rice. Climate change may change the pest–plant relationship resulting in positive or negative impact on incidence and severity of different diseases and insect pests. Sheath blight (*Rhizoctonia solani*), a minor disease in early 1970s, is now a most destructive disease of rice. Similar change has also been observed on the incidence and severity of some other diseases and pests.

- Less land, less water and less labour
- Deteriorating soil health
- Complex abiotic and biotic stresses
- Hostile environment for marginal farmers with small holdings
- Changing climate leading to adverse effects on productivity

### Economic Environment

In the last few years India has been playing a major role in the globalization of agriculture particularly in relation to rice trade due to economic liberalization leading to availability of international market for export of rice and its value added products. Robust economic growth with good investment opportunities have led to aggressive investment in R&D sector by Private companies. Increasing interest of private entrepreneurs for partnership in large scale production of technologies and a vibrant seed market provide tremendous opportunities for the economic upliftment of rice farmers. However, less remunerative prices and escalating cost of agro-inputs continue to pose major challenges to small and marginal farmers. Overall, diversified agriculture production system with increasing employment opportunities and an improved economic status leading to increased demand for quality and diversified products can be the driving force to create a conducive economic environment.

- Aggressive private sector investing in R & D
- Vibrant seed market
- Less remunerative prices to rice farmers
- Escalating cost of agro-inputs

### Scientific Advancement

While the research programmes are planned envisaging the current and future issues hampering the enhancement of rice productivity, the scientific advances in various fields give several technologies which can be adopted to address the issues. The climate change across the nation is about to change the pattern of rice cultivation opening up new opportunities and threats. The activities taken under Biodiversity and its characterization offer the adequate genotypic variability for new and unexpected situations. Practices like precision farming and conservation agriculture are to take off with informed choice of each step of rice cultivation from germination, maintenance of field conditions, irrigation, package of practices and harvesting. Scientific progress in allied disciplines viz., nano technology, information technology, space technology and GIS has given the opportunity for their spatial and temporal application about irrigation, fertilizers, pesticides, pest occurrence and soil related issues. Successful demonstration of molecular breeding and disease diagnostic approaches can now be scaled up to meet the future research needs. Sequence information generated from genomics and related disciplines in rice and other cereals can be utilized to identify the genes responsible for important agro morphological traits and their validation through genetic engineering.

- Climate change
- Biodiversity
- Genomics, phenomics, metabolomics and bio-informatics
- Molecular breeding
- Precision farming
- Disease diagnostics
- Conservation agriculture
- Nano-biotechnological applications
- Genetic enhancement of yield and hybrid rice technologies
- Information technology
- Space technology and GIS
- Genetic engineering

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# Goals and Targets

IIRR is committeid to develop technologies to enhance rice productivity, resource and input use efficiency and profitability of cultivation without adverse effects on the environment. The goal is also to enhance the efficiency of the organization to take up challenges and deliver desired results with competitive funding andtimely delivery. We also aim at delivering means of technology transfer for rapid adoption of the new technologies by the farmer and transform these into enhanced production.

It is assumed that the area under rice may further shrink to about 40 million ha for various reasons. Therefore, the rice productivity needs to be enhanced from the present 2.54 t/ha to 3.3 - 4.05 t/ha in the next 40 years to keep pace with the increasing demand.

Based on the available trends, target production and productivity of four rice ecologies (Irrigated, Rainfed Shallow lands, Rainfed Uplands and Deep and Semi- deep lands) have been worked out. It is apparent that productivity of irrigated rice needs to be enhanced to 3.79 - 4.56 t/ha, while that of rainfed shallow land rice needs to be raised to 3.1-3.8 t/ha. In view of this, the major targets that can be set for future before the Institute include:

- Redesigning rice plant type with more photosynthetic efficiency, biomass and harvest index to enhance genetic yield potential
- Stabilizing rice productivity through improving biotic and abiotic stress tolerance and high quality seed
- Improving the grain and nutritional quality and value addition of rice
- Sustaining soil health in rice ecologies.
- Enhancing water productivity
- Improving input resource use efficiency
- Sustaining rice productivity under changing climate
- Farm mechanization to reduce drudgery and improve profitability
- Sustainable Pest management
- Validation and commercialization of technologies.
- Evaluation and identification of technologies suitable for different rice ecologies

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# Way Forward

### Bridging Scientific and Technology Gap

Scientific developments need to be rapidly converted into adoptable technologies and validated under diverse rice ecologies. The AICRIP setup needs to be revamped to meet the future demands and transformed from routine field testing centers to technology developing and highly proficient evaluating centers. Fewer, well equipped centers would concentrate on technology development and larger voluntary centers would meet the requirement of validation of technologies.

