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Editors

P K Shetty
M R Hegde
M Mahadevappa

INNOVATIONS IN RICE PRODUCTION

NATIONAL INSTITUTE OF ADVANCED STUDIES
Bangalore, India

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Preface

Agriculture is an integral part of India's economy and society. It has about 130 million farming families; the majority of them are small and marginal farmers who practice subsistence agriculture. The green revolution which occurred in late 1960s was a turning point in Indian agriculture. There was remarkable growth in agriculture during the Green Revolution period and this sector has been successful in keeping pace with growing demand for food grains in the country. However during 1990-2010 the food grain production in the country grew at an average 1.4 per cent, whereas the population growth was at 1.6 per cent. Fortunately, we have achieved a food surplus during last two years. But in the long run, concern of food security is likely to become more intense with increasing population and decreasing land availability. By 2020, to meet the food demand of 1.3 billion populations, India needs to produce 281 MT of food grains with an annual growth target of 2 per cent.

Rice is one of world's most favoured staple foods and more than 90% of rice is produced and consumed in Asia. Rice being an important crop in India, there is a lot to focus on enhancing rice production and productivity. Rice is grown in 43.4 million hectares in kharif and rabi /summer season out of the total 141 million hectares of land under cultivation. The area under rice is likely to reduce in future years due to diversification policies adopted by the government. Currently, the rice production in the country is passing through serious constraints like plateauing of yield, water scarcity, increased use of agro inputs, irregular monsoon, increasing soil mineral stress, flash floods, water logging, labour scarcity, inadequate storage facilities, invasive pests & diseases, lack of policy innovations and inadequate institutional dynamics. India needs to focus on proper utilization of resources in diverse agro-climatic zones in the country by providing quality seeds, developing high yielding varieties/ hybrid rice, effective natural resource management, developing strategies on biotic and abiotic stress management, cost effective mechanization and promoting agricultural stewardship. Further, there is need to strengthen various initiatives by both State/ Central Government and cooperative involvement of all the stakeholders which will help in enhancing rice production and productivity in the country.

Improving rice production and productivity is the common problem as it touches everybody in the country including scientists, policy makers, farmers and consumers etc. It is important to increase the India's investment in R&D in agriculture in general and rice in particular as rice contributes significantly to the GDP and earns valuable foreign exchange. With reference to rice production in India and China, we need to appreciate the strategies followed by China on hybrid and super hybrid rice program. India needs to aggressively formulate a favourable policy and provide adequate funding for hybrid rice technology.

India needs to enhance the rice production to support growing population and also to keep sufficient in buffer stock in quality warehouses. There is need to build more warehouses in the country for storage of rice to meet any unforeseen situations, as we cannot afford to buy the rice from other countries due to high international price. Therefore, even from the food security point of view, India needs to grow more rice. But at the same time, we should also make judicious use of water by diversifying with crops like vegetables, fruits, millets, pulses etc, as the demands for them are increasing with increase in income. The places or regions where rice are grown need special attention and our efforts need to be directed towards increasing the productivity. The rice technologies need to be constantly updated and bring new innovations in rice production. Further we need to aim at saving the water and developing input efficient cultivars. We need to make the policies for MSP with proper timeline. Thus, MSP if fixed before the cropping season will facilitate the farmers to take suitable decisions on the crop and realise better returns.

This book contains lead papers from distinguished scientists and policy makers in the country. Some of the chapters in this book reviews the past, present and future of rice production and productivity in India with reference to the research, policy and institutional dynamics. The authors of this book are distinguished agriculture scientists, policy makers, economists, breeders, irrigation experts, extension specialists and other stakeholders from different parts of the country.

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Contents

Key Research Inputs and Technologies in Rice Production in Pre and Post Green Revolution Era
B.C. Viraktamath 1

Strategies for Enhancing Production and Productivity of Rice in India
K. Srinivasa Rao 19

Growth in Production, Productivity, Costs and Profitability of Rice in India During 1980-2010
Parshuram Samal 35

Hybrid Rice Programmes and its Experience in India
Aldas Janaiah and Fangming Xie 53

Hybrid Rice and Water Saving Technologies – A Possible Solution for Inter State Water Dispute
M. Mahadevappa 65

Constraints of Rainfed Rice Production in India: An Overview
Krishna M. Singh, A.K. Jha, M.S. Meena, and R.K.P. Singh 71

Present Situation and Prospects of Rice Production in India with Special Reference to Karnataka
K. Narayana Gowda and M.P. Rajanna 85

Emerging Insect Pests and Diseases of Rice under various Rice Ecosystems
K.S. Behera, M. Jena, U. Dhua and A. Prakash 93

Important Socio-economic and Ecological Factors Affecting Rice Production in India
K.V. Rao, B. Shailaja, B. Nirmala and B.C. Viraktamath 117

Rice Factor Productivity in India : Economic Implications
M.G. Chandrakanth, L. Ranganath and T.N. Prakash 127

Agricultural R&D Investment by India and China: A Comparative Analysis with Specific Emphasis on Rice Production
K.R. Karunakaran 141

Biotechnological Options for Rice Improvement
R.M. Sundaram, S.M. Balachandran, M.S. Madhav and B.C. Viraktamath 167

Knowledge Management Portal for Enhancing Rice Production and Productivity
Shaik N. Meera, G.A.K. Kumar, M.P. Rajanna, R.L. Kunkerkar, P.S. Pandey and B.C. Viraktamath 203

Achievements, Challenges, Technology Dissemination of Rice in India
R.S. Kulkarni, K.P. Raghuprasad and Mallika Meti 215

Nature and Dimensions of Farmers' Indebtedness in India
Meenakshi Rajeev, B.P. Vani and Manojit Bhattacharjee 221

Recent Developments in Water Management and Conservation in Rice
P.V. Veerraju, K.P. Aruna and Putra 235

Contributors 239

Summary 243

Key Research Inputs and Technologies in Rice Production in Pre and Post Green Revolution Era

B.C. Viraktamath

The current Indian population of 1.22 billion is expected to reach 1.3 billion by 2020 and 1.53 billion by 2030 AD. Since rice is the staple food for most of us, food security primarily depends on this wonderful crop. Globally rice is cultivated now in 160 million hectares with annual production of around 650 million tonnes of rough rice and average productivity of 4.18 tons/ha of rough rice (FAO stat 2007-08). More than 90% of the rice is produced and consumed in Asian countries. The other continents in which rice is grown are Africa (7.78% of the global area), South America (6.4%) and North America (1.4%). In India during the period 2011-12, rice is cultivated in an area of 44.0 million hectare with a production of 103.41 million tons of paddy with an average productivity of 2.35 t/ha milled rice or 3.52 t/ha rough rice.

Though, rice production growth trend had kept in pace with population growth rate during last five decades, signs of decreasing growth rate are evident. This has been a cause of concern.During the green revolution period the semi-dwarf, fertilizer responsive, high yielding genotypes of rice and wheat were introduced, which led to phenomenal increase in production and productivity of these crops. It appears that the technology introduced during the green revolution has reached a phase of diminishing returns. Hence it is very pertinent to critically consider whether the rice production can be further increased to keep pace with population growth with the current green revolution technologies. It is estimated that by 2030 at least 140-150 million tons of milled rice is to be produced in India to maintain the present level of self sufficiency. Is there a need for a paradigm shift in rice research to meet the challenges of the future decades for ensuring food security? Do we need to adopt the gene revolution technologies? The possibilities and prospects

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of utilizing the new technologies for enhancing rice productivity in order to achieve food and nutritional security are examined in this paper.

Breeding strategies during pre-green revolution era

Most traditional varieties in tropical and subtropical Asia grown earlier to 1960s, were tall, maturing in 160-170 days, many were photoperiod sensitive, and had harvest index of 0.3 to 0.4 with yield not more than 1 t/ha. These were suitable for growing one crop of rice a year during the rainy season. These varieties did not respond well to additional fertilizers. These plants had weak stem and would lodge due to tall stature. The only breeding strategy during this phase was introduction and pureline selection. This did not result in perceptible impact on productivity. As an aftermath of Bengal famine, International Rice Commission was setup in 1949. An ambitious programme of hybridization between *indica* and *japonica* sub-species of rice *Oryza sativa* was taken up during 1950s. Though the project did not result in spectacular success, varieties like Mahsuri and Malinja in Malaysia, ADT27 in India and Circna in Australia were released. Mahsuri became very popular variety in India also and has been used in subsequent breeding programme extensively.

Breeding strategies during green revolution era

With the establishment of Central Rice Research Institute in Cuttack, India in 1950 and the International Rice Research Institute (IRRI) in the Philippines in 1960, rice improvement research gained momentum and focus. Breeders soon realized that to increase the yield potential, it was necessary to promote responsiveness of the rice plant to management, make it photo-insensitive and redesign the plant architecture to prevent lodging. This was accomplished by reducing the plant height through incorporation of a dwarfing gene *sd-1*conferring short stature, from a Chinese variety, Dee-geowoo-gen. The first semi-dwarf high yielding variety (HYV) developed was TN1 in Taiwan, which was followed by IR8 developed by IRRI. Soon after India released Jaya as the first HYV during 1968. Preceding to the event was establishment of All India Coordinated Rice Improvement Project (AICRIP) by the Indian Council of Agricultural Research (ICAR) at Hyderabad in 1965. These first generation HYVs were semi-tall, profuse tillering, photo-insensitive, fertilizer responsive, non-lodging with a yield potential of 4 t/ha.

Such varieties ushered in the green revolution in the country. During the next three decades encompassing 70s, 80s, & 90s, over 580 varieties were developed and released for various rice ecologies. Sixty of these were released by the Central Agency for cultivation across the country while rests were released for specific states by the state release authorities. They ranged from 75 to 185 days crop growth period. Yield potential recorded was from 1.5 to 7.5 t/ha. During these three decades, rice area increased by 21%, production by 125%and productivity by 86%. India not only became self sufficient in rice but also started exporting rice – both the scented Basmatis and non-basmatis.

Until the end of 2011, 944 rice varieties and hybrids have been released for commercial cultivation. Half of these are for irrigated area while other half are for rainfed rice ecologies (Fig. 1).

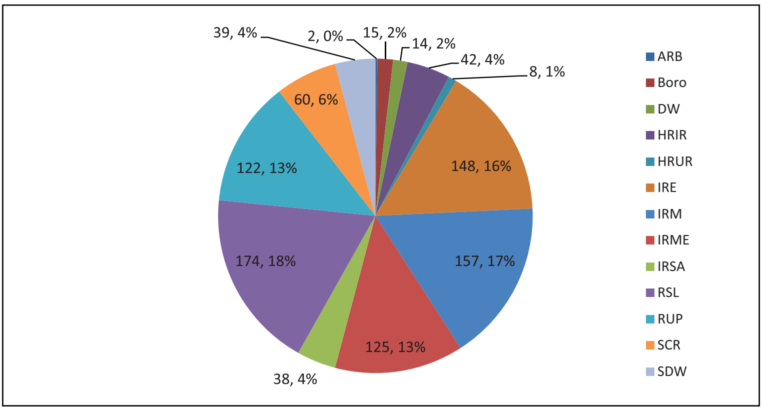

Fig. 1 : Rice varieties released for different rice ecologies

ARB- Aerobic rice, Boro- Boro area, DEW – Deep water land, HRIR-Hill rice irrigated, HRUR-hill rice upland, IRE- Irrigated early, IRM-irrigated medium, IRME-irrigated mid early, IRSA-irrigated saline/alkaline area, RSL-Rainfed shallow land, RUP-rainfed upland, SCR-scented rice, SDW-semi-deep water land,

The key to this success was the selection of the genotypes with rapid vegetative vigor at the early growth stages. This helped farmers to grow two rice crops during the year in areas where good irrigation facilities existed, or introduce a non-rice crop in the rice-based system depending on the resources available. While the profitability in rice farming increased with new varieties, a relatively small number of improved varieties replaced thousands of traditional ones, thereby reducing the genetic variability of the rice crop. The reduction in biodiversity, coupled with vegetative growth and continuous cropping, increased the vulnerability of the rice crops to insects and diseases. Scientists addressed this problem by incorporating resistance to major insects and diseases in newly released modern varieties. Large germplasm collections were screened and donors for resistance identified. Utilizing these donors, improved varieties with resistance to three major diseases (blast, bacterial blight and tungro) and three insects (brown planthopper, green leafhopper and gall midge) have been developed. Large-scale adoption of varieties with a broader genetic-base has helped stabilize rice yield and reduce the use of pesticides.

During this phase, the emphasis has also been on development of varieties with better grain quality suited to different regions of the country and for export. Improved scented varieties like Pusa Basmati, Sugandhmati, Yamini etc. have enhanced rice exports. While 2.2 million tons of basmati rice worth 10,580 crores is exported from the country during 2010-11, even non-basmati type varieties are exported to the tune of 3.0 to 5.0 million tons worth another 4,000 crores rupees in foreign exchange.

Post green revolution technologies

During 1990s and 2000s limitations of green revolution technologies were surfacing resulting in a kind of stagnation in yields. The HYVs with *sd-1* gene for dwarfing have certain genetic limitations for further enhancement of yield potential. These varieties are over dependent on external application of fertilizers and demand continuous submergence. Because of these two factors, incidence of pests and diseases has been higher than the earlier varieties. Several alternative approaches are being explored to meet the future challenges in terms of enhancing genetic yield potential, increasing resource use efficiency, tolerance to biotic and abiotic stresses and improving nutritional quality of the rice grain. Some of these are dealt hereunder.

Development and use of hybrids

Convinced of the potential of hybrid rice technology to enhance productivity and production of rice, in light of the remarkable success of the Chinese in this field, Indian Council of Agricultural Research (ICAR) initiated a goal oriented project in December, 1989 to develop and utilize hybrid rice in Indian Agriculture. First set of hybrids were developed and released in 1994. Till now 59 hybrids have been released, 35 from public sector and 24 from private sector. The hybrid rice seed production and cultivation packages have been developed and optimized. During the year 2011, hybrids were cultivated in an area of 2.0 million ha. It is expected that during the next five years hybrids will cover about 3 - 5 million hectares. The popular hybrids being cultivated in the country are 6444, PHB-71, KRH-2, Sahyadri, DRRH3 etc. More than 20 private seed companies are actively involved in hybrid rice research, development and large scale seed production. Over 95 percent of the hybrid rice seed in the country is produced by the private sector.

By cultivation of hybrids farmers are obtaining an additional yield advantage of 1-2 t/ha, the additional net profit being in the range of Rs. 3,000 – 5,000 per ha. In hybrid rice seed production, seed yields of around 2.0 t/ha are obtained with a net profit of Rs. 25,000 to Rs. 30,000/- per ha for the seed growers.

At present hybrids are cultivated in Uttar Pradesh, Chattisgarh, Jharkhand, Bihar, Haryana and Punjab. Some of the major constraints to further expansion of hybrid rice are lack of matching grain quality, lack of resistance to major pests and diseases and higher seed cost. Research efforts to overcome these constraints are underway. Recently released hybrids like DRRH-3, 2T P 11 and JK 3333 have excellent cooking quality. It is expected that hybrid rice will play a major role along with the New Plant Type (NPT) varieties, in raising the productivity and production of rice in the coming decades.

Development of aerobic rice adapted to water stress conditions

Water stress is an important abiotic stress limiting rice yields across the world. Traditionally rice crop requires almost thrice the quantity of water when compared to maize and wheat. The progressive reduction in water resources across the world necessiates the development of alternative strategies to combat water stress in rice. One such strategy is the development of "aerobic rice" which can survive without constant flooding. Biotechnology can help in development of aerobic rice through the application of molecular markers, genetic engineering and genomic tools. Novel molecular and biotechnological methodologies can be used to identify stress-related genes and use them as probes for selection of tolerant genotypes and for generation of transgenic plants. Similarly, identification and utilization of molecular markers linked to gene(s) associated with drought tolerance can tremendously boost the capacity of rice cultivars to resist water scarcity.

Deployment of biotechnological tools

The efforts of rice breeders have no doubt brought the rice yield levels to such a stage where at least for the present, food production growth will outrace population growth. But we should not be complacent as the vagaries of monsoon and disturbing trend with respect to soil health are bound to destabilize rice production and we must therefore be ready to face the challenges of the future by judicious and prudent application of biotechnological tools. From a breeder's perspective, biotechnology helps to add precision in the breeding process to become more target oriented and purposeful as compared to traditional breeding. Biotechnology can help in improving rice breeding through:

1. Transfer of economically important traits across genus/ species barrier into the rice gene pool (i.e. Broadening the genetic base)
2. Manipulation of target trait without disruption to the non target regions of the rice genome (i.e. Increasing efficiency in selection)
3. Shortening the breeding cycle

The three broad applications of rice biotechnology that are expected to contribute both directly and indirectly towards rice improvement efforts in India are discussed here.

DNA marker technology

The application of molecular markers in rice improvement started with the efforts of Cornell University and IRRI using RFLP markers for development of molecular linkage maps in rice. The first restriction fragment length polymorphism (RFLP) map of rice was developed in 1988. Later a comprehensive genetic map was developed with more than 2250 DNA markers. RFLPs being laborious and costly were then replaced with more robust, simple to use PCR based markers like microsatellites or simple sequence repeats (SSR), Inter-simple sequence repeats (ISSRs), Sequence tagged sites (STSs) etc. These simple PCR based markers help breeders to track the introgression of the target genes across segregating progenies. Markers tightly linked to the gene(s) of interest can be used at any crop stage for testing the presence of the gene(s) without waiting to observe its phenotypic manifestations. In addition, markers, which are co-dominant (eg. Microsatellites) also help us to know the allelic status of a gene and thus are very helpful in recurrent/ backcross breeding programs for introgression of recessive but agronomically important gene(s). More than 25 agronomically important rice genes have already been tagged with markers and can readily be deployed by breeders in breeding programmes.

A successful use of marker-aided selection (MAS) has been shown in pyramiding four Xa-genes for bacterial blight resistance. A similar success story with respect to development of bacterial blight resistant rice cultivars through marker assisted selection has been reported by the research group at Punjab Agricultural University, Ludhiana. DRR, Hyderabad has also developed and released 'Improved Samba Mahsuri' with three bacterial blight resistance genes (*Xa21, xa13 & xa5).* This variety is becoming quite popular and the field tests suggest that this variety possess excellent BLB resistance along with grain quality and yield similar to that of Samba mahsuri. This material has been developed through an Inter-Institutional collaboration between Centre for Cellular and Molecular Biology, Hyderabad and Directorate of Rice Research, Hyderabad. Similarly, Indian Agricultural Research Institute has released Improved Pusa Basmati with two BLB resistance genes (*Xa21* and *xa5*) by using MAS.

There has been rapid progress in marker technology in the recent past. Markers have been developed for various desirable agronomic traits such as yield and yield related traits like grain number, grain filling that might directly contribute to yield enhancement. One of the introgressed line derived from the cross *KMR3* and *O. rufipogan* designated as IET 21542 carrying two yield QTLs has recorded 34% higher yield than the best hybrid check. Like wise, a QTLs for grain number located on chromosome 4 designated as qtlGn4.1 has been intorgressed from the the new plant type line Pusa 1266. Addressing the biotic stresses like BLB, blast and gall midge, several resistance genes have been tagged and closely linked markers identified for pyramiding two or more genes to confer durable and multiple resistance.

Genetic engineering for rice improvement

Genetic transformation is another tool that promises to revolutionize Indian rice production scenario. The most important advantage of transgenic technology is the capacity to mobilize useful genes from non-rice gene pool to rice with least disruption to rice genome. Ever since the publication of the first reports on successful production of transgenic rice plants of Japonica in 1988, a large number of rice varieties have been introduced with agronomically and economically important genes. Direct DNA transfer methods such as protoplasts, biolistic method and Agrobacterium-mediated methods are being used routinely in rice transformation in the biotechnology laboratories across the world including India. Transgenic indica rice tolerant to biotic stresses such as insect pests and disease caused by viruses, fungi and bacteria have been developed and tested by research groups worldwide. Transgenic rice with herbicide resistant gene has also been tested under field conditions.

In India, transformation studies initially involved standardization of various gene transfer techniques. The marker genes freely available in public domain to most researchers like *gus* and *hygromycin* resistance were widely used for confirmation of transformation events. Subsequently, genes that confer resistance to pest or disease were targeted and within a few years, Nayak and co-workers reported the development of first transgenic rice with Bt gene in 1997. Since then, several groups started working on transfer of different genes into important genotypes of rice, most notably the introduction of *Bt* genes such as *cry1A(b)*, *cry1A(c)* to obtain resistance against yellow stem borer. Research groups in India have recently succeeded in transferring *Bt* genes into indica rice cultivars such as IR64, Karnal Local and Pusa Basmati using *Agrobacterium* strategy.

Similarly, work is in progress in development of transgenic rice resistant to bacteria leaf blight and sheath blight using constructs with *Xa21* and Thaumatin like proteins. Production of transgenic plants of cv. Chaithanya possessing *gna* lectin gene which confers resistance against sucking insect pest of rice has been reported.

Engineering rice to survive adverse abiotic stress is also receiving attention. The abiotic stress, which limit rice yields, include Salinity, alkalinity, drought and cold. Traditional breeding has contributed significantly to salinity tolerance and salt tolerant varities like CSR10, CSR11, CSR27, CSR30 etc. have been developed in India. But unlike biotic stress resistance where a single gene conferred resistance can effectively combat the pest/disease, abiotic stress tolerance is complicated due to the involvement of many genes. Studies using molecular markers basically aim at tagging and mapping of genes/QTLs associated with abiotic stress tolerance. Once tightly linked markers are available for such QTLs associated with the tolerance traits can be pyramided in the background of a popular high yielding cultivar. Genetic engineering is another promising biotechnology approach for developing rice cultivars with enhanced abiotic stress tolerance. It is beyond doubt that transgenic technology offers more powerful solutions for incorporation of complex traits like abiotic stress tolerance compared to traditional breeding approaches.

Nutritional quality improvement is another area where genetic engineering is playing a critical role. Considering the inadequacy of rice with respect to human nutritional requirement and the non-availability of enough genetic variation in rice gene pool with respect to nutritional traits, researchers worldwide have targeted deployment of transgenes from other taxa for nutritional improvement of rice. Three genes - two from daffodil and one from a bacterium *Erwinia uredovora* – have been used to provide the biosynthesis pathway for the production of beta-carotene, a precursor of Vitamin A, in rice. Transgenic rice , known popularly as Golden Rice, has already been produced through transformation of a japonica rice variety, T309 and recently in an indica rice IR64. Since the inventors of the technology have donated it free-of cost to developing countries like India, Department of Biotechnology and Indian Council of Agricultural Research have formalized a programme to transfer the beta-carotene biosynthetic traits to locally popular Indian rice varieties through marker assisted backcross breeding and genetic transformation. Directorate of Rice Research, Hyderabad, Indian Agricultural Research Institute, New Delhi, University of Delhi, South Campus, New Delhi and Tamilnadu Agricultural University, Coimbatore have been entrusted with the responsibility of developing Indian version of 'Golden rice'.

Ferric chelate reductase gene allows plants to absorb more iron from soil, thus, widening the scope of rice varieties with high iron uptake. Similarly soybean Ferretin gene has been cloned into rice and have reported two-fold increase in iron content in rice grains. It has been reported that a thermo-tolerant phytase gene from *Aspergillus fumigatus* has been transferred to rice and this has resulted in tremendous increase in iron content in rice grains due to degradation of iron chelating phytic acid by the phytase enzyme. Similarly, over expression of cystein-rich protein, which increases the cysteine content that may substantially degrade phytate during food preparation and digestion, is another exciting development in using biotechnology for nutritional improvement.

Transgenic technology is also being employed to attempt to convert rice from C3 to C_4 plant. It is hoped that through this the photosynthetic efficiency and consequently, the yield can be increased tremendously. The researchers at the Washington State University have made efforts in engineering C_4 photosynthesis pathway, using an *Agrobacterium*-mediated transformation system. They have independently introduced into rice three maize genes encoding the C_4 photosynthetic pathway enzymes: phosphoenolpyruvate carboxylase (PEPC); pyruvate orthophosphate dikinase (PPDK); and NADP-malic enzyme (ME). The transgenic rice plants expressed high levels of these genes and the maize enzymes remained active in rice plants. Most importantly, PEPC and PPDK transgenic rice plants exhibit higher photosynthetic capacity than untransformed plants, mainly due to an increased stomatal conductance (i.e., more atmospheric CO_2 becomes available for fixation). Preliminary field trials conducted in China and Korea have shown 10-30% and 30-35% increases in grain yield for PEPC and PPDK transgenic rice plants, respectively. A further enhancement of the photosynthetic capacity of rice will require engineering a limited C4 pathway of photosynthesis by simultaneously expressing the three previously mentioned key enzymes in proper cellular compartments. Ultimately, for the most efficient operation of the pathway to concentrate CO_2 around Rubisco in the leaf, the concomitant installation of Kranz leaf anatomy will be essential.

Application of genomic tools for rice improvement

Similar to DNA marker technology and rice transgenics, rice genomics is another area with full of prospects. The developments in the last five years have been explosive and we now have a complete sequence of the rice genome. As the rice genome is being completely sequenced, biotechnologists have started a systematic assessment of the phenotypes resulting from the disruption of putative gene sequences with genetic resources such as mutants, near-isogenic lines, permanent mapping populations, and elite and conserved germplasm. Functional genomics, to a large extent, is analogous to the extensive germplasm screening that has allowed the extraction of useful traits in conventional breeding programs, yet with DNA sequence level precision on a global genome scale. The judicious utilization of the sequence information through functional genomic analyzes will certainly offer solutions to many a breeding problems through means hitherto not thought of. The availability of rice genome information is the foundation for the identification of orthologous genes in cereals and also facilitates the sequencing of other cereal genomes. An international collaboration was established for completion of rice genome sequencing and to coordinate the concerted utilization of sequence information for the benefit of humankind. This initiative called the International Rice Genome sequencing Project (IRGSP) is publicly funded and has 8 countries as its members. IRGSP has recently released completion of rice genome sequencing to ten-fold redundancy.

Crop and resource management

Crop production and cultivation practices during the pre-green revolution period were less input intensive, imprecise in water management and mainly dependent on ITKs for pest management. Farm implements being used were also primitive and did not get rid of the drudgery.

However, with the advent of green revolution, crop and resource management research intensified with the introduction of management and input responsive, photo-insensitive plant type based high yielding rice varieties. The latter provided ample opportunities for increasing cropping intensity depending on the resources available and developed, indicating the need for development of management technologies for intensive and efficient use of resources and inputs to realize the yield potential with enhanced factor productivity of evolved rice varieties and the production system. Combination of cultural and input management strategies involving identification of nutrient efficient varieties, integrated management of nutrients with balanced use of inputs, appropriate crop residue and organic/ green manuring practices, use of modified fertilizers and production potential of cropping systems and their sustainability were some of the areas of research pursued.

The unique system of soil puddling for rice establishment, weed and water control not only benefited rice growth and nutrition, but also favoured loss of nutrients like nitrogen through several means from the system resulting in low N use efficiency. Rice derives more than two-thirds of its total N from native soil pool and about 25-35 per cent from the applied fertilizer N. Nitrogen losses through volatilization and leaching accounted for about 50 per cent from fertilizers such as urea. Coating of urea with suitable materials to control transformation of applied N in soil reduced N loss and increased its utilization by rice. Neem cake-coated urea (NCCU) applied as basal dose performed better than split-applied prilled urea under uncontrolled water situations in diverse soil types. Neem-cake possesses both urease and nitrification-inhibition properties, and a 10-15% higher efficiency through NCCU than prilled urea. Placement of fertilizer N in the reduced zone of soil decreased gaseous loss and improved use efficiency of the applied N. Urea super-granules (USG) developed for placement at desired depth, i.e. 10-15 cm, were extensively tested across the country. The field trials indicated 6 to 30% higher efficiency due to basal placement of USG over the conventional split application of prilled urea. Subsurface application of urea solution in the root zone of rice 10 days after transplanting by an indigenously fabricated applicator was also found equally effective in improving use efficiency of applied fertilizer N. Under controlled irrigated systems application of N fertilizer in 2 or 3 split doses depending on the duration of the crops to match with plant requirement of modern HYVs, preferably incorporating basal dose in the soil and top dressing after draining water improved N use efficiency. About 26 per cent of N efficiency was attributed to poor water control generally encountered in rainfed low land systems. Real time N management guided through chlorophyl meter or leaf colour chart enhanced N use efficiency substantially and saved 20- 30 per cent of N fertilizer .

Water management showed strong interaction with the efficiency of applied N as well as that of water. While rotational irrigation at 7 day interval resulted in significant yield reduction and increase in N loss through ammonia volatilization showing seasonal variations, a 4- day cyclic irrigation optimized water use with no loss of grain and applied N. A net saving in irrigation water to the extent of 18-24 per cent could be achieved in transplanted irrigated rice with rotational irrigation resulting in substantial improvement in water use efficiency. Rice varieties differ in their response to nutrient and water management indicating importance of choice of varieties for integration to ultimately reach high input and resource use efficiency. Rice varieties like Swarna, Rasi, IET 15342, IET 11771, IET 12884 and hybrids were observed to be more efficient in utilizing nitrogen while Rasi, IET 12884 and hybrids recorded higher water use efficiency by 22 per cent over continuous submergence.

Grain yield response to phosphorus application is substantial in most of acid and heavy clay soils. Dipping of rice seedlings in super phosphate soil slurry before transplanting or nursery application of P proved effective in terms of cost reduction with no yield loss and saved nearly 40 per cent of P fertilizer, while as P source, DAP or ammonium polyphosphate (APP) proved superior to SSP for their higher P use efficiency. Application of mixture of phosphate rock and SSP or phosphate rock alone (applied 2-3 weeks before planting or sowing) were efficient P sources for rice particularly in acid soils of pH 6.0 or below. Varieties such as Rasi, Vikas etc, showed considerable tolerance in low soil P fertility and also responded to P application indicating choice of such varieties for different levels of crop management.

Management of potassium (K) involves its application in single or split doses depending on soil type and crop / variety demand. In high rainfall areas with coarse-textured soils, split application of K (half at planting and half at panicle-initiation stage) gives higher efficiency. Based on the research findings, split application of K in rice has been recommended in Andhra Pradesh, Kerala, Orissa and Uttar Pradesh. Benefits of split application of K in rice have also been realized in West Bengal and North-Eastern hills regions. The productivity of rice hybrids is improved by split application of K (basal and at PI stage) to support high grain filling demand of the hybrids. In intensively cultivated rice crop systems with total productivity of more than 10-12 t/ha it is preferable to apply higher (25-50%) dose of K to maintain nutrient balance in the system and prevent its depletion for sustaining long term productivity of the system. Recycling of rice residues not only supplied substantial K into the system thereby saving fertilizer K, but also maintained favourable soil quality and its productivity.

Almost half of the rice growing soils are deficient in Zn. It was found that Zn deficiency in rice can be alleviated by applying 50 kg $ZnSO_4$/ha at transplanting once in 2 or 3 seasons. However, the optimum rate varies with the type of soil and its deficiency status, variety and method of Zn application. Rice yields decline appreciably with a 10-20 days delay in Zn application on Zn-deficient soils. Broadcasting and mixing of $ZnSO_4$ into soil is the most efficient method. Mid-season correction can be done with foliar sprays of 0.5 % $ZnSO_4$ solution. In salt affected soils it is advisable to double the dose of $ZnSO_4$.

Scarcity of labour and increasing wages make the manual weeding less efficient and uneconomical. Several herbicides like butachlor, oxadiazon, anilophos and oxyflurofen were found effective in controlling common weeds in lowland rice. Recent research has shown that use of herbicide combinations like butachlor + 2, 4-D Na, anilophos + 2, 4-D EE, pretilachlor + 2, 4-D EE, bensulfuron- methyl + butachlor etc. control wide spectrum weed flora and were cost effective in transplanted rice. Butachlor + safener, Pretilachlor + safener or Pyrazo sulfuron ethyl gave best control of weeds in direct-sown rice under puddle conditions.

Among the several labour saving methods of cultivation being developed and adopted are direct seeding through broad casting or through use of drum seeder and mechanical transplanting which are becoming popular. Combine harvesters are also being used increasingly that saves time and labour cost of harvesting.

Rice crop established by broadcast sowing of seeds under puddled conditions generally suffers from uneven growth and gives lower yields than a transplanted rice crop. Line sowing of sprouted seeds at 20 cm spacing with a row seeder produced excellent crop stand and similar yields to that of transplanted crop. Varieties like 'Vikas', 'IET 9994', 'IET 10402' and 'Jalapriya' performed well.

Crop protection through integrated pest management

Major focus of recent research in field of crop protection has been on development of specific pest and multiple pest resistant rice varieties for different rice ecologies, studies on variability of pest populations, identification of new effective and eco-friendly chemicals, development and evaluation of alternative strategies for regulation of pest populations, development of weather based pest forewarning systems and formulation and on farm evaluation of integrated pest management packages for various situations.

New sources of broad spectrum resistance against insect pests and their biotypes have been identified in a concerted network program. The results of this multi-location evaluation covering 15,820 accessions of germplasm during 1993-99 period identified 276 accessions resistant to blast, 50 to bacterial leaf blight, 28 to sheath blight, 282 to brown planthopper, 74 to stem borer and 395 to gall midge. Utilising some of these sources of resistance breeding for multiple pest resistance was intensified. Some of the recently release pest resistant varieties display multiple resistance.

Effective, economic and eco-friendly insecticides for need based application in the managements of insect pests have been identified. These include fipronil (75 g a.i. ha^{-1}), carbosulfan and chloropyriphos (1.0 kg a.i. ha^{-1}) as granular applications and sprays of fipronil (50 g a.i. ha^{-1}) against pest complex and of thiomethoxam and imidacloprid (25 g a.i. ha^{-1}) against leaf and planthoppers. Commercial neem formulations were found to be moderately effective against BPH, WBPH, GLH and leaf folder under greenhouse conditions.

Among the newer formulations of fungicides evaluated capropamid 30 SC for blast, thifluzamide 2 SC for sheath blight and Opus 12.5 SC for false smut were highly effective. Procarb and copper hydroxide (3 g/1) were effective against false smut. Isoprothiolane, kasugamycin, tricyclazole and carpropamid were identified as effective and blast specific fungicides and Validamycin, thifluzamide, and hexaconazole as sheath blight specific fungicides. Among biopesticides, Achook and Neemgold for blast control and AFF-3 for sheath blight control appeared promising.

Biocontrol agent like fluorescent *pseudomonas* strain controlled sheath blight disease either alone or in combination with carbendazim. A combination of fluorescent *Pseudomonas* sp. and *Bacillus* sp. was also effective in controlling sheath blight. But *Pseudomonas florescense* was found ineffective in reducing blast and in preventing yield loss. An entomopathogenic nematode *Rhabditis* sp., was found to be potential against stem borer and leaf folder. *Trichogramma japonicm* and *T. chilonis* has shown promise against stem borers and leaffolders.

Use of sex pheromone in population monitoring and pest control through mass trapping and mating disruption has been demonstrated on large scale FLDs and on farm trials.

Effective integrated disease management strategies against blast and sheath blight involved cultivation of resistant varieties and need based fungicide application. For BLB it involved cultivation of resistant varieties and judicious nitrogen application. IPM package for insect pests under rainfed rice production systems consisted of resistant variety, balanced fertiliser application, release of *Trichogramma* egg parasitoids, use of pheromone traps against yellow stem borer and need based application of pesticide as the situation demands. Such a package effectively checked pests and resulted in increasing net profits of the farmers.

Conclusion

In view of the growing demands due to ever increasing population, it is imperative that rice production and productivity need to be enhanced through application of modern tools of science. Anticipatory, strategic and basic research on rice needs to be strengthened with financial and policy support to meet the future challenges of climate change, water crisis and land and labour shortages. It is also equally important to make rice cultivation more profitable and less labour dependent. Paradigm shift is needed in the way we grow rice in the backdrop of declining resources, escalating labour cost and deteriorating soil health. 'Grow more with lesser inputs' would be the way forward for sustainable rice production in the coming decades.

Strategies for Enhancing Production and Productivity of Rice in India

K. Srinivasa Rao

Rice is the most important staple food crop in India occupying maximum area under cultivation and contributing nearly 44% of the total food grain production and provides 43% calorie requirement for more than 70% indians. Rice production in India has transformed from chronic stage with 30 million tones in 1965 to sustainable strong surplus level of 104.2 million tones in 2011-12. A critical analysis of the factors contributing for the increase in production suggest that area expansion and extension of area under irrigation contributed to the extent of 8.3% and 15% respectively while remaining 76.7% has come from varieties and fertilizer inputs and adoption of improved crop and pest management practices. Though there has been marked increase in productivity of rice from 1.10 to 2.33 t/ha through 1965-2011, it is still much below the yields ranging from 3.70 – 8.00 t/ha achieved by some of the countries like Egypt, China, Japan, and Korea. Currently India is not only self sufficient in food production but also emerged as the largest exporter of rice which exported 7.1 million tonnes of rice (both Basmati and non basmati) during 2011-12. Further to sustain the present level of self sufficiency keeping face with the present level of population growth, yield improvement of not less than 2.5 to 3.5 percent annual growth rate is required to add at least 2.0-2.5 million tones of additional rice per annum.

As the area under rice is stabilized at around 44 million ha, the only option left for achieving future production target is yield improvement. The global food projections for 2020 A.D. made by International Food Policy Research Institute indicate that the demand for rice will increase 60%. For low-income countries of South and South-east Asia, rice demand may double within the next 40 years. India's rice production target for 2025 is 140

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million tones. To meet this, it is immensely necessary to increase the productivity levels without adversely affecting the natural resource base. Achievement of the targeted production would be an uphill task in the coming decades with the shrinking natural resource base, deteriorating soil health and soil productivity, declining input use efficiency, plateuing of yields in irrigated ecologies and lack of a major yield breakthrough in rainfed ecologies. However, it is not uncommon to produce higher yield of paddy up to 6 t/ha in medium to lowland situation and 3 t/ha in upland by adopting improved production technologies coupled with adoption of situation specific high yielding varieties. Nevertheless, there is still large yield gap between the present average rice yield and the yield potential of modern rice varieties developed for different ecosystems. Therefore, the aim is to reduce this gap and to explore the possibilities of increasing the productivity levels in all the rice growing ecosystems substantially through proper adoption of varietal, technological and socioeconomic/policy measures. To achieve the targeted production in the next millennium following strategies are suggested.

Using hybrid technology in potential and target areas

Despite of increase in rice production and productivity over last few decades, there is plateuaing of yield levels in high yielding varieties. In such situation, hybrid rice is one of the potential, practically feasible and readily adoptable technologies to enhance production and productivity of rice. So far Forty-six hybrids (29 from public sector and 27 from private sector) have been released for commercial cultivation for different ecologies and suitable agronomic package of practices have been standardized to enhance the productivity. The popular hybrids are PA 6444, PHB 71, Pusa RH 10, KRH 2, Rajlaxmi, Sahyadri, DRRH 2 etc are cultivated predominantly in eastern UP, Bihar, Jharkhand, Chhatisgarh and Madhya Pradesh covering about 1.3 m ha of area (3.0 % of total rice area). These hybrids have yield advantage of about 1 t/ha over high yielding (check) varieties without major differences in input cost and labour requirement. Recently the CRRI has developed hybrid CRHR32, the first long duration hybrid with moderate resistance to RTD, sheath blight, GLH and leaf blast and was released as CR Dhan 701 by CVRC for irrigated and shallow lowlands of Bihar and Gujarat.