### Bridging the Technology and Adoption Gap

Proven technologies need to be aggressively pushed for adoption. Fostering a strong public-private sector partnership is going to be the basis for achieving the desired goals. Development of commercial wing for marketing the in-house technologies not lucrative for the private sector through 'Agri Innovate India' company of DARE, Govt. of India will be an essential step. Self-sustaining information campaign using the modern ICT tools under the RKMP needs to be pushed for the benefit of other agriculture departments.

### Expanding the Export Potential

Recent trends in rice exports suggest that India can emerge and continue to be the leading rice exporter. Besides the premium priced aromatic Basmati rice, as per the Government Policy, we can even target to export medium and slender grain rice for which there is a growing demand.

### Synergy Between Agriculture and Allied Sciences

Recent success in achieving the targets of National Food Security Mission (NFSM) during the XI five year plan in increasing the rice production by 10 million tonnes, calls for macro-level planning and execution. Advances in satellite based remote sensing and space application science have empowered us for real time macro- planning, monitoring and execution of disaster management and handling of drought and floods and mitigating their negative impact on rice production. Anticipation of acute labour shortage for rice cultivation driven by large scale migration of rural people to urban areas, escalating labour and input cost and ageing population draws our urgent attention to selective mechanization of rice cultivation. Large scale use of machines like combine harvesters on hire-operate basis is providing an empirical solution to the problem. Such a situation calls for development of suitable cultivars and cultural practices.

### Strategic Partnerships and Alliances

Some of the research goals, like development of C4 rice or engineering biological nitrogen fixation would necessarily involve strategic partnership with leading research laboratories in the world as well as private sector for funding. Collaboration with organizations within the country like CSIR, DBT and even ICMR would also be indispensable.

### Demand Driven and Responsive Research

The Institute would take up research on immediate demands based on end users' perspective like the rice transplanter suited for our soils or mechanical weeder for SRI. Such objectives are taken up on demand by various end users and their representatives like state departments or private sectors and funded by time framed delivery system.

### Research Prioritization

To achieve the goals set above, an 11-point strategy has been developed to enhance and sustain rice productivity to meet future demands of domestic consumption and surplus for export. Besides, long term futuristic research and flagship programmes are also outlined.

*(1). Futuristic Research*

- **Development of C4 rice**
  Targeting technology development for future, several challenging research issues for increasing rice productivity are being addressed. Rice has C3 pathway of photosynthesis and conversion of C3 rice into C4 would improve its photosynthetic efficiency thereby enhancing the yields more than 50%. Phenotypic plasticity has been observed in C3 and C4 plants in their photosynthetic characteristics. Around 20 genes associated with C4 pathway have been reported to be transformed into rice with an objective of studying their impact in the morphology and metabolism.

- **Designing rice plant with biological nitrogen fixation ability**
  Nitrogen requirement for cereal crop production is conventionally met by the application of synthetic nitrogen fertilizers. Considering the economic and environmental impacts of synthesizing and utilization of the nitrogen fertilization, biological nitrogen fixation (BNF) will be focused for meeting nitrogen requirement in rice. From legumes, several key regulatory and structural genes for nitrogen fixation have been characterized and known as '*nif*' genes. Studies suggested the same genetic elements to be central for AMS (acquiring mycorrhizal fungi system) in rice and RNS (root nodule symbiosis) in legumes. Now, attempts are being made to target the mycorrhizal symbiotic genetic network of rice to accommodate rhizobial symbiosis for nitrogen fixation. Rice appears to have genetic predisposition for symbiosis with rhizobia like presence of homologues of early nodulin genes and a few symbiotic genes. The response of rice to rhizobial Nod factors is also encouraging. Though challenging, the introduction of '*nif*' genes into cereals would have positive impact on economic and environmental aspects of fertilization in rice cultivation
- **Physiological studies on productivity**
  As the staple food of most Asian people, rice (*Oryza sativa* L.) cultivation and genetic modification have been the subject of significant research and development efforts, particularly to improve production and grain quality. However, the yield potential of inbred and hybrid rice cultivars has apparently reached a plateau in the improvement of biomass and harvest indices. Grain yield and grain yield per day have progressively increased during the years and such increases are mainly attributed to the expanded sink size as a result of more spikelets per panicle, especially for the case of super rice. Both biomass and harvest index were increased with the improvement of cultivars. Increase in biomass for modern rice cultivars was associated with an enhancement of leaf area and photosynthesis. However, stagnation in rice yield has been observed which is a major cause of concern. Although scientists were successful in breeding varieties with large panicle and high spikelet number like NPTs and Super Hybrids, they could not achieve the targeted yield levels mainly due to problems in grain filling. It is imperative to understand the physiological function of the morphological traits incorporated for high yielding plant types and identifying the factors that limit the grain filling of large panicles is of paramount important. Studying the physiological basis of GxE interaction in yield potential,

designing different NPTs for various environments, and developing crop management strategies for achieving the full expression of yield potential in NPT lines.