Extension of unutilized areas during boro season in Bihar, West Bengal and Assam with provision for tube-well irrigation

Major portion of the increased rice production has to come necessarily from the high rainfall with low irrigation potential areas of eastern regions in about 8-10 million ha. Productivity increase of *boro* rice may step up rice production in this zone in the years ahead. In this area predominantly monocrop of rice is practiced. With the anticipated provision of construction of tanks, ponds, shallow tube wells, winter rice (*boro* rice) can be popularized. Investment on developmental infrastructure like irrigation will be rewarding to boost yields of *boro* rice in the states of Bihar, West Bengal and Assam. The irrigation will also help in raising leguminous crops in the rice-rice cropping system, which may also break the life cycle of insect pests.

Adoption of location specific high yielding varieties

Variety being the major missing link in most ecologically harsh environments of Eastern India, the performance of currently available high yielding rice varieties are to be demonstrated along with package of technologies through organized compact block demonstrations. This will help to enlighten the extension personnel working in the area about the potential of all such varieties and facilitate a rapid varietal dissemination process through seed exchange in the areas concerned.

Now a number of high yielding varieties suitable to the fragile rice ecosystems of eastern India are available which can replace the traditional types and can increase average yield levels to 3.0-3.5 t/ha. Newly developed high yielding varieties are resistant and are the most effective, economical and practical means of tackling the various biotic and abiotic stresses experienced by rice crop. Varieties like Anjali, Vandana, Kalinga III, Heera, Sneha, Annada in rainfed uplands (with yield potential of 3.0-4.0 t/ha); Ratna, Saket-4, Udaya, Radha and Chandrama, Satya Krishna, Chandan in irrigated lands; Lunishree ,Sonamani, Luna Sampat and Luna Suvarna in coastal saline lands; Savitri, Moti, Pooja and Tulasi in rainfed lowlands (shallow)., Gayatri and Sarala in rainfed lowland (medium deep) and Durga in deep water areas showed promise with considerable yield advantage. The coarse grain varieties Savitri and Gayatri, which are photosensitive and with good submergence tolerance produce yields of 5-6 t/ha in shallow low lands. Gayatri is also performing well in intermediate lowlands. The recently released rice varieties Varshadhan and Hanseswari in Semi deep water areas, Naveen, Satya Krishna, Chandan in Irrigated areas; a basmati mutant, Geetanjali and a short grain aromatic rices Ketekijoha, Nua Kalajeera, Dhusara, Chinikamini have already shown signs of promise and are being rapidly accepted by the farmers. Rice varieties developed by using Marker-assisted breeding method viz. Swrna Sub 1 (which can give grain yield of 3,5 t/ha even after remaining completely submerged for 2 weeks) and a drought tolerant Sahabhagi Dhan (released for drought affected areas of Jharkhand and Orissa yield 3-4 t/ha in 90 to 100 days and is resistant to leaf blast, moderately resistant to brown spot and sheath rot and is also moderately resistant to stem borer and leaf folder) helps to boost productivity.

Raising production-input efficiency

Productivity gains can also be achieved by improving the efficiency of the production inputs used in rice farming. They are better land preparation to ensure optimum crop stand, more timely planting of appropriate crop varieties, balanced fertilization, control of menacing weeds, disease and insects and proper rain and irrigation water management.

Establishment and sustenance of plant population

Establishment proper crop stand is the immediate necessity in the ecologically harsh rainfed environments for obtaining sustainable rice production. Timely sowing, which determines the initial crop stand and its subsequent establishment in the field, is a non-monetary input, which is of great importance and relevance in rainfed rice cultivation. It varies with the onset of monsoons in different regions, type of land situation, availability of resources like seed, fertilizer, bullock power, etc. For better crop stand following measures have to be followed in different land situations.

- ***Rainfed uplands:*** Farmers traditionally follow broadcasting seeds, as it is convenient. However, this practice often results in inadequate crop stand due to surface placement of seed. Hence, in order to derive maximum benefit from the applied resources, it is essential that adequate plant stand is established. Dibble seeding behind the plough (or drilling with seed drill) with a spacing of 20 cm between rows and 10-15 cm between hills with 8-10 seeds per hill proved to be better in establishing adequate crop stand and ultimate yield. A seed rate of 300-400 seeds/m^2 (75-100 kg/ha) is adequate to establish adequate crop stand.

- ***Rainfed lowlands:*** The time of sowing is determined by the occurrence of summer rains, land situations and energy considerations. Studies conducted at CRRI, clearly indicated that early sowing in May is advantageous, since the crop germinates with the rains and grows sufficiently tall to tolerate the adverse impact of submergence and flash floods. Since the time factor is crucial in lowlands sowing should be completed as far as possible before the end of May itself. Delayed sowing may be risky and results in low yields.
  In order to establish adequate crop stand, early seeding in lines at an inter-row spacing of 20 cm and 15 cm between hills either by drilling or dibbling behind the plough at 5-6 cm depth using 400-600 seeds/m2 has been recognized as the key management practice for higher productivity of rainfed lowland rice. Even though direct seeding is superior to transplanting, it is some times not feasible due to early land submergence. In such cases, planting has to be done early in July with a spacing of 20x15cm if water depth is favourable and initial submergence is unlikely. Otherwise if water depth were higher it would be appropriate to go for aged seedlings of 50 - 60 days. To tolerate the adverse effect of higher water depths and flash floods, seedlings planted in the main field should be vigorous and robust enough. Fertilizer application to nursery beds helps in producing such healthy seedlings. A fertilizer application @ 100 kg N/ha and 40 kg each of P_2O_5 and K_2O/ha to the nursery was found to produce seedlings with well developed root system, tall height, higher dry matter production, tillers/plant and N concentration in the plant tissues at planting compared to the poor and slow growth of unfertilized seedlings.

Developing contingency crop planning under severe stress conditions

Uncertainty characterizes rainfed rice farming in India. Unpredictable production constraints limit the crop performance. Keeping this in view, contingency crop planning should be available at doorstep to tackle the adverse situation.

- ***Vegetative propagation:*** Excess water accumulation due to heavy premonsoon rain rules out the usual practice of direct seeding. Farmers perhaps have no other alternatives but to go for planting under this situation. Instead of conventional method of transplanting using nursery-raised seedlings, planting with seedlings/vegetative tillers uprooted from a previously direct-sown crop is found beneficial. In addition to their utility in planting under excess water environment, these tillers may suitably be employed for mid season correction of the crop stand suffered from crop losses following prolonged submergence during the growing period.

- ***Late planting:*** In shallow lowlands often transplanting are delayed upto September despite favourable water regimes due to several reasons like energy problems, cultivation of jute pre *kharif* crop in Jute-rice system, and failure of main rice crop due to flash floods. In such cases varieties suitable for delayed planting and having tolerance to tungro virus are preferred. The varieties promising for such situations are Gayatri, Durga and Padmini with a yield potential around 4.0t/ha. These varieties are to be planted using 60 days old seedlings adopting a closer spacing of 15 cm x 15 cm and higher N level of 80 kg/ha.

- ***Double transplanting:*** This method consists of raising seedlings in primary seedbed, transplanting in secondary seedbed and finally transplanting in main field. This method is already in practice in some parts of Eastern U.P. and Bihar.

- ***Mixed cropping:*** Growing varieties together having dissimilar maturity is another contingency plan rendering an insurance against the total crop failure compensating for the losses likely to be caused therein. Mixed cropping constituting the early and late maturing varieties together have the advantages of overcoming the devastation caused due to flooding appeared at the growth stages. Under the circumstances of initial crop submergence causing failure of early duration crop, the late maturity group can be reaped well and *vice versa*. On the other hand, the season experiencing no crop failure can offer the yield of both the crops; nonetheless, stand establishment achieved therein can contribute about 18 - 20% more yield over that procured from late maturity variety alone.

- *Foliage pruning:* The crop by virtue of its growth habit has the propensity to elongate with the increase in water level ensuring its sustenance over the complete crop submergence. Therafter, heavy top foliage makes them vulnerable to lodge prematurely immediately after the recession of floodwater. The situation becomes more critical when crop lodging happens at the stage of flowering. Pruning of the top foliage helps the crop to restrict their vertical growth and subsequently prevent lodging for a considerable period of time. Studies at CRRI suggests foliage pruning preferably at the collar region at 80 - 100 days growth of semi-tall to tall varieties is advantageous. Moreover, in no way it impairs the usual growth and productivity of the crop. On the contrary, it would have additional benefit providing a nutritious green fodder to the cattle, particularly at the places having dearth of fodder during that period.

Integrated crop management (ICM)

Integrated Crop management practices, involve the application of best management practices such as planting young seedlings, judicious use of water and nutrient, integrated pest management and the like. On farm studies conducted elsewhere on ICM in India, indicated yield enhancement by 1.4 to 1.5 t/ha, 50 per cent reduction in the nursery management costs, 10 per cent reduction in management cost and water saving by 25-30 per cent and increase in overall profit to farmers. Farmers have to be trained to adopt ICM practices so as to enable them to produce more rice with lesser and lesser inputs. Other knowledge-based techniques such as Judicious use of water, site specific nutrient management practices, LCC based N management etc. will help the farmers to produce quality produce at lesser cost and which will help become more competitive in national and international markets

Integrated nutrient management (INM)

Integrated nutrient management(INM) is one of the major strategies to increase crop production and the productivity. INM includes combined use of various sources of nutrients, viz., chemical, organic and bio-fertilizers. Incorporation of 5 - 10 t/ ha/year of compost/FYM/including poultry droppings along with chemical fertilizers improve crop yield and soil health. Wherever possible, incorporation of crop residues preferably legumes should be encouraged. Green manuring with Dhaincha supplies around 60 kg N/ha which is almost adequate to sustain a rice crop in relatively fertile soils whereas in poor soil it may be supplemented with top dressings of N at 30-40 kg N /ha. Wherever good water management is possible, Azolla dual cropping/ incorporation is recommended with supplemental application of N and P. Use of other bio-fertilizers such as BGA, Azospirillum, phosphorus solubilizing micro-organisms should be encouraged with a good quality control support. Bio-fertilizer use should also be popularized for other crops in the rice based cropping system. For achieving higher efficiency of fertilizers, particularly of N, it should be well incorporated, band placed or deep placed depending upon the rice cultures practice. For deep placement, step should be taken to manufacture and supply urea super granules/tablets especially in rainfed lowland conditions of eastern India.

Integrated weed management (IWM)

Judicious combination of following component practices should be followed for evolving an effective integrated weed management system in rainfed rice areas.

- Cultivate the land instead of keeping it fallow after the harvest of the previous crop of rice. Summer tillage helps in exposing the vegetative propagates and rhizomes of the difficult weeds like *Cyprus rotundus* (nut grass) and control them effectively.

- Follow stale seedbed method wherever feasible. Prepare the land well pulverized and level it. Keep it in that condition for some time i.e. at least 10 days during which time a flush of weeds germinate; Then take up a shallow cultivation to remove those weeds; Then take up sowing of rice; The weed problems afterwards are minimized with this system to a considerable extent.

- Grow weed competitive cultivars for example: Vandana, Kalinga III, Vanaprabha, RR151-3

- Use higher seed rate i.e.75-100 kg/ha

- Encourage row seeding either behind the plough or using a seed drill.

- Apply nitrogen in splits after removing the weeds. Otherwise weeds take away the nutrients.

- Use mechanical weeders like finger weeder, wheel hoe or wheel cum finger weeder for controlling weeds in between the lines and supplement it with hand weeding to remove weeds in between the plants.

- For controlling wild rice in lowland ecosystem follow row seeding rather than broadcasting, adopt puddling and transplanting instead of direct seeding, remove wild rice types and burn them.

- Application of herbicides is the cheapest alternative to manual/ mechanical weeding. In irrigated transplanted rice application of early post-emergent herbicide (3-5 DAT) viz., pyrazosulfuron ethyl (20 g ha^{-1}) helps to suppress the newly emerged sedges and broad leaf weeds. In case of severe infestation of grassy weeds at early stage, spraying of bispyribac sodium (35 g ha^{-1}) at 12-15 DAS/T is recommended. Among post-emergent herbicides, almix (8 g ha^{-1}) can be applied against sedges and broad leaf weeds at 15-18 DAT and bensulfuron methyl + pretilachlor (londax power granule) at 10 kg ha^{-1} against mixed population of grassy weeds, sedges and broad leaf weeds at 8-10 DAS/T.

- In direct wet seeded rice, Post-emergence application (at 8-10 DAS) of bensulfuron methyl + pretilachlor (londax power granule) at 10 kg ha^{-1} helps to control broad spectrum of weeds. Almix (4 g ha^{-1}) applied at 15-18 DAS is found effective for controlling the dominant sedges and broadleaf weeds in early sown crop. Early post-emergent herbicides like pyrazosulfuron ethyl (20 g ha^{-1}) applied at 3-5 DAS helps to suppress the weeds effectively in late-sown crop. In case of severe grassy weeds infestation, post-emergence application of bispyribac sodium (35 g ha^{-1}) at 12-15 DAS is found effective.

- In rainfed uplands application of bispyribac sodium (35 g ha^{-1}) at 12-15 DAS is recommended for suppressing the grassy weeds and sedges effectively. Late emerging weeds, if any, can be controlled by operating a finger weeder within rows at 30 DAS. Mechanical weed control by operating finger weeder at 15-20 DAS combined with hand weeding for removal of unwanted plants within rows serves as alternative method of chemical weed control. It also helps for better aeration as well as root encourage in rainfed uplands.

- In rainfed lowland, application of early post-emergent herbicide, pyrazosulfuron ethyl (20 g ha^{-1}) is found effective for suppressing sedges and broadleaf weeds at the beginning when applied 3 days after transplanting (DAT). Spraying of bispyribac sodium (35 g ha^{-1}) 12-15 DAT is found effective against grassy weeds. In case of heavy incidence of mixed weed population, application of bensulfuron methyl + pretilachlor (londax power granule) shows very good control when applied at 10 kg granule ha^{-1} by mixing with sands at 5-8 DAT.

Integrated pest management (IPM)

To combat dynamic pest and disease problems under intensive rice production system, location specific IPM strategies utilizing the most appropriate combination of the available component technologies viz., pest resistant varieties (Gall midge - Shakti, Neela, Shaktiman, Kakatiya, Sarsa, Phalguna., BPH - Udaya, Vikramarya, Sonasati., Stem borer - Ratna., Gundhi bug - Sneha., BLB - Savitri, Gayatri, PR 4141, Deepti, IR 20, Govind, Ratna, PR 109., RTV - Pusa 33, Vikramarya, IR 36., Blast - Rasi, Poorva, Jaya, Bhagavati, Annapurna, Annada, Udaya, IR 36), adoption of cultural practices (Stubble burning, summer tillage, Use of modern levels of N & Balanced fertilization, eradication of alternative hosts- weeds, timely planting, Use of quality seed with seed treatment), conservation of natural biological control agents and use of sex pheromones (for monitoring and direct control by mass trapping particularly for yellow stem borer), rationalized use of pesticides (Carbofuran for control of stem borer, BPH and gall midge., Other insecticides monocrotophos, Carbaryl etc. Important fungicides- for treatment of most fungal diseases- Bavistin, Ceresan. Use of fungicides like Hinosan and Bavistin. For RTV control- Use of carbofuran, alternated use of synthetic pyrithroids like Cypermethrin for control of vector population which spread RTV) based on monitoring have been utilized effectively in the pest management.

Scientific water management

Water usage in the current irrigated rice production system is extremely high. It takes about 3000-5000 liters of water to produce 1 kg of rice. This profligates usage of water in irrigated rice production making it unsustainable. With the current rate of water usage, maintaining productivity in many currently irrigated areas will be difficult unless more water-efficient rice production technologies suitable for irrigated areas are developed. According to estimates of IRRI, a 10% reduction in water use for rice irrigation would free 150 billion cubic meters (m3), or 25% 0f total fresh water used in Asia for non-agricultural purposes. Reducing water inputs to irrigated rice will also result in significant environmental benefits. Some of the water efficient rice production technologies in irrigated areas are

- ***Aerobic rice:*** Growing rice with aeration or under non-flooded condition is termed as aerobic rice. In other words cultivation of high-yielding rice varieties in direct-sown, non puddle, aerobic soils under irrigation is called as aerobic rice. With the new aerobic rice technology, it would be possible to get reasonably good yields with only 2-3 irrigations, thus saving 30-40 per cent of water. Investigations carried out by CRRI and others on aerobic rice cultivation have indicated that a satisfactorily high yield can be obtained with significant amount of water savings. However, in order to harness the full potential of aerobic rice production system, it is imperative to evolve aerobic rice genotypes with enhanced efficiency to take up iron and other micronutrients, ability to produce high productive tillers and low spikelet sterility under aerobic conditions and develop better crop management strategies to tackle weeds, nematodes and iron deficiency. Collaborative research between IRRI and NARS resulted in identification of rice varieties that resist aerobic yield decline, tolerating continuous cropping in dry soils

- ***System of rice intensification (SRI):*** SRI is another emerging water saving technology, which can help the farmers to overcome the present water crisis. Initially developed in Madagascar, this technology is becoming popular in India. Infact, the slogan adopted for SRI cultivation "Grow more from less" aptly describes its usefulness to our farmers. Major changes in this system are lower seed rate (5 kg/ha), planting young seedlings of 10-12 days at wider spacing (20-25 cm), use of more organic nutrient source, regular weeding and using less water (no flooding). This system can save about 30-40 per cent of water and at the same time farmers can get higher yields.

- ***Alternate wetting and drying (AWD):*** In AWD system, conventionally transplanted (lowland) fields are allowed to drain between irrigations, retaining a water layer only during sensitive crop stages like flowering. AWD can reduce water usage by up to 15% with little yield loss. Adoption of AWD on a larger scale will require new varieties with more tolerance to dry soils. Numerous studies conducted on the manipulation of depth and interval of irrigation have shown that maintaining a saturated soil or alternate wetting and drying upto the flowering stage, compared with continuous shallow submergence, could reduce water applications to the field by 40 to 50 percent without significant loss in yield

Integrated multi-enterprise farming systems approach

Integration of various agricultural enterprises viz., crops, dairying, poultry, piggery, fishery etc. in farming become indispensable. If one think to make agriculture, a profitable profession, concerted efforts are needed to reorient the crop production systems towards integrated multi-enterprise farming systems. Such efforts improve farmer's income but also increase family labour employment, help recycling of farm wastes and judicious utilization and conservation of farm resources with environmental protection.

Diversification of crops and alternate land use system

In response to commercialization of agriculture, it will be important to shift from routine food grain production system to newer crops/cropping systems to meet ever increasing demand of pulses, oilseeds, fodder, fruits, vegetables and other commercial crops and make agriculture an attractive and profitable business. Emphasis on post-rice catch crops of pulses/oilseeds like lentil, linseed, toria, groundnut, castor and sunflower, wherever possible making use of the residual soil moisture.

Unbunded uplands are highly prone to soil erosion because of their undulating topography. Hence in these land situations, it is ideal to grow crops other than rice despite the fact that the farmers still grow rice only because of their affinity to it. The various alternative crops include fingermillet, different pulses and oilseeds. The inter-cropping system of groundnut and pigeonpea (4:1) could be also more suitable under this situation. Under bunded uplands which are considered more favourble from the point of view of moisture availability, the inter-cropping system of rice and pigeon pea (4:1) was found to be more remunerative and such a system also acts as an insurance against crop failures. Alternatively sequence cropping of rice followed by horsegram, safflower and blackgram also can be adopted. In rainfed lowlands also there is ample scope to grow a second crop after the harvest of lowland rice in November-December by utilizing the available residual moisture. The crops like sesame, wheat, linseed, sweet potato, mungbean, rajmah, cowpea and watermelon can be cultivated. The yield obtained from these crops can be considered as a bonus. Relay cropping i.e. sowing of the second crop in the standing crop of rice even before its harvest can be feasible with the crops viz., linseed, lentil, gram, black gram, greengram and lathyrus (kesari) are suitable.