*(2) Flagship Research Projects*

- **Pre-breeding for broadening the genetic base to enhance yield, quality and stress tolerance in rice.**
  Though the rice production in India has five fold increase since past 50 years, the common semi dwarfing gene *sd1* and common cytoplasm sources led to the yield stagnation. Thus broadening genetic base including several other related species is now essential in rice. The effectiveness of genes from the wild donors has been amply demonstrated in rice. Wild species of *Oryza* are the reservoirs of genes for important agronomic traits such as yield, quality and nutritional characteristics, resistance to biotic and abiotic stresses. Limited genetic variability in the cultivated germplasm pool for several biotic and abiotic stresses also warrants the use of wild relatives of *Oryza* for prebreeding efforts.
- **Soil and plant health management under changing climate.**
  Understanding soil health impacts in relation to climate change is possible through the use of indicators (measurable attributes or values) which relate soil physical, chemical and biological properties to ecological functions and which can be monitored in the context of sustainable land management and climate change. Key soil health indicators affected by climate change include aggregate stability, SOM, carbon and nitrogen cycling, microbial biomass and activity, and microbial fauna and flora diversity. Although tentative steps are underway, greater efforts are required to explore individual and interactive effects of drivers of global change (e.g. land use change, increasing temperatures, elevated $CO_2$ concentration, variability in the amount, intensity and distribution of rainfall, and increasing atmospheric N deposition) using controlled environment and long-term research experiments to assess soil health indicators that can be responsive to such treatment variations over wider spatiotemporal scales, and consequently, their monitoring and inclusion in a minimum data set can assist us in devising greenhouse gas mitigation and climate adaptive strategies.

*(3) Enhancing genetic yield potential*

- **Widening the genetic base, Wide hybridization and introgression**
  To combat the problem of narrow genetic base, pre-breeding should

be a necessary activity that explores unadapted germplasm like wild species of rice for useful traits. Wild rice with more than 20 species serves as an important resource for essential traits of agronomic importance. Various rice genome complexes and use of wild rice in trait improvement has been demonstrated in rice. Keeping in view the importance of wild rice and its potential for improvement of several important traits, a study for genetic variability for traits like resistance to yellow stem borer, sheath blight, weed competitiveness etc. should be attempted and emphasis should be on the use of modern biotechnological tools for rescuing plants produced through wide-hybridization and for mapping and pyramiding of novel genes associated with biotic/abiotic stress resistance identified from wild relatives and land races of rice.

- **Exploiting hybrid vigour**
  Heterosis is an enigmatic phenomenon, which has been exploited for several years for increasing yield and productivity in various crops including rice. It is generally believed that the extent of heterosis in the F1 is directly proportional to the genetic variability of the parental lines. However, in rice, the exploitation of heterosis is limited in the presently deployed three-line system of breeding as the number of maintainers and restorers are limited. In order to widen the variability of the maintainer and restorer gene-pools, an intensive pre-breeding program has been launched at IIRR in coordination with other key AICRIP partners of hybrid rice wherein variability available from both primary and secondary gene pools of rice is being gainfully utilized through the deployment of biotechnological tools. Tools like SNP markers, genomics, transcriptomics and proteomics will be utilized in consonance with phenotypic traits to study the phenomenon of yield heterosis and characterize the parental lines for developing heterotic pools in rice and for precision breeding of parental lines to enhance their genetic diversity and thus realize better levels of heterosis. Attempts should also be made to utilize tools like targeted mitochondrial and nuclear genome editing to develop novel male sterile lines, thus diversifying cytoplasmic male sterile lines.
- **Allele mining and gene discovery**
  Identification and exploitation of naturally occurring variability in the rice gene-pool is an important component of crop improvement programs. The modern tools of biotechnology like genomics and transcriptomics can help to identify novel sequence variations in candidate genes associated with agronomically important traits like

biotic and abiotic stress tolerance, improvement of yield, grain quality and nutrition etc. Wild relatives and land races of rice are an important repository of such variability and efforts are on at IIRR to track the variability present in the primary and secondary gene pool of rice and gainfully use them in breeding programs by adopting novel breeding strategies and modern breeding tools like genomics-assisted breeding.