Encourage farm mechanization in small & marginal farms by providing new as well as enhancing existing subsidies

Mechanization not only help the farmer to do the job effectively, efficiently and with less of drudgery but also helps in timely operations which is a non monitory input for increasing rice production. It also help him to reduce the production cost and crop losses to a certain extent. In the states of eastern India the number of small and marginal farm holdings is very large (95-96%). Therefore mechanization of small farms is important to increase production and productivity of this region. Hence, the mechanization of small farms can be taken up by providing loans and subsidy for power units, mechanical and animal type hand tools, bullock operated implements and machines, small pumps, pedal operated equipment, storage bins of metallic type, small processing units etc. Big and costly machines be provided or subsidized on community levels or custom services be provided where timeliness is very important. This will help in mechanization of small farms

Post-harvest technology, by-products utilization and rice based products

Post-harvest losses from harvesting to milling amount to about 25% of total rice grain harvested. More than 15% of grains could easily be saved from rats, pests, storage & fungi by using proper storage like improved galvanized steel storage silos etc., Rice milling standards need to be improved as milling yields determine the economic value of rough rice. Value addition through proper processing technologies will be the key for enhancing our domestic and export business with rice and rice products. Very little efforts have been made towards developing a market for rice based products which is potential source for income generation and employment in rural areas. Rice food products can be derived directly from rice grain, homogenized cooked rice grains, dry milled flour, wet milled flour and rice starch through modern processing techniques.

Strengthen technology delivery system through on farm / farmer participatory research

The complexity of production problems and environment demands, calls for speedy and efficient information dissemination/exchange service to reduce the time lag between technology generation and technology-adoption. For this, a strong 'researcher-extensionist-farmers linkage' at grassroots level is a necessity. It needs to be properly aligned and strengthened. There are still many improved agricultural technologies already available or at an advanced stage in research pipeline with potential of doubling and tripling the yields. These technologies should reach the targeted group of farmers for adoption. Fortunately, the untapped yield reservoir in various rice ecosystems is quite high.. Hence we must give high priority to bridge the gap between harvestable potential and actual yields in farmer's field by identifying and removing the constraints responsible.

Human resource development

Human resource development holds the key to break the stagnation in agricultural growth and productivity. In this direction steps should be taken to conduct Farmers' Field Schools (FFSs), development of techno agents and establishment at farmers groups, Farmers training on integrated crop management in command areas, exposure of farmers to improved rice cultivation practices like SRI and specialized training on seed production (both hybrid and inbreed) are vital to empower them.

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Growth in Production, Productivity, Costs and Profitability of Rice in India During 1980-2010

Parshuram Samal

Technological advances in agriculture and government policies have increased food availability in India during the past 45 years and made India self-sufficient in cereals production. Despite significant achievements in the past, we have been less attentive to some of the undesirable social and environmental consequences of our achievements (Tilman *et al.*, 2002 and Hazell, 2010). We are now in a good position to act on these consequences and to outline various policy options to meet the challenges ahead. The guiding principles of five-year plans in India are provided by the basic objectives of growth, employment and social justice. The Twelfth Plan has chosen 'faster, sustainable and more inclusive growth' as its central theme (Government of India, 2011). It has been realized that disparities among regions have increased and the gains of the rapid growth have not reached all parts of the country in an equitable manner (Government of India, 2006). Therefore, for growth to be more inclusive, it is necessary that the benefits of rapid growth be shared by different sections of the population and by all the regions of the country. It has been concluded by many studies that agricultural sector has the largest poverty reducing effect than any other sector of the economy (Fan *et al.*, 1998; Hazell and Ramasamy, 1991; Ravallion and Dutt, 1996; World Bank, 2007).

Foodgrains production is the most important activity in India, which provides income and employment to a larger section of the population. Analysis of data across the Indian states revealed a high degree of correlation between the extent of poverty and yield in fooodgrain production. Poverty is more acute in Odisha, Bihar and Madhya Pradesh, where foodgrain yield has remained low and growth has been slower than in progressive states such as Punjab and Haryana (Hossain, 1995). Among the foodgrain crops, rice is the most important in terms

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of area coverage, contribution to total foodgrains production and supply of calories in the diet. Rice provides about 30% of total calories in the Indian diet (Mclean *et al.*, 2002). Given that the country still has about 37% of its population below poverty line (Government of India, 2009), the growth in rice production and productivity is critical to the well being of millions of consumers as well producers. Further, the Indian rice production accounts for 21% to global rice production, thus, contributing largely to global food security. Therefore, further increase in productivity of rice is a major concern to the policy makers and other stakeholders in the development process.

Growth in population and economic prosperity are the two driving forces for increasing rice demand in India. According to the estimates of the national commission on population, India's population will be 1340 millions in 2021. It is estimated that the demand for rice will be 113.3 million tons by the year 2021-22 (Kumar *et al.*, 2009). In addition to this, India is exporting about two million tons of basmati rice per year, which earns valuable foreign exchange for the country. In order to achieve this target, the productivity of rice has to be brought to the level of 2.7 tons per ha, which is 2.2 tons presently. The present rate of production growth (1.27%) is below the population growth rate of 1.63 per cent. Therefore, the present deceleration trend in production and yield is a cause of concern and has to be reversed to meet the growing demand and also to meet the need of export markets. Moreover, the profit margin in rice cultivation has eroded making rice cultivation unattractive.

Against this backdrop, this study attempts to analyze the trends in rice production and productivity, growth rate in cost and profit in rice cultivation across Indian states, which will help in targeting appropriate policies to boost rice production and productivity in poorly performing states.

Data and analytical framework

The secondary data on area, production and yield of rice for the study was collected from various issues of the publication 'Agricultural Statistics at a Glance' published by Directorate of Economics and Statistics, Ministry of Agriculture, Government of India (DES) and Economic Survey, 2011-12 (Government of India, 2012) for 17 major rice growing states (Andhra Pradesh, Assam, Bihar, Chhatisgarh, Gujarat, Haryana, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Punjab, Tamil Nadu, Uttar Pradesh, Uttarakhand and West Bengal). These 17 states accounts for more than 96% of total rice area and production of India. The cost of cultivation data for the study was collected from the various issues of the publication 'Cost of Cultivation of Principal Crops of India' published by the DES. Cost of cultivation for the recent years (2004-05 to 2009-10) has been collected for 15 states (Andhra Pradesh, Assam, Bihar, Chhatisgarh, Haryana, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Odisha, Punjab, Tamil Nadu, Uttar Pradesh, Uttarakhand and West Bengal) from the office of the DES and used for this study. The data (area, production, yield, cost of cultivation and profit) for the newly formed states like Jharkhand, Chhatisgarh and Uttarakhand has been merged with Bihar, Madhya Pradesh and Uttar Pradesh respectively for comparison over years. Interpolation was done to fill the gap for the years, where cost of cultivation data was not available. Growth trends in cost of cultivation for both total cost (C2) and operational cost (A2+FL) were computed. Similarly, growth trends in profits over total cost (C2) and operational cost (A2+FL) were also computed. Cost and return data for Kerala state was available from the year 1997-98 onwards and these data was used for the analysis. Time series data for the two states *viz.* Maharashtra and Gujarat is not available before 2005-06 and therefore, the cost, profit and their trend analysis was not computed.

The average decadal figures on area, production and yield for 1980s (1980-81 to 1989-90), 1990s (1990-91 to 1999-2000), 2000s (2000-01 to 2009-10) and compound growth rates are computed for the major rice growing states. The triennium average figures were used for computing growth rates, which takes into account the year to year variability in rice production due to several biotic and abiotic factors. At all India level, the analysis was carried out up to the year 2010-11 based on the data availability. The log-linear functional form ($Y = a\ b^t$) was used to compute the growth rates. The disaggregated growth analysis for kharif and rabi/summer season was carried out in major states, where rabi/summer season production accounted for more than 10% of total production of the state. The trends in costs of cultivation and profit in rice cultivation across 12 states were studied using the data collected for the period 1980-81 to 2009-10. All the prices were converted into constant prices of 2009-10 using state specific consumer pricing index numbers for agricultural labourers for comparison, computation and reporting. The term yield and productivity was used interchangeably throughout the paper. The production and yield reported in the paper are in terms of milled rice.

Results and discussion

Growth in area, production and yield of rice

Rice is grown in two major seasons in India i.e. during kharif in all the states and rabi/summer in some of the states. Presently, kharif and rabi/summer rice accounts for 89% and 11% of total rice area and 85% and 15% of total rice production respectively at all India level. The growth experience over the last 30 years (1980-81 to 2009-10) at all India level shows that maximum production and yield growth was obtained during 1980s (Table 1). The production growth rate per year during that period was 3.43% mainly due to yield growth (3.14%). During subsequent periods, the yield growth has reduced to 1.26% during 1990s and 1.49% during 2000s, for which production growth has also decelerated. During 1980s and 1990s, the area growth was less and therefore, had less influence on production growth. The growth rate in area during 1990s was more in comparison to 1980s because of increase in area, both in kharif and rabi/summer season. However, during 2000s, the area growth rate became negative and decreased at the rate of 0.15% per year due to decrease in kharif season area. The growth in production during 2000s was 1.33% per year mainly due to yield growth (1.49%). Disaggregated by season, the area has declined at the rate of 0.30% per year in the kharif season during the last decade. However, during rabi/summer season, the area has increased at the rate of 1.35% per year. The production growth during the last decade (2000s) was mainly due to increase in kharif season yield growth at the rate of 1.54% per year. The rabi/summer yield growth was observed to be 0.63% per year only. The yield growth for the most recent 5 years for which data was available (2006-07 to 2010-11) shows that the yield rate has further decelerated to 1.18% per year from 1.49% observed earlier. This was observed because of faster deceleration in yield growth of rabi/summer rice than kharif rice.

Table 1. Growth in area, production and yield of rice in India (1980-2010)

Figures in percentage

	Area	Production	Yield
India (Total)			
1980s	0.27** (40.69)	3.43* (59.74)	3.14* (1465)
1990s	0.52* (43.21)	1.79* (80.04)	1.26* (1851)
2000s	-0.15 (43.41)	1.33** (89.19)	1.49* (2052)
2006-2010	0.10 (43.55)	1.27 (94.86)	1.18** (2178)
India (Kharif)			
1980s	-0.05 (38.40)	2.90* (54.22)	2.94* (1410)
1990s	0.24** (39.72)	1.38* (70.26)	1.13* (1768)
2000s	-0.30 (39.37)	1.23** (76.92)	1.54* (1952)
2006-2010	-0.21(39.08)	1.02 (80.87)	1.23*** (2069)
India (Rabi)			
1980s	5.73* (2.29)	8.63* (5.51)	2.71* (2366)
1990s	3.84* (3.49)	4.89* (9.77)	0.98* (2786)
2000s	1.35 (4.03)	1.97 (12.27)	0.63** (3031)
2006-2010	2.88** (4.46)	2.80** (13.99)	-0.08 (3135)

Figures in parentheses indicate area in million ha, production in million tonnes and yield in kg/ha;
*,** and *** indicate significant at 1% , 5% and 10% respectively.

The growth experience in area, production and yield of states in different periods are different and presented in Tables 2, 3 and 4. The growth rate in production was positive and significant in all the states under analysis except Kerala and Tamil Nadu during the last 30 years (1980-81 to 2009-10). There was continuous and significant decrease in area under rice in the state of Kerala, for which negative significant production growth was observed. However, yield growth in Kerala was positive and significant. The positive significant yield growth in Tamil Nadu was neutralized by negative significant area growth, for which the production growth was not significant during the period under consideration. Similarly, during the period 1990-91 to 2009-10, the growth rate in production was positive and significant in all the states except Kerala and Tamil Nadu. The negative production growth rate in Tamil Nadu was due to significant negative growth rate of both area and yield. The growth experience of different states was different in different time periods when decadal rice area and production was considered. The production growth was excellent for states like Punjab, Uttar Pradesh, West Bengal and Madhya Pradesh during 1980s due to significant growth in productivity and/or area. Moderate production growth has been achieved by the states like Bihar, Odisha, Haryana, Assam, Tamil Nadu and Andhra Pradesh mainly due to increase in growth in productivity. During 1990s, the overall production growth rate at all India level was 1.79% per year. This was due to significant growth rates (> 1%) in production in states like Haryana, Karnataka, Gujarat, Bihar, Uttar Pradesh, Punjab, West Bengal and Assam. This production increase was mainly due to increase in yield growth except in the Haryana state. Haryana did well due to maximum expansion of area only. States like Andhra Pradesh, Madhya Pradesh and Maharashtra registered low level of growth during the period. The production growth rate in Odisha was negative during 1990s due to negative growth rate in yield. During 2000s, the production growth has further slowed down due to area reduction in many states. The states which have registered significant area increase were Gujarat, Punjab and Maharashtra due to significant yield growth. Gujarat registered highest production growth rate per year (8.04%) due to increase in both yield and area. The other states which did fairly well in increasing production were Odisha, Haryana, Madhya Pradesh, Punjab and Maharashtra due to significant yield growth.

Table 2. State wise growth trends in area of rice (1980-81 to 2009-10)

Figures in percentage

State	1980s	1990s	2000s	Growth 1980-81 to 2009-10	Growth 1990-91 to 2009-10
Andhra Pradesh	-0.20 (3727)	-0.38 (3839)	0.36 (3672)	0.02	-0.32
Assam	0.68* (2330)	0.16 (2507)	-1.26* (2454)	0.27*	-0.22***
Bihar	0.07 (5180)	-0.27 (4988)	-0.39 (4873)	-0.25*	-0.22
Gujarat	0.05 (505)	1.73* (608)	2.55* (667)	1.47*	1.23*
Haryana	2.12* (545)	5.55* (829)	0.96 (1061)	3.38*	3.13*

State	1980s	1990s	2000s	Growth 1980-81 to 2009-10	Growth 1990-91 to 2009-10
Karnataka	0.09 (1149)	1.61* (1328)	0.53 (1373)	0.87*	0.61**
Kerala	-3.59* (696)	-4.90* (463)	-4.51* (279)	-4.42*	-4.91*
Madhya Pradesh	0.43* (4945)	0.90* (5298)	-0.37* (5407)	0.47*	0.30*
Maharashtra	-0.14 (1505)	-0.62* (1526)	0.18** (1521)	0.04	-0.08
Odisha	0.31 (4259)	0.23** (4495)	-0.08 (4438)	0.23*	-0.02
Punjab	5.12* (1632)	2.36* (2234)	0.60* (2630)	2.67*	1.81*
Tamil Nadu	-2.82* (2153)	1.42** (2152)	-0.90 (1847)	-0.87*	-0.88**
Uttar Pradesh	0.17 (5332)	0.65* (5619)	-0.17 (5987)	0.59*	0.65*
West Bengal	1.13* (5299)	0.50* (5858)	-0.22** (5774)	0.53*	0.03

*, ** and *** indicate significant at 1%, 5% and 10% respectively.

Table 3. State wise growth trends in production of rice (1980-81 to 2009-10)

Figures in percentage

State	1980s	1990s	2000s	Growth 1980-81 to 2009-10	Growth 1990-91 to 2009-10
Andhra Pradesh	1.73*** (8012)	0.60 (9726)	1.99 (11141)	1.79*	1.31*
Assam	1.94* (2548)	1.61* (3365)	-1.08 (3707)	1.83*	0.90*
Bihar	3.50** (5273)	3.07*** (6244)	0.41 (6740)	1.59*	1.20**
Gujarat	-0.49 (624)	3.16* (891)	8.04* (1133)	3.16*	2.95*
Haryana	2.65* (1383)	4.70* (2167)	4.01* (3082)	4.09*	3.87*
Karnataka	-0.41 (2238)	3.73* (3148)	1.21 (3422)	2.07*	1.55*

State	1980s	1990s	2000s	Growth 1980-81 to 2009-10	Growth 1990-91 to 2009-10
Kerala	-2.61* (1181)	-4.12* (926)	-3.04* (636)	-3.05*	-3.68*
Madhya Pradesh	4.16* (4292)	0.60 (5644)	3.15** (5794)	1.91*	0.86**
Maharashtra	-0.89 (2176)	0.84** (2396)	1.65** (2416)	0.68*	0.49**
Odisha	3.34* (4555)	-0.78 (5774)	4.33* (6319)	1.85*	0.77***
Punjab	7.47* (4925)	2.58* (7430)	2.71* (10000)	3.93*	2.96*
Tamil Nadu	1.86*** (5106)	1.56*** (6716)	-2.64 (5353)	0.37	-1.44**
Uttar Pradesh	6.85* (7211)	2.81* (10887)	-0.23 (12045)	3.13*	1.36*
West Bengal	5.76* (8149)	2.39* (12302)	1.04* (14498)	3.24*	1.81*

*, ** and *** indicate significant at 1%, 5% and 10% respectively.

Table 4. State wise growth trends in yield of rice (1980-81 to 2009-10)

Figures in percentage

State	1980s	1990s	2000s	Growth 1980-81 to 2009-10	Growth 1990-91 to 2009-10
Andhra Pradesh	1.94* (2141)	0.94* (2530)	1.66* (3021)	1.77*	1.63*
Assam	1.25* (1093)	1.46* (1342)	0.15 (1507)	1.55*	1.12*
Bihar	3.49* (1013)	3.40** (1248)	0.70 (1372)	1.84*	1.39*
Gujarat	-0.97 (1212)	1.36** (1462)	5.62* (1665)	1.67*	1.63*
Haryana	0.53* (2532)	-0.70*** (2641)	3.05* (2901)	0.69*	0.73**
Karnataka	-0.50** (1945)	2.10* (2363)	0.71 (2481)	1.18*	0.92*
Kerala	1.02* (1703)	0.83* (2005)	1.54* (2288)	1.42*	1.29*

State	1980s	1990s	2000s	Growth 1980-81 to 2009-10	Growth 1990-91 to 2009-10
Madhya Pradesh	3.72* (867)	-0.27 (1066)	3.53* (1072)	1.43*	0.56
Maharashtra	-0.80 (1443)	1.46* (1572)	1.44** (1587)	0.64*	0.56**
Odisha	3.03* (1065)	-1.00*** (1284)	4.44* (1421)	1.62*	0.78***
Punjab	2.23* (3006)	0.24 (3326)	2.10* (3797)	1.21*	1.14*
Tamil Nadu	4.82* (2397)	0.11 (3116)	-1.63 (2865)	1.23*	-0.60***
Uttar Pradesh	6.66* (1350)	2.16* (1934)	-0.04 (2008)	2.53*	0.69*
West Bengal	4.60* (1528)	1.88* (2099)	1.27* (2510)	2.71*	1.78*

*, ** and *** indicate significant at 1%, 5% and 10% respectively.

The major rabi/summer growing states are Andhra Pradesh, Assam, Karnataka, Kerala, Odisha, Tamil Nadu, and West Bengal. The growth trends of all the above states are analyzed for both the seasons and presented in Table 5. The kharif season production growth was found to be positive and significant during 1980s in three eastern states *viz.* Assam, Odisha and West Bengal due to significant yield growth. During 1990s, significant production growth was observed in Karnataka, Tamil Nadu and West Bengal only. In Karnataka, the significant production growth was due to increase in both area and yield, while in West Bengal it was due to increase in yield growth only. The increase in production growth in Tamil Nadu was due to area expansion. During 2000s, four states *viz.* Assam, Kerala, Odisha and West Bengal have shown positive and significant decrease in area during kharif season. However, due to significant yield growth, the production growth was significant and positive in Odisha and West Bengal. The production growth was positive and significant in rabi/summer season during 1980s and 1990s in all the states due to both yield and area growth except Karnataka, Kerala and Tamil Nadu (Table 5). In Kerala, the production growth was negative in all the 3 decades due to significant decrease in area. In Karnataka, the production growth during 1980s was not significant due to significant negative growth in yield. In Tamil Nadu, the area growth was negative and significant during 1990s, for which the production growth was also negative. During 2000s, only two states viz. Andhra Pradesh and Odisha recorded positive significant growth in production. The production growth was positive and significant in Andhra Pradesh due to significant yield growth, while in Odisha, the production growth was positive due to both area and yield growth.