*(4) Stabilizing rice yields*

- **Incorporation of disease and insect pest resistance**
  Biotic constraints to rice production cause yield losses of about 25%. The major insect pests of significance in rice are yellow stem borer, brown plant hopper, white backed plant hopper, leaf folder, gall midge, green leaf hopper and gundhi bug. Diseases caused by bacteria, fungi, and viruses are also some of the key biotic stresses affecting rice. The major ones are blast, bacterial blight, sheath blight, rice tungro disease and false smut. Also, some diseases hitherto considered as minor have become serious in many rice growing areas. Though chemical control continues to be the most common option for tackling majority of pests and diseases, deployment of host-plant resistance has also proved as effective and eco-friendly. However, efforts to breed for resistance are often hindered by pest diversity, especially when resistance is based on single gene. Under these circumstances, conventional breeding strengthened by molecular tools such as marker aided selection and gene pyramiding with the help of molecular markers appears to be the most promising approach for evolving a broad spectrum and durable resistance mechanism to the majority of the biotic stresses.
- **Tolerance to soil and water stresses**
  The frequent occurrence of abiotic stresses such as drought and submergence has been identified as the key to the low productivity of rainfed ecosystems. A recent estimate on climate change predicts the water deficit to deteriorate further in years to come and the intensity and frequency of drought are predicted to become worse. The earlier approach of improving grain yield under drought through selection of secondary traits did not yield the expected results to improve yield under drought. Similarly, at the molecular level, initial efforts in rice were devoted to mapping of QTLs for secondary drought-related traits Proof of concept that conventional breeding based on direct selection for yield under artificially imposed drought stress can result in actual gains in drought resistance needs

to be introduced in breeding programs. The development of near-isogenic genetic stocks that differ in drought resistance will lead to better understanding of molecular and physiological mechanisms of drought. At the molecular level, sequencing of the rice genome and the development of new genomics and post-genomics tools for detecting genetic polymorphism, gene discovery, and functional analysis of stress-related genes and mechanisms and the localization of QTLs with large effects on yield under drought stress that may be useful in marker-aided backcrossing have opened a new era. Pyramiding three or more QTLs to enhance yield under drought could be a possible strategy for the near future.

- **Enhanced nutrient use efficiency**

  Nutrient use efficiency of crops is being improved through temporal and spatial management of the form and amount of nutrient inputs as being demonstrated by various agronomic practices. In addition, understanding of the genetic basis of nutrient efficiency would lead to the development of nutrient use efficient varieties thus reducing the application of nutrients. Earlier studies on genetics of nutrient use efficiency were limited as increasing productivity with heavy nutrient inputs was the main focus. But in the backdrop of environmental degradation due to the excessive nutrients and its impact on climate change, nutrient use efficiency in crops is need of the hour for sustainable and eco-friendly agriculture. Of the various essential nutrients required for crops, nitrogen (N) and phosphorus (P) are fundamental to crop development because they form the basic component of nucleic acids, proteins and many organic molecules. Till now varieties responding to nutrients with high uptake efficiency and utilization efficiency manifested in terms of yield were selected. Since uptake and utilization are interdependent, the efficiency for nutrients was not studied earlier. Germplasm of major food crops has been screened under low inputs to identify the promising genotypes, however the mechanism of nutrient use efficiency was complex to be deciphered by explanation of single major genes and the effect of environment has confounded the studies. The genetic studies for nutrient use efficiency have been further complicated mostly by low heritability, high environmental variability, difficulty of field screening and absence of clear selection criteria. From the reported studies, it can be inferred that nutrient use efficiency should be targeted for optimum nutrient inputs rather than zero inputs as the nutrients are essential building blocks for realizing the output. With high throughput phenotyping and genotyping approaches along with the availability of genome sequences, the genetics of nutrient use efficiency is now being interpreted in rice.

- **Mitigating arsenic and fluoride toxicity**
  Arsenic can move from the soil into rice grain, and rice produced in high-arsenic soil has higher arsenic than average. The arsenic in soil or irrigation water is sometimes high enough to inhibit plant growth, resulting in low yield. Scientists have identified rice varieties that grow well in high-arsenic conditions and can minimize arsenic accumulation in the grain. Plant breeding programs need to focus on developing varieties which can grow under high Arsenic concentration. Also, rice plants in more flooded soil (anaerobic conditions) take up more arsenic. So, an effective way to lessen arsenic uptake is to use moderately dry growing methods through irrigation management.