Table 5. Growth trends in Kharif and Rabi/ summer area and production and yield of rice in seven major rice growing states (1980-81 to 2009-10)

Figures in percent

States	Kharif			Rabi / Summer			Production share of Rabi/ Summer Rice
	Area	Production	Yield	Area	Production	Yield	
Andhra Pradesh							
1980s	-0.56	1.18	1.70*	0.82	3.11**	2.25*	41.7
1990s	-1.78**	-1.42**	0.31	3.22*	4.87*	1.54*	
2000s	-0.65	0.84	1.51*	2.40	3.85***	1.47*	
Assam							
1980s	0.56**	1.77*	1.22*	6.70*	9.44*	2.48	19.6
1990s	-0.39**	0.75	1.15*	9.23*	12.09*	2.63*	
2000s	-1.61*	-1.66***	-0.10	1.16**	1.55	0.39	
Karnataka							
1980s	-0.19	-0.67**	-0.49**	1.89***	0.78	-1.01*	28.8
1990s	0.73*	2.89*	2.15*	5.07*	6.34*	1.20*	
2000s	-0.05	1.41	1.46	2.64	3.89	1.21	
Kerala							
1980s	-3.51*	-2.66*	0.88*	-4.15*	-2.26*	1.96*	22.8
1990s	-5.31*	-4.63*	0.73**	-2.27*	-1.40*	0.92*	
2000s	-4.85*	-3.20*	1.73*	-3.05	-2.71	0.41	
Odisha							
1980s	0.20	3.03*	2.78*	2.71*	7.62*	4.84*	11.0
1990s	0.07	-1.14	-1.22***	2.88*	2.87*	-0.11	
2000s	-0.27*	4.37*	4.67*	2.81***	4.10**	1.37**	

States	Kharif			Rabi / Summer			Production share of Rabi/ Summer Rice
	Area	Production	Yield	Area	Production	Yield	
Tamil Nadu							
1980s	-5.82*	-1.38***	4.84*	$	$	$	10.8
1990s	1.99*	2.03**	0.01	-2.17**	-1.24	1.05**	
2000s	-0.57	-2.57	-1.89	-3.89**	-3.20	0.85	
West Bengal							
1980s	0.11	4.18*	4.07*	11.47*	13.56*	1.83*	30.8
1990s	-0.61*	0.99*	1.60*	5.76*	6.40*	0.59**	
2000s	-0.41*	1.53**	1.96*	0.32	0.03	-0.29	

*, ** and *** indicate significant at 1%, 5% and 10 % respectively;
$ The growth rates could not be computed due to appearance of many extreme values in the data set.

The above discussion points to the general finding that the scope of area growth for rice production has been exhausted in India. Production and yield growth has been decelerated and future growth in rice production has to come from yield growth through technological improvement.

Trends in cost of cultivation and profit

The growth rates in operational cost (A2+Family Labour) and total cost (C2) have been computed for different states and presented in Table 6. The cost of cultivation per ha has increased in all the states and the growth rates in C2 cost varied from 0.59 % to 3.28 % and operational cost varied from 0.06% to 3.43% per year in different states, when data for the period 1980-81 to 2009-10 was considered. The growth rate in cost of cultivation was faster and more than 2% in states like Odisha, Assam, Karnataka, Madhya Pradesh, W. B. and Haryana. The absolute cost of cultivation (C2) varied from Rs 19386 to Rs 51749 per ha in different states in the recent past, when average data for the period 2007-09 was considered. Similarly, the absolute average operational cost varied from Rs 13611 to Rs 34025 per ha in different states in the period mentioned above.

Table 6. Growth trends in cost of cultivation and profit in rice cultivation in different states of India (1980-81 to 2009-10) along with irrigation coverage

Figures in percentage

State/Period	CoC (C2)	CoC (A2+FL)	Profit (over C2)	Profit (over A2+FL)	IRR (%) (2008-09)
Assam	2.60*(22472)	2.88* (16306)	$ (-77)	-2.12* (6088)	5.3
Madhya Pradesh	2.51* (21936)	2.87* (14087)	$ (4934)	-0.15 (12783)	28.3
Bihar	1.07*(19386)	1.81* (13611)	$ (2361)	-1.93* (8136)	40.8
Odisha	3.28* (28098)	3.43* (18952)	$ (2997)	-0.02 (12143)	46.8
West Bengal	2.45* (37524)	2.78* (27510)	$ (1064)	-1.61 (11078)	48.4
Kerala+	0.59* (39620)	0.06 (29282)	$ (10769)	6.58*** (21107)	72.2
Karnataka	2.57* (41735)	3.10* (28249)	-1.63** (16657)	0.06 (30143)	74.7
Uttar Pradesh	1.41* (30706)	1.42* (19826)	$ (7366)	1.10** (18247)	79.1
Tamil Nadu	1.27* (46615)	1.39* (34025)	$ (6449)	-0.90**(19039)	93.3
Andhra Pradesh	1.83* (51749)	1.68* (32943)	4.91* (10554)	2.67* (29360)	96.8
Punjab	0.82* (49707)	0.16 (27748)	3.68* (24945)	2.72* (46904)	99.5
Haryana	2.37* (49862)	1.76* (27806)	6.42* (27489)	3.97*(49546)	99.9

CoC: Cost of Cultivation, IRR: Irrigated Rice area.
Figures in parentheses indicate average Cost of cultivation and profit for the period 2007-09.
*, **, and *** indicates significant at 1%, 5% and 10% respectively.
$ Growth rate could not be computed due to negative profit in some years.
+ Growth rates for Kerala state has been computed based on data for the period 1999-2000 to 2009-10.

The absolute profit over operational cost varied from Rs 6088 to Rs 49546 per ha in different states. The return from rice cultivation has covered the variable costs in all the states. The average profit over total cost varied from Rs -77 to Rs 27489 in different states in the recent period (2007-08 to 2009-10). The profit based on total cost has become negative in some years in states like Assam, Bihar, Madhya Pradesh, Odisha, West Bengal, Uttar Pradesh, Kerala and Tamil Nadu, for which the growth rate could not be computed. The growth in profit over total cost was positive and significant in irrigated states like Andhra Pradesh, Punjab, and Haryana due to better quality rice production and better price realization. The growth in profit over operational cost was found to be negative in most of states barring some irrigated states like Andhra Pradesh, Punjab, Haryana and Uttar Pradesh. The first three states have registered significant positive growth rate in profit over 2.5% per year during the period 1980-81 to 2009-10. The growth in profit in an irrigated state like Tamil Nadu was negative due to negative growth in yield during the period 2000-01 to 2009-10. Further, growth in profit over total cost has declined at the rate of 1.63% per year in the state of Karnataka. The above observations contradict the observation made by Dev and Rao (2010) that agricultural price policy has been largely successful in playing a major role in regard to providing reasonable level of margins of around 20% over total costs to the farmers. Their observation is true only for irrigated states like Punjab, Haryana and Andhra Pradesh.

Table 7. Cost of production of rice and price realization in different states of India (1980-81 to 2009-10)

State/ Period	CoP (Rs) per quintal (C2)	CoP (Rs) per quintal (A2+FL)	Price (Rs) realization per quintal	MSP (Rs) per quintal at constant 2009-10 price	Difference Column (4) – Column (5) (Rs)	No. of years of less price realization
1	2	3	4	5	6	7
Assam						
1987-89	682	483	758	684	74	13
1997-99	750	518	889	764	125	
2007-09	814	578	812	989	-177	
Madhya Pradesh						
1987-89	826	488	827	700	127	4
1997-99	872	553	862	797	65	
2007-09	846	497	1021	993	28	
Bihar						
1987-89	781	409	895	676	219	13
1997-99	699	407	800	804	-4	
2007-09	780	479	823	972	-149	
Odisha						
1987-89	577	346	711	647	64	17
1997-99	702	451	737	768	-31	
2007-09	781	485	864	980	-116	
West Bengal						
1987-89	682	394	831	675	156	10
1997-99	818	513	877	781	96	
2007-09	857	591	881	1000	-119	

State/ Period	CoP (Rs) per quintal (C2)	CoP (Rs) per quintal (A2+FL)	Price (Rs) realization per quintal	MSP (Rs) per quintal at constant 2009-10 price	Difference Column (4) – Column (5) (Rs)	No. of years of less price realization
1	2	3	4	5	6	7
Kerala						
1997-99	1001	764	1009	733	276	NIL
2007-09	889	613	1131	967	164	
Karnataka						
1987-89	763	422	1038	715	323	NIL
1997-99	750	464	1075	801	274	
2007-09	811	519	1146	1011	135	
Uttar Pradesh						
1987-89	782	510	894	740	154	18
1997-99	683	439	783	824	-41	
2007-09	794	486	985	982	3	
Tamil Nadu						
1987-89	814	549	1015	689	326	1
1997-99	832	579	957	806	151	
2007-09	932	653	1063	989	74	
Andhra Pradesh						
1987-89	819	491	884	732	102	NIL
1997-99	837	524	886	816	50	
2007-09	884	534	1065	994	71	
Punjab						
1987-89	688	444	852	729	123	NIL
1997-99	750	449	934	877	57	
2007-09	739	407	1109	1009	100	
Haryana						
1987-89	728	525	1092	729	363	0
1997-99	1041	663	1158	882	276	
2007-09	1082	586	1658	1014	644	

CoP: Cost of Production, MSP: Minimum Support Price

The cost of production per quintal and price realization by farmers is presented in Table 7. The realized price covered the cost of production based on variable costs (A2+FL) in all the states. But, the realized price did not cover cost of production based on C2 costs in some states like Assam during 2007-09 and Madhya Pradesh during the period 1997-99, when triennium average data for three periods across all the states were considered. More importantly, the realized price was less than the government announced support price in 7 out of 12 states during the period under consideration (1980-81 to 2009-10). Out of 30 years for which data was considered, the number of years in which realized price ruled below support price varied from 1 to 18 years in different states. In five eastern states *viz.* Assam, Bihar, Odisha, Uttar Pradesh and West Bengal, there are serious problems in providing support price to the farmers. The realized price was below the support price for all the latest 5 years (2005-06 to 2009-10) for the above five states. The average realized price was below the support price in the range of Rs 4 to Rs 177 at aggregate level in different states. The price realization by many farmers must have been much more than these figures, and thus, acts as disincentive to adopt modern technologies and increase productivity. The above observations reject the hypotheses taken for the study that the support price mechanism is working well in all the states of India.

The above discussion leads to two observations. First, while irrigated states like Andhra Pradesh, Haryana and Punjab are able to maintain profit with high level of input use, state like Tamil Nadu has failed. This may be due to declining fertility of native soils and negative yield growth during the recent period. The growth rate in yield was -1.63 % per year for the state of Tamil Nadu, during the period 2000-01 to 2009-10. This observation needs detailed investigation. Second, in other eight states due to less realized price by the farmers, the profits have eroded and approached either zero or have become negative. The less realized price was perhaps due to poor market infrastructure development in those states and more so in eastern states.

Conclusion and policy implications

Increasing rice production in India is not only important from the point of view of food security but also its poverty alleviating effect. However, the growth in rice production has been slowed down in recent years and has to be accelerated to meet the demand for the future years. The scope of area expansion in rice has been exhausted and future production growth in rice has to come from yield growth through technological improvement.

But, the yield growth has been slowed down in recent years in major rice producing states. This calls for strengthening research and developmental programmes to develop environment friendly appropriate technologies and its proper dissemination. State wise analysis of cost of cultivation data revealed that the costs per ha has increased in all the states and profits decreased in majority of the states. In five eastern states *viz.* Assam, Bihar, Odisha, Uttar Pradesh and West Bengal, there are serious problems in providing support price to the farmers. The realized price was below the support price for all the latest 5 years (2005-06 to 2009-10). Therefore, government should review the support price, procurement procedures and operations in these states on priority, by inviting private agencies for procurement and development of proper storage facilities and market yards. This would help the government to develop backend infrastructure and give the farmers necessary incentives to adopt modern farming practices to raise productivity and profitability.

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Hybrid Rice Programmes and its Experience in India

Aldas Janaiah and Fangming Xie

India's rice sector has experienced remarkable progress over the past four decades, largely driven by technological breakthroughs. Yield improvement has been considered a major thrust in the rice research programs in India, mainly in the public domain, over the past 50 years. Several studies indicated high payoffs to rice research in India (Evenson and Mckinsey 1991, Evenson 1993, Kumar and Rosegrant 1994, Pingali *et al* 1997, Janaiah and Hussain 2004, Janaiah *et al* 2006). Yield improvements in rice were major sources of a strong output growth, largely because of the widespread adoption of modern rice varieties in favorable irrigated environments (Barker and Herdt 1985, David and Otsuka 1994, Hussain 1997, Pingali *et al* 1997). However, the intensive rice-growing states of Andhra Pradesh, Tamil Nadu, Punjab, and Haryana, which made significant yield improvements in rice until the 1980s, witnessed either a plateau or deceleration in yield growth after 1990 (Table 1). As shown in figure 1, the economically exploitable yield of existing high-yielding varieties (HYVs) of rice have almost reached the technical optimum in irrigated rice systems with the universal adoption of High Yielding Varieties-HYVs (Janaiah *et al* 2005). On the other hand, increased demand for rice will make it difficult to meet the food requirements of the growing population and increasing income-induced consumption levels. Demand for rice is also projected to increase in many developing countries in the face of increasing prices of other food items such as fruits, vegetables, and livestock products (Mohanty 2008).

Table 1. Yield growth of rice in Indian states, 1971-2007 (% per annum)

State	1971-80	1981-95	1996-2007
	(TE)[a]	(TE)	(TE)
Andhra Pradesh	2.6***[b]	1.9***	2.0***
Karnataka	1.6**	1.8***	2.0***

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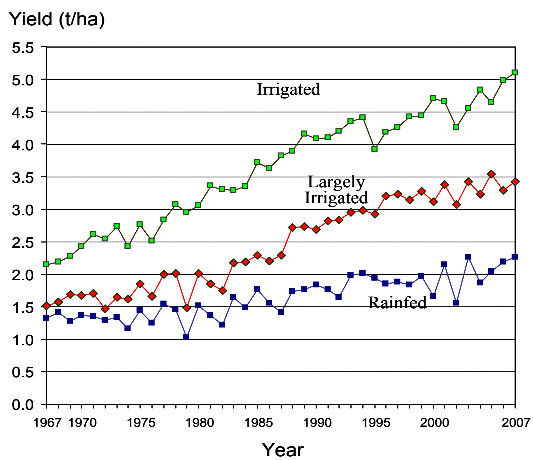
State	1971-80 (TE)[a]	1981-95 (TE)	1996-2007 (TE)
Tamil Nadu	0.4	3.5***	–1.7
Orissa	0.7	3.1***	2.6***
Bihar	–0.2	2.5***	–1.1
West Bengal	1.3**	4.1***	1.9***
Assam	0.2	2.2***	0.4
Maharashtra	5.1**	1.1**	0.1
Madhya Pradesh	–1.2	2.7***	2.4*
Uttar Pradesh	2.0**	4.1***	–0.7***
Punjab	4.4***	0.8***	1.9***
Haryana	4.9***	0.6***	2.2***
All India	1.6***	2.8***	1.1***

[a]TE = Triennium ending (detrended by three years' moving average).
[b]*** = 1% level of significance, ** = 5% level of significance, * = 10% level of significance.



Ecosystem	Average yield (t/ha) 1967-69	1989-91	2005-07	Growth rate(%/year) 1967-90	1990-2007
Irrigated	2.21	4.12	4.91	2.8	1.1
Largely irrigated	1.59	2.75	3.42	2.4	1.3
Rainfed	1.33	1.79	2.17	1.2	0.9

Source: Directorate of Economics and Statistics, Ministry of Agriculture, India.

Fig. 1. Trends in rice yield for irrigated and rainfed ecosystems, India, 1967-2007.

Hybrid rice R&D initiatives and experiences: an overview

Policymakers and research managers in India considered hybrid rice as a readily available technology during the late 1980s to reverse the declining trend of productivity growth under irrigated environments. China's miraculous success in the popularization of hybrid rice technology in the late 1970s and the 1980s motivated India to invest more resources for hybrid rice R&D in the 1990s. The private seed sector also participated in a big way in the early 1990s in these countries in research, seed production and marketing, expecting a huge and guaranteed seed business with rice being a widely cultivated crop in the country.

India was the first country to initiate hybrid rice research at the Central Rice Research Institute, Cuttack, in the early 1950s (Sampath and Mohanty 1954). Subsequently inspired by Chinese success, research efforts on hybrid rice started in the early 1980s in collaboration with IRRI, Philippines. The Indian Council of Agricultural Research began a focused hybrid rice R&D program in 1989 with an objective of developing and releasing indigenous rice hybrids to farmers (DRR 1997). The rigorous efforts of hybrid rice R&D in India over the past two decades resulted in the development and release of 35 rice hybrids, by both the public and private sector. Since the first-generation rice hybrids released to farmers in the early 1990s, hybrid rice R&D has encountered major challenges in India such as acceptable grain quality, pest and disease resistance, seed costs, etc. However, it is important to note that the hybrid rice R&D strategy being adopted is dynamic, and it continues the refinement process by taking farmers' feedback/constraints into consideration in research priority setting to meet emerging challenges. Thus, there is considerable improvement in the recently released hybrids as compared with the first- and second-generation hybrids of the 1990s in grain quality, yield gain, pest and disease resistance, seed yield, etc. (DRR various reports, 2000-08). Several farm-level impact studies carried out during the 1990s and early 2000 (Janaiah 2002, Janaiah and Hussain 2002), provided useful feedback on and insights into the hybrid rice R&D program for re-orienting its strategy toward farmers' preferences that resulted in the development of many farmer-acceptable hybrids after 2003.

Current status in tropical Asia

The efforts of the hybrid rice R&D program over the past 15 to 20 years across tropical Asia resulted in the development and release of a considerable number of rice hybrids for farmers. Table 2 summarizes the progress made in the hybrid rice R&D program in selected Asian countries. India is the second country after China to develop and release the first rice hybrid during the 1994 dry season (DS), while in other countries, such as Vietnam and Bangladesh, the first released rice hybrids were imported from China (Janaiah and Hussain 2003). It was reported based on early experiences that many farmers who grew hybrid rice initially for one or two seasons started dropping out from hybrid rice cultivation in India (Janaiah 1995, 2000, 2002, Janaiah et al 1993, 2002) and Bangladesh (Hussain et al 2001). Therefore, the rate of hybrid rice adoption by farmers was too limited and scattered in these countries until 2004. Subsequently, Bangladesh imported more than 50 rice hybrids largely from China and India, which were notified and released by the National Seed Board of Bangladesh. By the 2008-09 crop year, about 8% of the rice area was planted to different rice hybrids in Bangladesh (Table 2).

Table 2. Current status of hybrid rice development and its adoption rate in selected Asian countries

Country	Year when R&D began[a]	Year of first hybrid release	Number of hybrids released, 2008[d]			Area planted to hybrid rice, 2008	
			Public sector	Private sector	Total	000 ha	% of total rice area
India	1989	1994 DS	9	26	35	1,400	3.2
Bangladesh	1997	1999 DS	2	51	53	735	7.6
Vietnam	1992	1992 WS[b]	15	10	25	645	9.0
Philippines	1993	1993 WS[c]	15	10	25	346	10.2

[a]Year when mission-mode R&D began, [b]First rice hybrid released was imported from China.
[c]First rice hybrid released in the Philippines was developed at IRRI, where hybrid rice research began in 1979, [d]Includes imported hybrids from China and India in Bangladesh and Vietnam. DS = dry season (Nov./Dec.-March/April); WS = wet season (June/July-October/November).