*(5) Improved grain and nutritional quality and value addition*

- **Investigation of quality determining genes**
  Grain quality in rice is difficult to define with precision as preference for quality varies from country to country and within the country from region to region and between ethnic groups. The concept of quality varies according to the preparations for which the varieties are used. Although, some of the quality characteristics desired by grower, miller and consumer may be the same, yet each may place different emphasis on various quality characteristics. The genetic makeup of the grain is a major factor influencing quality in rice. Characteristics influencing qualities in rice include hull and pericarp colour; grain size, shape, weight, uniformity and general appearance; milling out put; kernel chalkiness, translucency and colour; cooking, eating and processing characteristics and cleanliness, soundness and purity. Since rice is consumed and processed mainly in whole kernel form, its physical appearance is particularly important. Generally, farmers grow varieties possessing best grain quality which ensures higher returns and eventually, yield priority becomes secondary. Demand for high quality rice is continuously on increase as the living conditions are being steadily improved, which necessitates the incorporation of preferred grain quality features as the most important objective next to enhancement in yield. Nevertheless the cooking and eating qualities have not been fully understood as regards to how many genes are involved and how they interact in controlling the Amylose content (AC), Gelatinization temperature (GT), Gel Consistency (GC) and Kernel length after cooking

(KLAC). Since many genes are involved in synthesis of rice starch, it is necessary to delineate the contribution of each gene/enzyme in the starch biosynthesis pathway to the rice cooking and eating qualities, so as to breed new rice varieties with desirable palatability. Significant information is available on molecular markers linked to major quality related traits in rice. But in most of the studies the molecular markers were developed involving exotic germplasm and a few *japonica* rice varieties only. Therefore the traits that exert major effects on the eating and cooking qualities are related to the physico-chemical properties of rice grains such as amylose content (AC), gelatinization temperature (GT), gel consistency (GC) and kernel elongation after cooking (KLAC) are being targeted for improving the quality traits of rice.

- **Bio-fortification**

  Billions of people around the world and in India suffer from 'hidden hunger' or micronutrient malnutrition affecting the health of an individual directly and development of nations indirectly. Cereals as major sources of carbohydrates in food chain are inherently low in iron, zinc and protein contents with lesser bioavailability. Interventions like supplementation with pills and supported enhancement of intake of animal products are not sustainable in the long run. The deficiency of iron, zinc, vitamin A and protein deficiency directly affect the health of an individual and indirectly economy of the nation by increasing the number of Disability-Adjusted Life Years (DALYs – a frame work, which quantifies the economic impact of disability and disease). Biofortification refers to the genetic enhancement of key food crops with enhanced nutrients. They can be effective in reducing the problem of malnutrition as part of a multi-pronged strategy that includes dietary diversification, supplementation, and commercial fortification, among others. Biofortification can be done by adopting either conventional breeding approach or through the genetic engineering approach depending upon the trait of interest and variability for the trait available in nature. Several research attempts across the world led to the identification of key genes involved in micronutrient metabolism and their use in crop improvement programs. Rice is being envisaged for the enhancement of micronutrients; vitamins and proteins through conventional and transgenic approaches to address the malnutrition issue of the nation.

- **Product diversification (low GI, RBO, instant and convenient foods, health and cosmetic products, bran oil)**
  To diversify the rice and rice based products, studies are on low GI, rice bran oil, health and cosmetic products are on at IIRR. The Glycemic Index (GI) is a classification of Carbohydrates in food based on their effect on blood glucose levels. Low GI rices are digested and absorbed slowly and lead to a slow, gradual rise in blood glucose levels. Preliminary studies are on low GI and will be intensified in future in collaboration with NIN and other institutes. Rice bran oil is the oil extracted from the rice bran fraction comprising outer layer of the brown rice and the germ. RBO has its unique properties like very high smoke point (RBO: 254°C) and mild flavour making it suitable for high temperature cooking methods such as stir frying and deep frying. Studies at Indian Institute of Rice Research have shown that the role of polishing time in the RBO content and varietal differences, thus diverse genetic material may be screened to identify the varieties with higher fat content in the rice bran and further breeding of the varieties for higher fat content. Efforts are to be mooted for the developing technologies for the stabilization of bran to improve the extractability and storability of the raw material for later usage. Rice based cosmetics are being made across the world with novel formulations that use one or more ingredients from rice. Two rice based products namely, Rice moisturizing lotion and Rice pain relieving gel were developed for the first time in India at IIRR. The product has been named as "Rice Riche Pain Relieving gel". Instant rice is also known as quick-cooking rice. It requires significantly less cooking time than raw milled rice which usually requires 15 to 25 minutes depending on cooking temperature. The proof of Instant rice has been demonstrated which only takes about 5 minutes to prepare before serving, however studies needs to be taken up for identification of suitability of the varieties for instant and health rice based foods.

*(6) Sustaining soil health*

- **Innovative nutrient management**
  Nutrient plays a key role in increasing agricultural production through intensive cropping. Sustainable agriculture can be achieved by efficient utilization of this costly input. Nutrient use efficiency can be improved by checking the path ways of nutrient losses from soil-plant system, making integrated use of nutrients from all possible

sources, optimal allocation of nutrients to cops and maximizing the utilization of applied and native nutrients by the crops.