Source: Janaiah and Xie, 2010

The active participation of the private sector and NGOs in the hybrid rice seed sector and the government's liberal policy on seed imports from other countries were a key factor in the increased diffusion of hybrid rice in Bangladesh. In Vietnam, the rate of hybrid rice adoption (mostly imported hybrids from China) reached about 8% of rice area by 2003. Since then, it stagnated at this level as Vietnam's government removed the price subsidy on seed cost during 2004. Hybrid rice adoption in the Philippines is modest at about 12%.

Experiences with hybrid rice in India

In India, the hybrid rice R&D strategy was basically targeted at reversing the decelerating yield trend under the intensive rice-rice systems of southern India and the rice-wheat systems of northern India. Later on, favorable environments in eastern India, especially the boro rice lands, were targeted for expansion of hybrid rice cultivation during 1995, when it was realized that the first-generation hybrids were not suited to the irrigated rice lands of southern and northern India (DRR 1997, Rao *et al* 1998).

Expectations arose and ambitious targets were fixed at the macro level for the expansion of hybrid rice cultivation. It was projected that hybrid rice would cover nearly 5%, 25%, and 60% of total rice area by 2000, 2010, and 2020, respectively (Barwale 1993). Based on these projections, an ex ante evaluation study estimated that hybrid rice would contribute 35–40% to meet the additional rice demand by 2020 (Janaiah *et al* 1993). Further, it was projected that this technology would generate huge employment opportunities for female workers through hybrid seed production in rural India. An ex ante assessment of hybrid rice potential in India based on on-farm trial data (1992-93 and 1993-94) reported 12% yield gains of hybrids over inbred varieties (Janaiah 1995). Farmers' perceptions during on-farm testing, however, indicated that the poor grain quality of the tested rice hybrids would constrain large-scale acceptance of this technology by both farmers and consumers in India (Janaiah *et al* 1993, Janaiah 2002). Many of the first-generation rice hybrids released during the 1990s in India were those tested during on-farm trials in 1992-93 and 1993-94, ignoring farmers' perceptions during the prerelease testing period. Many commercial farmers in the irrigated environment began dropping out from hybrid rice cultivation after one or two crop seasons. In spite of the efforts of seed companies to move hybrid rice from one state to another to obtain a market, area expansion remained much below the projected level until early 2000. Thus, the adoption rate of hybrid rice in India was meager, less than 1% of total rice area until 2003 (Table 3), although the first rice hybrid was released in 1994.

Table 3. Area planted to hybrid rice cultivation in India, 1996 to 2008

Year	Gross rice area (million ha)	Area planted to hybrid rice[a]	
		000 ha	% of gross rice area
1996	42.84	50	0.12
1997	43.43	90	0.21
1998	43.45	100	0.23
1999	44.80	150	0.33
2000	45.16	175	0.39
2001	44.71	180	0.40
2002	44.90	200	0.45
2003	41.18	275	0.67
2004	42.59	570	1.34
2005	41.91	750	1.79
2006	43.66	1000	2.29
2007	43.81	1100	2.51
2008	43.77	1400	3.20

Source: Janaiah and Xie, 2010.

In 2004, the hybrid rice R&D strategy in India was re-oriented, especially with respect to expanding the multilocation testing approach to on-farm evaluation of a wide range of rice hybrids under diverse production environments across the country. The strategy was also re-focused toward favorable rainfed areas where rice is grown by using groundwater, mainly in the eastern parts of the country. The current base yield of different inbred varieties of paddy under rainfed uplands is low, With yield of hybrid rice under on-farm testing reported at 4 to 4.5 t/ha, with a net yield gain of about 30–35% its production will help ot substantially enhance production. Further, a large number of private seed companies started engaging in R&D and seed production after 2004, expecting a huge business as rice was a widely cultivated crop (Ramesha *et al* 2009). Some state governments have initiated an incentive policy in the form of a subsidy on hybrid rice seed during the initial years for the promotion of hybrid rice. Another significant development in hybrid rice R&D during recent years is the development and release of the first Basmati rice hybrid from a public-sector institution (Indian Agricultural Research Institute, IARI) for the states of Punjab and Haryana. As many as

20 private seed companies have entered into an agreement with IARI to access seeds of base material of this hybrid from IARI, and have produced a large quantity of F_1 seeds and marketed them in Haryana and Punjab recently.

Share of hybrid rice in India's rice sector

All the developments in hybrid rice R&D strategy and policy after 2004 led to a real kickoff for the technology in farmers' fields, especially in eastern India. The adoption rate of hybrid rice, which was less than 1% during the first decade after the release of the first hybrid, increased substantially to 3.2% by 2008 (Table 3). The area planted to hybrid rice during 2008 was estimated at about 1.40 million ha of the total rice area, largely concentrated in Chattisgarh, Bihar, and eastern Uttar Pradesh. The contribution of hybrid rice to total rice production in India as a whole was about 5.6%, although its share of total rice area was only 3.2% (Janaiah and Xie, 2010). Hybrid rice thus covered about 7% of the rice area in eastern India, accounting for nearly 13% of the rice output in the region. This shows that there is a potential opportunity for India to increase rice production in the future, especially in the low-income areas of eastern India, without additional rice area or even by releasing some of the existing rice area to other crops by the large-scale adoption of hybrid rice, as has been done in China. As rice is a key source of livelihood in eastern India, where poverty and malnutrition persist widely, a considerable increase in yield through hybrid rice will have a major impact on household food security, income, and nutrition besides an economy-wide impact in the region. The large-scale adoption of hybrid rice, however, depends on the sustainability of the technology in farmers' fields (Janaiah and Xie, 2010.

Farm-level impacts, yield and profitability gains

The impact assessment study jointly conducted by the International Rice Research Institute (IRRI) and Acharya N.G. Ranga Agricultural University in 2010 showed that the hybrid rice varieties are indeed superior to the inbred rice varieties for yield and profitability in Chattisgarh and eastern Uttar Pradesh. Hybrid rice out yielded the existing inbred varieties by about 36% in Chattisgarh and 24% in Uttar Pradesh under farmers' field conditions. However, for Haryana, the yield of both Basmati rice hybrids and popular inbred rice varieties (non-Basmati) is almost the same. On average, the yield gain of hybrid rice over the existing popular inbred rice varieties in eastern India is about 30% in farmers' fields, which is a phenomenal increase under rainfed uplands (Janaiah and Xie, 2010). Net farm profit from the cultivation of hybrid rice and inbred rice varieties was computed based on three parameters: yield, total input costs, and market price of grain (Table 4). Hybrid rice cultivation generated an additional net profit of about 13% in Chattisgarh and about 33% in Uttar Pradesh. Although farmers in Chattisgarh received 13% additional net profit from hybrid rice cultivation, this is lower than in Uttar Pradesh because of higher input costs and a relatively lower output price for hybrid rice. An additional profitability is a key motivating factor for the adoption of hybrid rice in these states. In Haryana, net profit is almost the same for both hybrid and inbred rice cultivation.

Table 4. Comparative cost-return profile (in US$ per ha) for the cultivation of hybrid and inbred rice varieties on sample farms in selected states of India.

Cost/return	Chattisgarh			Uttar Pradesh			Haryana		
	HR	IR	%Diff.	HR	IR	%Diff.	HR	IR	%Diff.
Grain yield (t/ha)	4.5	3.3	36.4	6.2	5.0	24.0	7.5	7.3	2.7
Market price (US$/t)	245	275	–10.9	163	169	–3.6	216	214	0.9
Straw value	44	40	10.0	25	27	–7.4	9	28	–67.9
Gross return	1,147	948	21.0	1,036	872	18.8	1,629	1,590	2.4
Total costs	606	470	28.9	441	426	3.5	786	763	3.0
Net return	541	478	13.2	595	446	33.3	843	827	1.9
Cost of production (US$/t)	135	142	–5.4	71	85	–16.5	105	105	0.3

HR = hybrid rice; IR = inbred rice varieties (conventional modern varieties), gross return also includes straw value (by-product value).

Source: Janaiah and Xie, 2010

Yield gain and profitability over the period

A critical review of the hybrid rice R&D program in India reveals that three generations of rice hybrids were released to farmers by both the public and private sector over the past 15 years. They are first-generation hybrids (1994-98), second-generation hybrids (1999-2003), and third-generation hybrids (2004 until now). Various farm-level impact studies carried out based on surveys of sample farmers in different states of India during 1993, 1998, and 2001 showed that hybrid rice was higher yielding by 12–16% than inbred rice, but did not generate additional net profit as yield gains could not compensate for the lower market price and higher input costs for hybrid rice (Janaiah

1995, 2000, 2002, Janaiah and Hossain 2003). The key findings of earlier studies are summarized in Tables 5. Noteworthy to mention here is that the level of yield gains and difference in output price and production cost for hybrid rice cultivation in India over the period.

Table 5. Comparative cost-return profile (in US$ per ha) for the cultivation of hybrid and inbred rice varieties from 1993 to 2001 in India.

Cost/return	1993-95[a]			1997-98[b]			2000-01[c]		
	HR	IR	%Diff.	HR	IR	%Diff.	HR	IR	%Diff.
Grain yield (tons/ha)	6.31	5.63	12.1	6.91	5.91	16	6.8	6.0	13.3
Market price (US$/ton)	98	107	-8.5	105	117	-11	119	128	-7.0
Gross return[d]	676	665	1.7	758	739	2.6	845	869	-2.8
Total costs	295	263	12.1	283	239	19	377	320	17.8
Net profit	381	402	**–5.2**	475	500	**–5.0**	468	549	**–14.8**

HR = hybrid rice; IR = inbred rice varieties (conventional modern varieties)

Sources: [a]Janaiah (2000); [b]Janaiah and Hossain (2000); [c]Janaiah and Hossain (2003).

Conclusion

A macro-level assessment of hybrid rice R&D program showed that the adoption rate of hybrid rice, which was less than 1% during the first decade after the release of the first hybrid in 1994, increased substantially to 3.2% by 2008, and contributed about 5.6% of the total rice output in the country. As rice is a key source of livelihood in eastern India, where poverty and malnutrition persist widely, a considerable increase in yield through hybrid rice will have a major impact on household food security, income, and nutrition, besides an economy-wide impact in the region.

The farm-level performance of the latest generation of hybrids in 2008 was significantly superior to that of the existing popular inbred rice varieties in yield and profitability gains. Both yield gains and additional net profitability of hybrids over inbreds have increased substantially in farmers' fields over the past 15 years. This explains why the adoption of hybrid rice was very slow, and lingering until 2003, and why it picked up during subsequent years in India. The difference in market price between hybrid and inbred rice has decreased over the period, which is a clear reflection of the improvement in grain quality in successive generations of rice hybrids over the period. On the whole, the latest generation of rice hybrids has considerably outperformed existing inbred rice varieties in yield gain and profitability in eastern India. Although there has been a considerable improvement in grain quality and consumer acceptance over the period, the large-scale adoption of hybrid rice in the future largely depends on the further improvement of grain quality, to make it comparable with that of popular inbred varieties.

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Hybrid Rice and Water Saving Technologies – A Possible Solution for Inter State Water Dispute

M. Mahadevappa

River water disputes are not peculiar to any one part of the globe. Increased pressure of both human (400 percent) and livestock (127 percent) populations during the previous century has imposed tremendous pressure on natural resources. Consequently, demand for drinking and irrigation water is rapidly increasing. India is facing complex situations in this respect. Arid zones in India face drought situations once in alternate or three years, and prolonged droughts, about five times in a century, leading to severe scarcity of food, fodder, fuel, fruits, flowers and fiber. Realizing the above situations, the British Government, as recommended by the first Famine Commission (1880), established five dry farming research centers during 1933 and many research centers for carrying out research on use of irrigation water. Subsequently ICAR established many training and research centers during 1954 to conserve precious soil and water resources, 23 AICRP locations and 47 macro watersheds for drought mitigation in 1970. Many states too had their own engineering research stations. It is of interest to note that, even though our rainfall is low and unevenly distributed, it is certainly not as low as in Israel, which receives between 400 mm and 800 mm annually. Israel has been a pioneer in developing efficient ground water conserving and water utilization technologies, rather than in ground water extraction technologies. India has something to learn from both China and Israel.

Reduction of area under water intensive crops – Chinese experience

Regions with shortage of irrigation water can richly benefit from the China's experience. China has been successful in reducing the area under paddy without sacrificing its production and in promoting cultivation of other export earning profitable crops thereby improving the agricultural economy of the farmers. Around 1643 liters of water are applied to produce one kg of paddy, since paddy uses around 40 acre inches of water per acre.

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With this water at least four acres of semi dry crops like ragi, groundnut, jowar, or sunflower can be cultivated. China was cultivating 99 million acres of paddy during the 1970s, and in the late eighties this was brought down to 79 million acres, saving 20 million acres (20 percent) without affecting the total paddy production. The land and irrigation water so saved was diverted to less water consuming and high value crops. China was able to do this by introducing high yielding varieties and particularly hybrids with improved management practices. China is now further reducing the paddy area to 62 million acres (saving 37 percent), with the introduction of 'super rice' and 'super hybrids' and the process has already commenced. The Chinese super rice varieties and hybrids have the potential of 69 quintals per acre as against 48 quintals per acre from the conventional HYVs and hybrids grown during the 1980s and 1990s. It is pertinent to mention here that, in India, paddy productivity is below 20 quintals per acre. The hybrid rice in India yields 32.4 quintals to 36.4 quintals per acre as per the data generated by the AICRIP, Hyderabad that indicates the potential of this technology.

Super hybrid rice in China with a productivity of 17 tones / hectare

Rice production in India

Rice occupies the enviable prime place among the food crops cultivated around the world. It is grown in 147 million hectares with a production of 476 million tonnes. India has the largest area among the rice growing countries and enjoys the second rank in rice production, the first one being China. India produces about 94 million tonnes of rice in an area of about 44.0 million hectares with a productivity of about 2.15 tons per hectare. Since land is a shrinking resource, increasing food production by expanding the area under cultivation is impossible. Agricultural land is being diverted to non agricultural purposes and for commercial crops. The option now available is to enhance marginal land productivity so that part of rice area can be made available to other less water consuming crops like what China has done successfully. Like land, demand for irrigation and drinking water is also increasing creating social problems like river water disputes. Therefore efforts to enhance rice productivity must receive top priority. This is possible through the application of modern science and technologies and some positive aspects in this line are covered in this article.

A. Exploiting potential of hybrid rice

Introduction of high yielding and non-lodging rice varieties in 1964 boosted the rice production of India substantially. However, the productivity has stagnated since the last two decades and the available technologies have failed to break the yield barrier of rice. Development and utilization of hybrid rice technology in China during the last three decades and north-eastern states in India since mid nineties have demonstrated that rice yield potential can be increased substantially through developing and popularizing hybrids. Today, China has gone one step ahead and developed 'super hybrids' with a yield potential of 17 t/ ha against the yield of about 7 t/ha realized with the introduction of first set of hybrids.

Varietal maturity period

Hybrids in general tend to mature comparatively early. Reduction in the field stand period of rice varieties is yet another option to improve the efficiency of the scarcely available water. Among the 53 hybrids developed in India by both private and public sector which are yielding 15 to 50 percent higher yield most of them including Pusa Basmati-1 mature early saving a field stand of about 15 to 25 days which saves water up to 25 percent.

Indian experience - scenario in southern states

According to the evaluation in the National trials, Karnataka Rice Hybrid (KRH-2) of University of Agricultural Sciences, Bangalore is the best hybrid among the presently recommended rice hybrids and is recommended in UP, Orissa and Himachal Pradesh etc. The much required medium slender grain hybrid DRRH-3 is released from Directorate of Rice Research (DRR) and also from some private companies. Besides these, State Agricultural Universities (SAUs) are also ready with fine grained hybrids and are in the pipeline. The UAS, Bengaluru has completed all tests with KRH-4 which is slender grained and free from aroma; so also other SAUs in South India. Thus, the belief that once prevailed that the quality hybrids may not be a possibility has been proved wrong. With this advancement, area under hybrid rice in southern states is expected to pick up faster. This technology will also generate employment opportunities for rural youth as seed production activity will have to expand to meet the hybrid seed requirement since the hybrid cultivation needs change of seed for every newly planted crop. Many new hybrids of farmer's choice are already released or are in the pipeline for south Indian states. If all the states of the Cauvery Basin seriously try to emulate China and focus attention with needed support from the respective governments to develop and popularize the appropriate technology, this technology will go a long way towards finding a solution for the long-standing inter-state river water dispute.

State wise analysis

Agriculture in Karnataka largely depends on the distribution of southwest monsoon, the normal rainfall being 1139 mms receivable in 55 normal rainy days. About 71 percent of rainfall is received during southwest monsoon, 17 percent during northeast monsoon and the balance is the premonsoon rainfall. With a net sown area of 104 lakh ha, the area irrigated is 24 percent. About 65 percent of the net sown area is in Kharif, 30 percent is sown in Rabi, and 5 percent in summer. About 33 percent of the area is deficit in rainfall during crucial crop growth in Kharif. In the state, an area of 27.2 lakh acres is planted to paddy producing around 35 lakh tones. Even if hybrid rice is planted to a modest 25 percent of this area over a period, 7.4 lakh acres can be released for other profitable crops with a saving of water that can irrigate an additional area of at least 24.7 lakh acres for the crops that are profitable in the region. Further, it is crucial to promote Hybrid Rice seed production in Karnataka, as the state has ideal locations for hybrid seed production, for meeting the demand for parental and hybrid seeds for the state as well as for other needy states in the Country.

Tamil Nadu's agriculture is dependent more on north-east monsoons, and the state which is next to Andhra Pradesh in rice production in South India, but one of the top states in productivity in the country, cultivates rice 3 to 4 seasons in a year depending on the regions suitable for different cropping systems. Of this, *Kuruvai* rice is grown totally using stored water drawn from the reservoirs that too in dry season. The two renowned Rice Research centers in this state– one at Aduthurai ie., Tamilnadu Rice Research Institute (TRRI) and the other at Coimbatore (Plant Breeding Station), have strong and reputed research groups ready with rice hybrids with a potential to yield 1- 2 tons more under the same input conditions as for presently cultivated high yielding varieties. Out of the 55 lakh acres, even 25% devotion to hybrid rice would save water sufficient for raising 55 lakh acres of light irrigated crops.

In the state of Kerala, however, the area under rice of 8.75 lakh acres is gradually coming down particularly due to labour problem. Although not much progress has been achieved in hybrid rice development, a beginning has been made at the Pattambi Rice research center. The work needs to be speeded up. As for Pondichery, the rice hybrids developed in Tamil Nadu are suitable and similar exercise as suggested for Tamil Nadu holds good.

B. Adopting SRI principles

There are situations in the rice belt of India where the System of Rice Intensification (SRI) principles can be tried by adopting situation-specific technologies for saving water as well as seed. There are many more other advantages like reduction in the field stand of the crop enabling early harvesting etc, which are not covered here. The claim as also experience in the recent past in all south Indian states is that saving of water to the extent of 30 to 50 per cent is possible under conditions where there is control over release of water to the plots. By considering the possibility of a modest saving of only 25%, we can easily extended irrigable area for another 20% or save the water for use in the next season if there is no scope for area expansion.

C. Potential for seed production

The southern states have enormous potential for commercial seed production in India, due to existence of irrigation facility, moderate rainfall, balanced day length, moderate humidity, more number of seasons permitting quality seed production of a number of diverse crops, availability of labor at competitive wage rates, and other favorable agro climatic conditions. This is the reason for so many MNCs to have established their seed units in south India particularly in Karnataka and Andhra Pradesh. This will create employment and livelihood opportunities to a large number of rural unemployed. Appropriate planning is needed to harness this potential to export seeds to other areas in India and abroad. In the process, a proper mix of public and private sectors in seed production is appropriate and scientific. Trade and planned support to both sectors by the concerned governments will pave the way for utilizing this potential in Southern states.

Conclusion

If the technologies that emerge from the exploitation of hybrid vigour and principles of SRI are adopted, there is ample scope to make tangible progress towards maintaining or even improving the production in all the riparian states by reducing the pressure on water demand and the dispute will gradually faint if an earnest effort is made collectively by all the states. The other water saving methods is promoting production of rice through direct seeded method and expanding the area under early maturing varieties wherever possible. The methods named as “Aerobic”, “Madagascar” and “SRI” comes under water saving methods, and it is appropriate to mention here that many of these water saving methods have practiced by our ancestors in India since age-old days. Tamil Nadu is far advanced in adopting SRI principles in 20% of the rice area which is commendable. The yield levels are maintained or increased because of the adoption of SRI and farmers of Tamil Nadu have further refined this method to improve the efficiency. These technologies can be a solution to the interstate water dispute since the extent of water demand by the riparian states is within 20% in each state, when we look at the thousand million cubic (TMCs) feet of water the states are fighting for.

Constraints of Rainfed Rice Production in India: An Overview

Krishna M. Singh, A.K. Jha, M.S. Meena and R.K.P. Singh

Rice is an important staple food-crop, which is grown in a diverse range of climatic and agro-ecological conditions in almost all parts of the world. More than a third of world's population, predominantly in Asia, depends on rice as a primary staple food. In Asia, more than 2.8 billion people derive 35 to 60 per cent of their calories from rice (Swaminathan, 1989). India occupies an important position both in acreage and production of rice. It has the largest area (42.9 million hectares) that accounts for about 27.1 per cent of the total rice growing area of the world. In respect of production, India ranks second after China by contributing 103 million tons for 2011-12. However, the average productivity of rice is merely 2177 kg per hectare.

Table 1. Area, production and yield of rice in India from 1950-51 to 2010-11

Year	Area (Million ha)	Production (Million Tons)	Yield (Kg./ha)
1950-1951	30.81	20.58	668
1955-1956	31.52	27.56	874
1960-1961	34.13	34.58	1013
1965-1966	35.47	30.59	862
1970-1971	37.59	42.22	1123
1975-1976	39.48	48.74	1235
1980-1981	40.15	53.63	1336
1985-1986	41.14	63.83	1552
1990-1991	42.69	74.29	1740
1995-1996	42.84	76.98	1797
2000-2001	44.71	84.98	526
2005-2006	43.66	91.79	2102
2006-2007	43.81	93.36	2131

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Year	Area (Million ha)	Production (Million Tons)	Yield (Kg./ha)
2007-2008	43.91	96.69	2202
2008-2009	45.54	99.18	2178
2009-2010	41.85	89.13	2130
2010-2011	36.95	80.41	2177
Compound Annual Growth Rate (%)			
1950-51 to 1959-60	1.26	4.46	3.15
1960-61 to 1969-70	0.83	1.19	0.36
1970-71 to 1979-80	0.88	1.9	1.01
1980-81 to 1989-90	0.41	3.62	3.19
1990-91 to 1999-00	0.67	2.02	1.34
2000-01 to 2010-11	-0.75	0.73	1.84
1950-51 to 2010-11	0.59	2.51	1.53

Table1 gives information on area, production and yield of rice in India from 1950-51 to 2010-11. The table revealed that there was an annual compound growth of 0.59 percent from 1950-51 to 2010-11 in the area of rice. The corresponding figures for production and yield growths were 2.51 percent and 1.53 percent. During 2000-01 to 2010-11, the rate of growth in area became negative due to failure of monsoons that retarded the pace of growth in production (0.73%). Because of impact of green revolution that is with adoption of high yielding production technologies and high yielding rice varieties the productivity growth reached to the peak of 3.19 percent during 1980-81 to 1989-90. However, it is concerning that in recent years the productivity in growth has decelerated.

The trends in rice area and production are shown in figure-1. It is seen that there has been frequent fluctuations in rice production due to varying productivity levels (figure 2). The figures clearly highlight that rice production is subject to varying degrees of risk due to various production constraints of which rainfed farming is one.

Fig. 1: Trends in Area and Production of Rice in India, 1950-51 to2010-11)

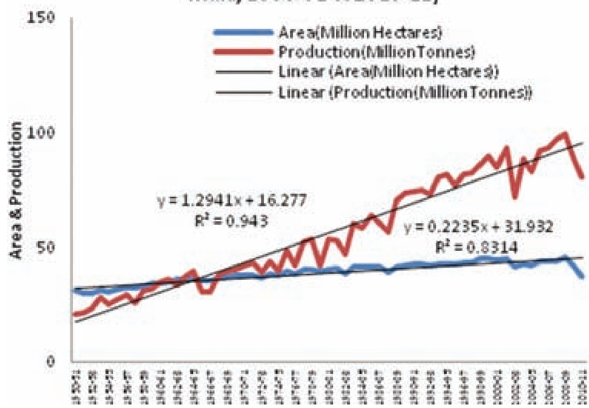
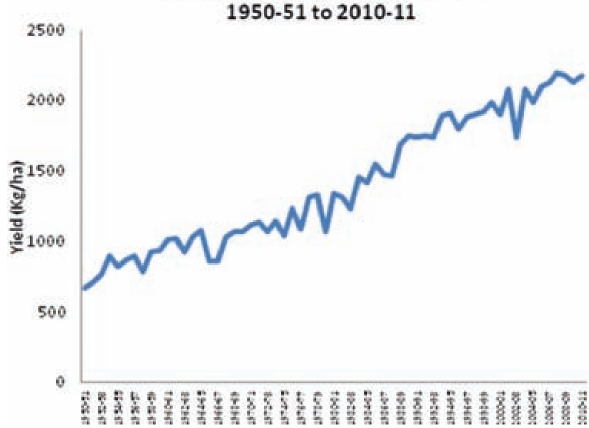


Fig. 2: Trends in Rice Yiled in India 1950-51 to 2010-11



About 12 million ha of the 40.2 million ha rice area cultivated during the rainy season remains uncultivated in the post rainy season (Table 2). It has been mentioned that if the existing rice fallow lands were brought under cultivation, it may usher another green revolution in the pre-dominantly rice-fallow states, benefiting millions of small landholders (Joshi *et al.* 2002). However, a number of technical, institutional, socioeconomic and ecological factors limit growing of a second crop after rice in rainfed rice fallow lands.

Table 2. State-wise estimates of rice area cultivated during Rabi (1999-2000)

State	Kharif-Rice Area (000 ha)	Rabi-Fallow (RRFL) (000ha)	RRFL as % of Kahrif-Rice Area	% of RRFL in India
Chhattisgarh	3,584	2,936	81.92	25.0
Madhya Pradesh	2012	1,753	87.12	14.7
Bihar	5,974	2,196	36.8	18.9
West Bengal	4,617	1,719	37.2	14.8
Assam	2,234	539	24.1	4.6
Uttar Pradesh	6,255	353	5.6	3
Others	15,508	2,463	15.9	21
Total	40,184	11,652	29	100

Source : ICRISAT 2009.

Rice is grown under diverse agro-ecosystems. Table 3 presents information on ecologies, area, production and yield of rice in India. It emanates from the table 3 that out of 44.6 million hectares of area under rice about 52 percent is rainfed. The average yield of rainfed rice varied between 1.0 to 1.8 tons/ ha whereas irrgated yield of rice was 2.8 ton/ha. It is obvious that there has been a wide variation in the yields of rice under different ecologies.

Table 3. Rice ecologies, area, production and productivity in India, 2001-02

Rice ecology	Area		Production		Yield
	Million ha	%	Million Ton	%	Ton/ ha
1. Irrigated	21.6	48	59.8	63	2.8
2. Uplands	6.0	13	6.0	7	1.0
3. Rainfed Lowlands	13.0	30	24.0	25	1.8
4. Deep Water	3.0	7	3.0	2	1.0
5. Coastal	1.0	2	1.2	2	1.2
Total	**44.6**	**100**	**93.1**	**100**	**2.1**

Source : Singh, B. N. 2006. Rainfed Lowland Rice Improvement : Current Status and Future Stratégies. Journal of Rice Research. Vol. 1(1), 104-112.

Table 4 presents rice yield gaps, estimated by Aggrawal *et.al* . 2008 for some of the important rice growing states in India. It is obvious that even with the available technologies and cultivars, a huge production gains can be achieved by bridging the yield gaps of rice. There are number of technical and socioeconomic constraints that lead to huge yield gaps in rice.

Table 4. Yield gaps in rice in India (kg/ha)

State	Simulated potential	Experimental potential	On-farm potential	Average
Bihar	3170	1510	820	1830
Karnataka	2280	1440	-	1860
Madhya Pradesh	2590	1540	1600	1910
Maharashtra	2480	-	-	1240
Orissa	2410	1320	2160	1960
Uttar Pradesh	2850	2230	1400	2160
West Bengal	1970	740	1190	1300
India	2560	1480	970	1670

Source: Aggarwal PK, Hebbar KB, Venugopalan MV, Rani S, Bala A, Biswal A and Wani SP. 2008.
Quantification of Yield Gaps in Rain-fed Rice, wheat, Cotton and Mustard in India. Global Theme on Agroecosystems Report no. 43. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Rainfed rice based systems in India provide livelihood options to the India's poorest people. While modern rice technology has made tremendous contribution for irrigated rice, little impact has been made under the rainfed situations. Eastern India alone accounts for nearly 60 per cent of India's 43 million hectare of rice, of which 80 per cent is rainfed. An estimated 450 million people in the region depend on rainfed rice as their major source of livelihood (IRRI, 1997). But the observation that the green revolution had bypassed the rainfed ecosystem still holds true and raising the predominantly rural population of eastern India out of poverty will require a major increase in agricultural productivity as the final engine of development. A majority of these rice areas are characterized by the resource poor farmers growing traditional varieties with very low level of modern inputs in high risk conditions (Sakarung, 1995). Modern varieties have not been found best suited to rainfed production environments. Due to limited success in developing suitable rice varieties against prevailing natural and climatic conditions viz.

drought, flood, submergence, soil salinity etc. these areas have not benefited much even after three decades of Green Revolution (Hossain, 1996). The average rice yield of the eastern India is just 1600 kg per hectare as against the average rice yields in the states like Tamil Nadu (3394 kg\ha), Punjab (3132 kg\ha), and Andhra Pradesh (2499 kg\ha). Hence enhancement of rice yields in the rainfed agro-ecosystems in general and in the eastern India in particular is of prime importance. A number of biotic and abiotic factors, mostly referred to as production constraints, affects the rice yield adversely and hence, needs a special attention so as the growing demand of continuously emerging population of this poor lagging region can be met (Kumar and Jha 2001). This productivity increase will require, among other factors, removal of major constraints to realize higher yields through appropriate research and policy intervention. The first step in this direction is identification of proper productions constraints that limits rice yield and addressing them.

Constraints of rice production

The production of rice is affected by a number of technical and socioeconomic factors. Constraints to achieve high yield can be classified into two categories; those that affect potential of the crop under farmer's environment; and those that affects farmers' ability and willingness to achieve the yield potential on his farm (Barker, 1979). Mahapatra (1994) classified different production constraints into six broad categories:

I. Biophysical constraints,
II. Socio-economic constraints,
III. Administrative constraints,
IV. Institutional constraints,
V. Procedural constraints, and
VI. Technological constraints.

With the inclusion of biotechnology programmes, some more classifications like biotic and abiotic constraints came into existence (Widawsky & O'Toole, 1996). In nutshell, the factors restricting adoption of improved technologies and \ or attainment of potential yield may be biotic, abiotic or technical and socioeconomic and \ or combination of these. Often these factors are intertwined with each other and hence the need for a multidisciplinary approach for solving them. Thus, knowledge about various production constraints would be helpful in understanding the reasons for low rice productivity under rainfed ecosystem in eastern India and prioritize them accordingly. Subsequent paragraphs present some of the important constraints that have been identified on the basis of previous research works.

Insect-pests

Insect-pests are serious yield reducing constraints for rainfed rice production in the eastern India. Damage caused by the insect-pests is one of the major factors of yield gap accounting nearly 30 per cent of the difference between potential and actual farm yield (Widawsky & O' Toole, 1996). Different studies (Heinrichs, *et.al.*, 1986; Thakur, 1994; Jha, 1998) shown that on an average 30 to 40 per cent of the total yield loss in eastern India is caused by the insect-pests. Stem borer, gundhibug, brown plant hopper, armyworm, leaf folder, case worm etc. are the major insect-pests of rainfed rice in eastern India. Since damages from these insect-pests are widespread and there is limited natural resistance in locally cultivated varieties of rice, varietal improvement through biotechnological approaches offers critical alternatives to insecticide use. This has a two-fold advantage: it serves to increase yields and reduces the dependency of resource poor farmers on insecticides, thereby addressing environmental concerns.

Diseases

Occurrence of various diseases on rice varieties grown under rainfed ecosystems in eastern India is very common. Selection of varieties unsuitable for the cultivation on rainfed lands and favourable moist weather harbor a number of rice diseases. As a result an average yield loss of 25-30 per cent per annum due to diseases is a regular feature in eastern India. It was found that occurrence of bacterial leaf blight (generally sporadic), brown leaf spot, and narrow brown leaf spot were severe in years of poor rains (Singh and Sahu, 1987). Other important diseases are blast, sheath rot and sheath blight. Bacterial leaf blight and rice blast was found most serious diseases in eastern India (Ramasamy and Jatilekson, 1996). Varietal resistance to disease, particularly bacterial leaf blight and rice blast, are needed as there are no effective genetic resistance currently available. Chemical and cultural controls need to be maintained and search for genetic resistance should be continued.

Weeds

Weeds are other important constraint as they compete with the rice crop and lead to a substantial loss in production. The yield loss due to weeds in rainfed ecosystems was found to be greater than that of irrigated ecosystems (Moody and De Dutta, *et.al.*1986). In rainfed lowland areas, moist aerobic conditions or shallow water for extended period of flooding during early crop growth, followed by prolonged periods of flooding to variable depths favour the growth of a more diverse weed flora and more competitive weed species and their population. Weeds compete severely with rice, reducing yield by 10-15 per cent depending on such factors as the weed species and their population. Yield losses due to unchecked weed growth range from 13 to 40 per cent with a mean value of 25 per cent (AICRP, 1969-1986). As far as rainfed lowland ecosystem is concerned, which is a dominant ecosystem in eastern India studies shown that yield loss due to uncontrolled weed growth may be as high as 62 to 75 per cent. Hence, development of fast growing weed tolerant varieties and effective weed management techniques are essential for increasing the rice yield in eastern India.

Rodents

Apart from insects, diseases and weeds, losses incurred due to rodent damage are substantial. The damages made by the rodents in rice fields and in storage accounts for about 10 to 18 per cent of the total production. In eastern states where rice is cultivated under rainfed rice lands, production losses due to rodents are significantly high. However, control of rodents is only possible through community approach, which requires more reliable Integrated Pest Management practices and creation of awareness among the farmers.

Abiotic technical constraints

As stated earlier, production of rice is a subject to a set of biotic and abiotic constraints. The reviews of some important abiotic constraints are being presented in following paragraphs.

Non-adoption \ poor adoption

Non-adoption of modern varieties as well as their component technologies has been a crucial production constraint under rainfed rice ecosystem. The studies have shown that the cumulative effect of adoption of technologies for rainfed rice production was able to increase yield by 30 to 40 per cent (Shenoi and Mandal, 1986; Jha, 1998). Almost all constraint studies reveal that the average rice yield achieved on farmers' fields, especially in rainfed rice ecosystem are lower than those commonly obtained in experimental plots (Srivastava *et.al.*,1990). The status of rainfed rice production in eastern India is even more concerning. It was estimated that the actual yield of rainfed rice in eastern India is 86 per cent lower than its potential farm yield. (Dey and Upadhyaya, 1986).

Scarcity of suitable package of practices

The technological components developed so far, has failed to satisfy the expectations of rainfed rice farmers due to one reason or the other. The findings of a number of studies (Thakur, 1994; and Jha, 1998) put forth the need for the development of more practical, problem based, cost effective and area specific technologies for rainfed rice production.

Temperature and radiation

Rice has a wide range of adaptability. However, it is susceptible to a number of environmental factors. Temperature and radiation are the two other important factors, which play crucial role in the production of rainfed rice in eastern India. The high minimum temperature and radiation during the monsoon seriously limit the yield potential of wet season rice in eastern India unless it is harvested in the later part of the year (Garrity, Oldeman and Lenka, 1986). Occurrence of cold at anthesis affects the rice production seriously. A majority of rice areas in eastern India experiences severe cold in winters and thus observes cold at the time of anthesis in the late transplanted rice. Huke (1982) reported that in high altitudes north eastern India low temperature is a constraint whereas in low altitudes regions high night temperature limits yield. Therefore, it is important to develop rice varieties, which may withstand vagaries of high and low temperatures, which are phenomena in eastern India.

Recurrent floods and droughts

Occurrence of recurrent floods and droughts are the regular features in most of the parts of eastern India. A majority of rice area, mostly rainfed, in Assam, North Bihar, Orissa and West Bengal experiences either floods or droughts or even both every year. Nearly 10 million hectares of lowlands in Bihar, Orissa and West Bengal are affected with flash flood and water logging (Prasad, *et. al*.,1986). In contrary, drought and moisture stress are the major limiting factors in upland rainfed rice in these states. Constraint analysis studies on rice in Bihar shown that yield losses due to occurrence of floods and droughts are substantial (Thakur, 1994 and Jha, 1999). Nearly, 95 to 100 thousand tonnes of rainfed lowland rice are lost every year in Bihar only. The losses caused by the floods in rainfed up and lowlands in Bihar accounts for about 12 to 27 per cent per annum of the actual production. Different studies reveal that drought is most significantly contributing to the yield gap in upland rainfed rice, where as flash floods submergence is the major constraint of rainfed low land rice (Herdt, 1996). The problem of flood and droughts cannot be solved merely through conventional technologies. Biotechnology embraces a range of technical possibilities, the future potential of which is still being hypothesized. However basic research on transfer of drought and flood tolerant genes is distinct possibility.

Water management

Results of different water management studies shown that the production of rice can be increased up to 20 per cent with the help of suitable water management technology. However, indiscriminate use of canal irrigation and ill drainage is affecting the rice yield adversely. Water management of ill -drained soil in rainfed lands is one of the major constraints (Prasad*, et.al*., 1986; and Hossain and Laborte, 1996). It was found that about one third of total rice, grown in eastern states is rainfed and grown in low topography, due to problem of drainage rice yields are substantially affected (Shenoi and Mandal, 1986). Hence, introduction of new and efficient water management techniques for rainfed rice production might be helpful in the enhancement of rice yield in eastern India.

Problematic soils

Bulks of soils in eastern states are problematic, thereby causing significant reduction in yields. Poor soil fertility is common in rainfed uplands where yields are constrained by lateritic soils with high iron and low nitrogen content, and a pH occasionally below five. Soil problem in other rainfed areas includes salinity, alkalinity and zinc deficiency. Apart from coastal saline soils of West Bengal and Orissa a majority of rainfed lands in Bihar and Assam are suffering from the problem of soil salinity. While some of these problems may be efficiently managed with affordable soil amendments, other constraints such as alkalinity and salinity cause greater yield losses, which might be partially averted through use of tolerant high yielding varieties.