- **Adopting resource conservation technologies**
  The natural resources are under immense pressure due to population growth and intensive agriculture. Soils are unable to sustain crops due to continuous and intensive cropping and reduced organic matter in soil. Development of salinity on irrigated land and ground water depletion due to over exploitation in areas where tube wells are the major source of irrigation and water quality issues have heightened awareness of the need for the judicious use of water. Tillage costs are rising, which accentuates the already serious labour shortages during peak periods of land preparation and harvest. For these and other reasons, the sustainability of these systems is in question. Improved tillage and crop establishment practices, especially for rice, show real potential for sustainably improving the productivity and profitability of rice-wheat systems. Reduced and zero tillage can improve yields, raise input-use efficiency, reduce the intensity of machinery use and lower reduction costs
- **Building up soil resilience through innovative carbon sequestration strategies**
  Wetland characteristics lead to the accumulation of organic matter in the soil and sediment, serving as carbon (C) sinks and making them one of the most effective ecosystems for storing soil carbon. It has been estimated that different kinds of wetlands contain 350-535 Gt C, corresponding to 20-25% of world's soil organic carbon. However, long term storage is often limited by rapid decomposition processes and release of C to the atmosphere from paddy fields. Hence, wetlands are dynamic ecosystems where significant quantities of C may also be trapped and stored in sediments. Soil organic carbon (SOC) storage has been widely considered as a measure for mitigating global climate change through C sequestration in soils. The loss and gain of organic C in soils depends on soil type, temperature, erosion, and vegetation type and land management. Maintenance of SOC in rice–wheat cropping system is important not only for improving agricultural productivity but also for reducing carbon emission. Soil management practices such as tillage operations are conventionally used for loosening soils to grow these crops. But long-term soil disturbance by tillage is believed to be one of the major factors reducing SOC in agriculture. Rice–wheat cropping system presents greater benefits of carbon sequestration from residue application in no-tillage system relative to that in conventional

tillage system. Low SOC in conventional tillage system is likely due to greater carbon losses through mineralization (although not measured) of applied residues under the prevailing hot and humid weather condition. However, it is promising that the rate of SOC sequestration is much higher in 0–50 cm soil depth than the reported average value for the South Asian region.

- **Utilization of microbial diversity**
  Microorganisms play an integral and often unique role in the functioning of ecosystems and in maintaining a sustainable biosphere. The role of microorganisms in maintaining the dynamic equilibrium and integrity of the biosphere is so critical that the continued existence of life is dependent upon the sustained, microbial-mediated transformation of matter in both terrestrial and aquatic environments. That almost all biological processes in the environment, either directly or indirectly, involve microorganisms is often overlooked with the potential benefits of regulating, optimizing and exploiting microbial activity largely unexplored. The extent of microbial diversity has not been adequately characterised and that there is an immense mismatch between our knowledge of that diversity and its importance in both ecosystem processes and economic development.

*(7) Enhancing water productivity*

- **Fine tuning of efficient agronomic practices (DSR, SRI, Aerobic, AWD, micro- irrigation)**
  Scientific management of available water resources will be one of the critical components of adaptation to climate change in near future. Socio-economic pressures driven by changes in water availability will increase in coming decades. Adoption of water management practices that increase the productivity of irrigation water will provide significant adaptation potential under climate change. A number of farm, irrigation system and basin level adaptation techniques and approaches are specific to water management for agriculture. Crop growth period offers essentially three alternative management practices to save irrigation water: saturated soil culture (SSC), alternate wetting and drying (AWD), and aerobic rice. In SSC, the soil is kept as close to saturation as possible, thereby decreasing seepage and percolation losses. Alternate wetting and drying (AWD) is an alternate method to flooded culture. By implementing a cycle of alternate low-level flooding and periods when the soil is allowed to dry out, water requirements can be reduced up to 30 per cent,

with no yield reduction. Aerobic rice ("Rice which allows air into soil") is a system of rice cultivation in which fields are not flooded as in transplanted cultivation, and water requirement of the crop is instead maintained by periodic supply of water. About 37% of water can be saved using aerobic rice compared to transplanted rice. The system of rice intensification (SRI), developed in Madagascar, is based on a set of practices to manage plants, soil, water and nutrients that reduce seed requirement, save irrigation water, lower the costs of production, while enhancing crop yield. This makes irrigated rice cultivation more productive, profitable and sustainable. SRI has shown consistent water-saving effects coupled with a higher grain yield. Direct seeding of rice, a common practice before green revolution in India, is becoming popular once again because of its potential to save water. Direct seeded rice under no/reduced tillage is an efficient resource conserving technology (RCT) holding good promise. Labour required for nursery raising, uprooting and transplanting of seedlings are saved to the extent of about 40%

- **Harnessing synergistic effects of water and nutrient interaction**

  The utilization efficiency of water and various other inputs is considerably low in wet land rice. Soil types and water status in the system play a major role in influencing the nutrient dynamics, weed dynamics, loss of nutrients and efficiency of utilization, pest dynamics etc. An integrated approach is required to be evolved for optimizing resource use and enhancing its productivity. Ample scope exists in irrigated rice to optimize resource and energy use, and sustain higher rice productivity given the right combination of efficient integrated soil, water, nutrient and crop management strategies integrated for a specific environment. Development and standardization of efficient package of soil, nutrient, water and crop management practices keeping in view the nutrient dynamics, losses, crop responses to input and resource use, and land preparation, and pest/disease/weed dynamics will be the major objective of optimizing water use and enhancing its productivity.

  The utilization of nutrients can be improved by optimum and synergistic interaction with other inputs viz., water, tillage and mulches. These inputs modify the physical, chemical and biological environment of soil, which influence the nutrient recovery by crop plants.

- **Utilization of biomolecules to reduce water loss**

  The adverse effects of water stress on crop growth can be mitigated by the application of chemicals such as nutrients, anti-transpirants and Plant Growth Regulators (PGRs), which induce the plants to become adaptive to water stress situations for a specified period and the water requirement for such periods can be minimized or saved. Anti-transpirant is and is any substance applied to transpiring plant surfaces for reducing water loss from the plant. In general, field crops are highly dependent or current photosynthesis for growth and final yield. Therefore, it is unlikely that currently available antitranspirant would increase yield of an annual crop unless crop suffers stress from inadequate water and or a very high evaporative demand, particularly during a moisture sensitive stage of development.

*(8) Improving resource use efficiency*

- **Precision nutrient management**
  Applying just enough inputs as and when needed by the crop would avoid overuse and misuse of fertilizers and pesticides, land degradation and erosion of biodiversity. Timely crop oriented nutrient management technologies such as the leaf colour chart (LCC) for nitrogen management of rice and site specific nutrient management (SSNM) approach for tailoring P and K application rates as per yield target and soil nutrient supplying capacity need to be adopted in large scale by the farmers. Location-specific N fertilizer splitting schedules for preventive N management follow a fixed schedule of fertilizer N applications. Such recommendations for location-specific N regimes are in wide spread use, usually developed on-station or on-farm in N fertilizer response experiments. Location-specific split schedules combined with LCC provide tools for preventive and corrective N management. Total fertilizer N requirements are calculated for location-specific split schedules. Predetermined N doses are adjusted during later growth stages depending on the plant requirement for fertilizer N. In general, nutrient use efficiency is greatest when all P and most K fertilizer is applied early in the season to avoid deficiencies at early growth stages. This requires a conceptual framework to guide farmers in the estimation of season-specific total fertilizer P and K requirements. The major benefit for farmers from improved nutrient management strategies can be expected as an increase in the profitability of rice cropping.
- **Crop diversification farming systems**
  In the era of shrinking resource base of land, water and energy, resource use efficiency is an important aspect for considering the

suitability of a cropping system. Hence, selection of component crops needs to be suitably planned to harvest the synergism among them towards efficient utilization of resource base and to increase overall productivity. Growing of crops such as vegetables, pulses and oilseeds in place of post rainy season rice is an alternative approach for realizing higher productivity and profitability. Moreover, growing non paddy crops during post rainy season has a special reference for efficient utilization of irrigation water, labour and other inputs for higher productivity, profitability and food. There is need to evaluate the possibilities of replacing post rainy season rice with other suitable upland crops and include summer season crops for higher productivity, resource use efficiency and sustainability.

- **Diagnostics of soil and plant nutritional problems and remedial measures**

  The productivity of soil depends on its fertility and thus on its physical, chemical and biological characteristics. To best mange soil and plant nutrients, an integrated approach to plant nutrition must be adopted by diagnosing the constraints in soil and plant nutrient management, understanding their problems and addressing them. Diagnosis of constraints and opportunities related to soil and plant nutrient management results in an overall assessment of the local diversity of current management practices related to natural resources and availability of external inputs and provides an opportunity to improve soil/crop productivity. To assess the ground situation in large tracts of the field/plots, it is pertinent to generate more information about the fertilizing capacity of the land and soils as early as possible. This should lead to formulate well documented guidelines for diagnosing soil and plant nutrient related problems there by providing opportunities for enhancing input use efficiency.

- **Selective mechanization for timely operations under labour shortage, reduce human drudgery, value addition and post harvest processing**

  Farm mechanization in rice is very important as it aids in the timeliness of operations, eliminates/reduces the human drudgery in farm operations and improves the productivity. Rice cultivation involves a number of labour intensive operations like transplanting, weed control, harvesting etc. The fact that labour is becoming increasingly costly and scarce during peak periods of farm operations also adds a new dimension to this problem. Timely operations through selective mechanization can also help to realize the potential of rice hybrids. Finding solutions to environmental problems in agriculture requires (improved) agricultural tools and machinery, for example, for soil tillage and pesticide application, the latter also addressing health concerns. Similarly, machines are required to assist with post-harvest loss reduction and on-farm processing. Thus it is recognized that agricultural mechanization is crucial in the fight against hunger and poverty, and at the same time to address environmental and health concerns.

- **Geo spatial technologies and models for precision farming**
  Precision farming is a management strategy which identifies, analyses and manages within field variability for increased profit and reduced environmental impact. Crop variability typically has both a spatial and temporal component which makes statistical/computational treatments quite involved. The promise of precision agriculture research will be the ability to define a Decision Support System (DSS) for whole farm management with the goal of optimizing returns on inputs while preserving resources. It can be said that the practice of precision agriculture was enabled by the advent of GPS and GNSS. The farmer's and/or researcher's ability to locate their precise position in a field allows for the creation of maps of the spatial variability of as many variables as can be measured which will enable them to devise appropriate management decisions. Precision agriculture management practices can significantly reduce the amount of nutrient and other crop inputs used while boosting yields. Farmers thus obtain a return on their investment by saving on phyto sanitary and fertilizer costs. The second, larger-scale benefit of targeting inputs—in spatial, temporal and quantitative terms—concerns environmental impacts. Applying the right amount of inputs in the right place and at the right time benefits crops, soils and groundwater, and thus the entire crop cycle. Consequently, precision agriculture has become a cornerstone of sustainable agriculture, since it respects crops, soils and farmers. Sustainable agriculture seeks to assure a continued supply of food within the ecological, economic and social limits required to sustain production in the long term. Precision agriculture therefore seeks to use high-tech systems in pursuit of this goal.

*(9) Integrated pest management*

Integrated Pest Management is an ecologically based strategy that focuses on long term solution of pests through a combination of techniques such as use of resistant varieties, biological control, modification of agronomic practices and habitat manipulation. Recent developments in scientific research related to biotechnology and other fields, technological innovations and new pesticide delivery systems as well as changes in markets and the policy environment offer new opportunities for reducing dependency on chemical pesticides and evolution of an holistic IPM for sustainable rice production. The modern versatile tool of biotechnology has enough potential to develop multiple pest resistant cultivars in rapid time through thorough understanding of molecular basis of tritrophic interactions among host, insect pest and natural enemies. Diagnostic tools and Decision support systems utilizing Geographical information system (GIS) maps along with weather data will be helpful for pest risk analysis and forecasting of major pests. In the last few years, newer environment friendly chemicals with novel modes of action and effectiveness at very low doses have fitted well into rice IPM programmes. Use of bio pesticides and other novel biomolecules can be advocated as environment friendly components of IPM, while precise delivery systems through deployment of nano-pesticides or nano-encapsulated pesticides and development of herbicide tolerant varieties are the other potential options ecologically sound IPM. The thrust areas of research include:

- Understanding molecular basis of tritrophic interactions
- Precise delivery system for pesticides
- Designing diagnostic tools through decision support system
- Enhancing ecosystems services
- Pest risk analysis
- Bio rational pesticides and biomolecules
- Herbicide residues and herbicide tolerant varieties

### *(10) Validation and transfer of technologies.*

Extension Education efforts of IIRR are known for their innovative concepts and field impacts. With unparallel innovative instinct and passion for making the difference in the lives of millions of rice farmers, a cafeteria of approaches are harnessed that range from traditional 'Frontline Demonstrations' to Hi-tech 'Rice Knowledge Management Portal'. A variety of extension approaches and methods are deployed for benefitting the farming community of the country.

The varieties/hybrids and technologies developed as a part of research and multi-location testing are validated for their suitability to various socio-economic and field conditions through FLDs. Organization of FLDs on newly released varieties/technologies is a very useful strategy for their popularization, and thereby helping to enhance the production and productivity of rice in the country. IIRR builds the capacity of stakeholders through regular trainings and the use of online tools to help improve rice production. For providing the most comprehensive agricultural knowledge directly from the scientific community, Rice Knowledge Management Portal was launched. RKMP now serves as an information highway for sharing rice knowledge across the country.

Gender mainstreaming in rice based cropping systems and field level adoption constraints are assessed from time to time. Large number of additional activities are planned for validation and transfer of technologies for years to come through

- Evaluation of technologies through FLDs
- Strengthening seed chain supply
- Breeder seed production
- Capacity building and HRD programmes.
- Dissemination of rice knowledge through e-extension.
- Impact and constraint analysis of adopted rice production technologies
- Gender mainstreaming in rice based cropping systems

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