Inadequate input use

Due to fear of crop failure or other input related constraints like, high input costs, unavailability of inputs in time in required quantity and other technical and socio-economic constraints, inadequate input use is common in rainfed ecosystem of eastern India. Studies have shown that fertilizer response is positively correlated with the availability of irrigation water. Uncertainty of rainfall, non availability of water in critical periods and excess standing water in fields constrain fertilizer use in rainfed rice fields. Similarly, high cost of agro-chemicals restrains the farmers in its use on the farm. Thus policies are needed to encourage the use of potential biological substitutes in the place of agrochemicals besides ensuring timely supply of critical inputs. In addition developmental agencies should make concerted efforts to develop irrigation potential through water harvesting and educate regarding its judicious use.

Conclusion

Rice is one of the most important crops in eastern India and it will continue to enjoy its leading position so long as it remains the staple food of the population of this region. Under the influence of increasing population pressure the demand for rice is expected to rise persistently in coming years. As the per capita availability of land is decreasing, future source of growth in this region lies in raising the productivity of rice crop. Even to sustain the food grains production, it is important to give due attention to the eastern India in general and to accord high priority for overcoming constraints of rice production in this region in particular. This can be achieved if rice research is directed to reduce production losses due to various biotic and abiotic constraints in rainfed rice ecosystems. Since elimination or partial solution of these constraints would have a major impact on rice production in eastern India because the yield gaps are very wide. The major rice production constraints and priority research problem areas of rainfed rice production in eastern India are drought and submergence, bacterial blight, leaf blast, brown plant hopper, weeds and poor soil fertility. Hence, it would be logical to prioritize research areas in rice on the basis of prevailing constraints under rainfed areas of eastern India. Besides, low input use, inappropriate plant spacing, late sowing and selection of inappropriate cultivars are some of the other technical constraints, which can be effectively overcome through the diffusion of relevant technologies among ultimate users or farmers. It requires further strengthening of linkages between 'Research & Extension' that facilitates feed-backs and disseminates the relevant technologies effectively.

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Present Situation and Prospects of Rice Production in India with Special Reference to Karnataka

K. Narayana Gowda and M.P. Rajanna

Rice is the world's most important food crop catering half of the world's population. It is the grain with second highest worldwide production of 721.4 million tonnes after maize (2010-11). Rice is a supreme commodity to mankind, because it is truly life, culture, tradition, status and a means of livelihood to millions. It is providing more than 1/5th of the calories consumed worldwide by the human being. It is a choice crop of millions of poor and small farmers not only for income but also for household food security. It also plays an important role in the food security of many nations including India. More than 90% of rice is produced and consumed in Asian countries. During, 2010-11 in India rice has covered 42.86 million ha. area with the production and productivity of 95.98 million tonnes and 2239 kg/ha., respectively (Table 1) (*http;//agricoop.nic.in/SIA111213312.pdf*, State of Indian Agriculture 2011-12)

Most of the Asian countries have been able to keep pace between rice production growth rate and that of population during the last four decades. This has been mainly possible due to the contributions made by the green revolution technologies. However, it is of great concern to note that the rate of growth in rice production has started declining during 90s and there has been a plateauing effect. The population growth in most of the Asian countries, except China, continues to be around 2% per year. Hence it is very pertinent to critically consider whether the rice production can be further increased to keep pace with population growth with the current green revolution technologies. It is estimated that by 2020 at least 115-120 million tons of milled rice is to be produced in India to maintain the present level of self sufficiency.

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In view of rapidly increasing population and decreasing and deteriorating resource base ensuring food security in the decades ahead is a very challenging task. During the last four decades, the green revolution technologies have helped immensely in keeping the rice production growth ahead of population growth. Of late, the gains of green revolution technologies are plateauing, causing great concern and creating a doubt in our ability to ensure food security in the decades ahead. To add to these, are the looming threats of global climatic changes whose precise impact on food production can only be anticipated. We have to devise ways and means to keep the production growth ahead of population growth. Radically new approaches and paradigm shifts are needed in rice research to enhance production and productivity in the decades ahead to meet the anticipated demands.

Fortunately, rapid advances in molecular biology and biotechnology offer us new hopes to utilize the gene technologies for facing these challenges, hopefully leading to an era of gene revolution. While continuing with the green revolution technologies, which have paid very rich dividends during the last four decades and undoubtedly will continue to play a vital role in decades ahead, we will have to intensify our research efforts to harness the new gene technologies for enhancement of production and productivity. These new tools may also help us expand the scope of rice research to shoulder the responsibility of ensuring nutritional and health security as well. Through the judicious and pragmatic application of DNA marker technology, development of transgenics and utilization of genomic tools, designer rice plants with higher yielding potential, better nutritional quality, resistance to biotic and abiotic stresses and with higher nutrient and water use efficiency may soon be created.

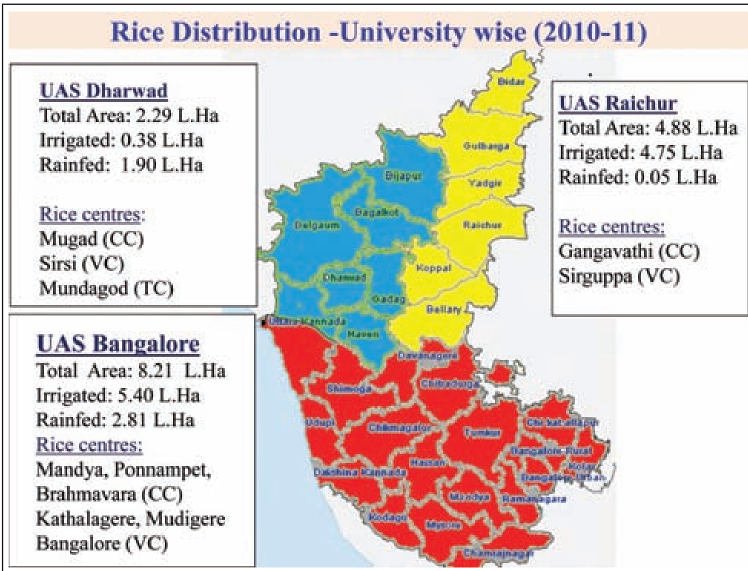
Another equally important change sweeping through the global economic environment with WTO regime is the stringent IPR and TRIPS regulations which likely to influence the accessibility of the fruits of rice research to the end users. While there are greater scopes of public and private sector collaboration to generate a win-win environment, rice research may never tend to be all public good affair. Free exchange of germplasm, pre-breeding material and other prerequisites for rice research advancement may not be readily forthcoming.

India requires development of necessary human resources, infrastructural facilities and interdisciplinary collaboration among plant breeders, molecular biologists, plant protection scientists, agronomists, physiologists, soil scientists, extension specialists and others. Thus to keep winning the war on food front, the green revolution technologies need to be supplemented and complemented by the nascent gene revolution technologies. We need to develop and effectively utilize all available gene revolution technologies for ensuring food security and keep India on forefront in rice production.

In Karnataka rice is a very important food crop. It is being cultivated in an area of 13.28 lakh ha. and producing about 38.56 lakh tonnes of rice with the productivity of 2924 kg/ha.(2011-12). It is grown under a variety of soil and wide range of rainfall and temperature. The crop is cultivated both under irrigated and rainfed. It is cultivated in places where the rains are as heavy as 3000 mm and in others where it is just 600 mm. In some areas only one crop is grown and in certain other areas three crops are raised. The duration of the rice varieties cultivated in the state varies from 110 to 180 days depending on season and agro-climatic location. The unique feature of rice culture in the state is that either sowing or transplanting is seen in all seasons of the year. Hence, it is highly challenging for the researchers to work with the problems of diversified rice cultivation.

The cultivation of rice in Karnataka can be seen in all the 30 districts and ten Agro-climatic Zones that are distributed to the three State Agricultural Universities *viz.,* University of Agricultural Sciences, Bangalore, Dharwad and Raichur. The distribution pattern of Rice area, Rice Research Stations and other details among the three Agricultural Universities is given Figure 1.

The Rice area in the state over last five years (2007-08 to 2011-12) is fluctuating between 14.25 to 15.25 lakh ha. except for 2011-12 wherein it was drastically reduced to 13.28 lakh ha. The production figure was almost constant around 38 lakh tonnes with an exception of 42.97 lakh tonnes during 2010-11. Similarly per hectare yield of Rice has also maintained consistency over years. However, it was interesting to note that it has shown upward trend during 2010-11 and 2011-12. The decrease in area during 2011-12 in old Mysore region (Mandya, Mysore, Chamarajanagara, Hassan and Tumkur districts) can be attributed to decrease in the market price of paddy during 2010-11. Increase in the price of sugarcane and its announcement well before the beginning of the season has also made the farmers to change their crop from paddy to sugarcane in many places. Table 1. illustrates the area, production and productivity of Rice in Karnataka over last five years (Source: Dept. of Statistics, Karnataka).



CC: Co-operative centers, VC: Voluntary centers, TC: Testing centers

Fig. 1. Distribution of rice area and rice research stations among three agricultural universities in Karnataka

Table 1. Area, production and productivity of paddy in world & Rice in India (2010-2011)

Particulars 2010-2011	Area (million hectares)	Production (million tonnes)	Productivity (Kg/ ha.)
World	161.3	721.4	4472
India	42.86	95.98	2239

Table 2. Area, production and productivity of Rice in Karnataka

Particulars	2007-08	2008-09	2009-10	2010-11	2011-2012
Area (Lakh.ha)	14.16	15.14	14.69	15.39	13.28
Production (Lakh tonnes)	38.69	38.02	35.12	42.97	38.56
Productivity (Kg/ha)	2875	2644	2517	2938	2924

(Source: DES & KSDA).

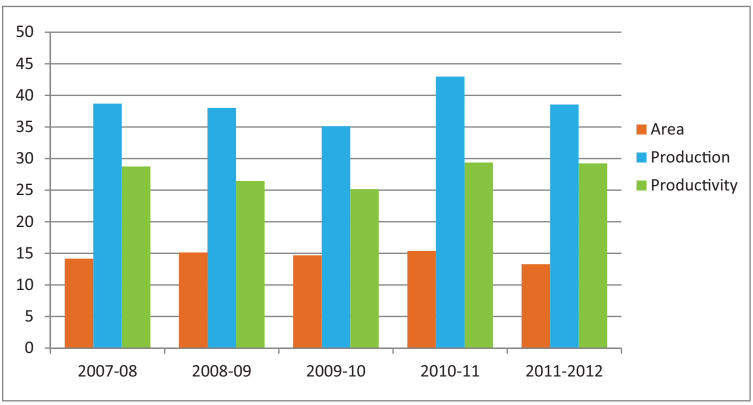


Fig. 2 The area, production and productivity of Rice in Karnataka.

Comparison of genetic yield potential of Rice varieties and the average yield being recorded in the state revealed that the farmers are harvesting only 60 to 70 per cent of the true potential yield of the improved varieties. Analyses of the reasons for this lower yield in different rice growing ecosystems indicated that delayed planting (beyond August in *Kharif* and February in Summer), maintenance of sub-optimum plant population, poor water management, use of imbalanced nutrition, sudden out-break of pest and diseases in irrigated areas and moisture stress and poor nutrient uptake in rainfed areas were found individually or in combination responsible for not able to achieve the genetic yield potential.

In the All India Coordinated trials as well as Station varietal trials conducted at AICRIP, ZARS, VC Farm, Mandya and in different rice research stations of UAS, Bangalore over last one decade yield stagnation has been observed in different sets of material (1999 to 2010 ZREP reports of Zone-7, UASB). Critical analyses of various trials indicated that there is an immediate need to widen the genetic base of the parents being used to develop the new rice varieties as there is no much diversity in the parents being used at present.

The cost of cultivation of Rice in the state varies widely from Rs. 25,000 to Rs. 40,000 per hectare *vis-a-vis* the benefit cost ratio from 1.20 to 1.60 in different parts of the state and it depends on ecosystems (irrigated, rainfed, tank-fed area, command area, maidan area, coastal area, hilly area, transitional area etc.,) methods of cultivation (direct seeded, transplanted, aerobic, SRI etc.,) type and quantity of inputs used (varieties / hybrids, organic / inorganic nutrients) and Season (*kharif* / *rabi* / summer). It also varies with use of self / hired labourers, mechanized / non-mechanized / partially mechanized cultivation *etc.*, Owing to increased cost of inorganic fertilizers, steep hike in the cost of cultivation was observed in the recent past. Estimation of the cost of cultivation during *kharif* 2011-12 at ZARS, VC Farm, Mandya representing the Cauvery command areas indicated that for the cultivation of one hectare of paddy Rs. 36,000.00 is required. The cost benefit ratio worked out to 1: 1.5. Hence, there is an urgent need to suggest the strategies to reduce the cost of cultivation and to increase the average yield of paddy to attain higher cost benefit ratio.

Owing to the above observations the following strategies have been suggested to overcome the major production constraints and to increase the benefit cost ratio in Rice Cultivation under irrigated, rainfed as well as in water limited areas.

- Breaking the yield barrier by widening the genetic base through hybridization and trait introgression through molecular approaches; can also be attempted by further strengthening the hybrid programme.

- Stabilizing the rice yields through incorporation of resistance to biotic (blast, sheath blight, BPH, gall midge) and abiotic stresses (drought, salinity, alkalinity and water submergence) by integrating traditional and molecular breeding approaches.

- Sustain soil health by encouraging to adopt suitable integrated nutrient management practices and cropping system with pulses and green leaf manures instead of Rice-Rice or Rice-Sugarcane in irrigated low land ecosystems especially in command areas where two or more than two crops are grown in a year.

- Enhance water productivity through wider adoption of SRI, Aerobic and AWD method of cultivation in water limited areas like tail end areas of the canal, tank-fed areas and bore well irrigated areas if, the cultivation of rice is inevitable.

- Develop web based forewarning systems to avoid crop losses due to sudden outbreak of pest and diseases in large areas.

- Identify and develop suitable varieties and agronomical strategies selecting genotypes resilient to climate change especially for increased / changed atmospheric temperature.

- Adopt mechanization of rice farms from seed to seed to reduce the human drudgery and to overcome the scarcity of farm labourers. This also helps to reduce the cost of rice production and thereby to increase the benefit cost ratio.

- Transfer of updated technology on rice production through various extension strategies like FLDs, FFSs, Video-conferencing, Rice Knowledge Management Portals and extension advisory services supported by Mobile phone based MMSs and SMSs.

The AICRIP centres located in the state are working in collaborations with SAUs and State Department of Agriculture to overcome the above constraints / limitations in Rice cultivation. Further, several DBT, DST and ICAR projects are also operating to provide solutions to these problems in all the three SAUs and several other institutions of Karnataka. However, with the existing rice technology available in India it is possible to increase the rice production by atleast by 25 percent. What is required is to develop an effective extension strategy to promote raising technology.

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Emerging Insect Pests and Diseases of Rice Under Various Rice Ecosystems

K.S. Behera, M. Jena, U. Dhua and A. Prakash

Insect pests and diseases are the major biotic stresses that limit rice production. The prevalence of insect pests and diseases vary according to the ecosystem in which rice is grown. The extent of loss due to different biotic stresses fluctuates widely depending upon the prevailing factors of abundance of these pests in a particular year or season. Though more than 100 insect species attack the rice crop, 20 of them cause economic loss. Insect pests causing significant yield loss over decades are stem borers, plant hoppers, gall midge, a group of leaf-eating caterpillars and grain sucking bug complex which feed on developing grain. (Pathak and Khan, 1994). Since the onset of green revolution in the country there is a continuous increase in the number of insect species as well as their diversity and spread in rice.

Rice is attacked by several insect pests during different stages of the crop. At the initial stage, termites, ants, grasshoppers, thrips, swarming caterpillar; at the early tillering stage, again thrips, case worm (CW), gall midge (GM), hispa, leaf folders (LF), swarming caterpillar, stem borer and cutworm are the major insect pests while at the late tillering stage leaf folder (LF), brown plant hopper (BPH), white backed plant hopper (WBPH), yellow stem borer (YSB) are the major insects and at panicle initiation stage, stem borers, leaffolders; at flowering stage gundhi bug (GB) and at maturity ear-cutting caterpillar are the major pests of concern. Ecosystem wise, the occurrence of different insect pests are termite, red ants, grasshoppers, GB, mealy bug (MB) in upland; in irrigated/rainfed favourable shallow lowland thrips, GM, swarming caterpillar, hispa, CW, LF, MB, YSB, BPH, WBPH, GB and cut worm whereas in rainfed lowland CW and YSB are the major insect pests recorded. Thus irrigated ecosystem harbours maximum number of insect pests. The key insect pests of rice on ecosystem basis reported during 2008 are mentioned in Table 1.

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Table 1. Ecosystem wise important insect pests of rice

Ecosystem	Insect pests prevalent
Raifed upland (Bunded & Unbunded)	YSB, GB, MB, Termites, Root aphids
Hill rice (High altitude upland)	PSB, LF, WBPH, RH, RG, BB,BSB
Deep water	YSB
Semi-deep water	YSB, RH, CW
Shallow rainfed lowland (Drought prone)	YSB, GM, SWC
Favourable lowland	YSB, GM,BPH, WBPH, LF
Submergence prone rainfed lowland	YSB, GLH, RH, LF, CW
Irrigated rice	SB, GM, BPH, WBPH, GLH,LF, GB, RT, MB,WM

YSB–yellow stem borer, GB-Gundhi bug, MB-Mealy bug, PSB – pink stem borer, LF–leaf folder, WBPH–White backed planthopper, RH–Rice hispa, RG–Root grub, BB–Black beetles, BSB- Brown shield bug, CW-Case worm, SwC-Swarming caterpillar, GM-Gall midge, GLH-Green leafhopper, RT - Rice thrips, WM-Whorl maggot

Source- Mangal Sain and Prakash (2008)

After the green revolution, there has been change in the status of several insect pests due to change in varieties cultivated, intensive cropping system and use of fertilizers. The important rice pests during the later part of green revolution and the occurrence of different insect pests in different parts of the country are given below (Table 2).

Table 2. Status of rice pests in different States of India

Pest	Intensity	Occurrence
Major Pests		
Gall midge	Severe Moderate to severe	Madhya Pradesh, Odisha, Bihar, Karnataka, Kerala, Uttar Pradesh, Bengal
Leaf folder	Moderate to severe Moderate to most severe	Andhra Pradesh, Kerala, Maharastra, Punjab, Tamil Nadu Assam, Bihar, Gujarat, Haryana, Jammu & Kashmir, Karnataka, Madhya Pradesh, Odisha, Punjab, Uttar Pradesh, Bengal
Brown Plant hopper	Moderate to severe Low to moderate	Andhra Pradesh, Karnataka, Kerala, Madhya Pradesh, Odisha and Tamil Nadu Assam, Maharastra, Rajastan, Uttar Pradesh

Pest	Intensity	Occurrence
Green leaf hopper	Moderate to severe Low to moderate	Andhra Pradesh, Madhya Pradesh, Tamil Nadu Assam, Bihar, Gujarat, Himachal Pradesh, Jammu & Kashmir, Uttar Pradesh and Bengal
Yellow stem borer	Severe Moderate to severe Low to moderate	Maharastra Andhra Pradesh, Kerala, Madhya Pradesh, Odisha Assam, Bihar, Gujarat, Haryana, Himachal Pradesh, Jammu & Kashmir, Karnataka, Punjab, Tamil Nadu, Uttar Pradesh and Bengal
Minor pests		
White backed plant hopper	Moderate to severe Light to moderate	Madhya Pradesh, Punjab, Uttar Pradesh Bihar, Gujarat, Haryana, Himachal Pradesh, Odisha
Hispa	Moderate to severe Light to moderate	Assam Himachal Pradesh and Bengal Bihar, Gujarat, Haryana, Madhya Pradesh, Odisha, Punjab, Uttar Pradesh
Gundhi bug	Light to moderate	Bihar, Gujarat, Haryana, Odisha, Madhya Pradesh, Tamil Nadu, Uttar Pradesh, Bengal
Swarming caterpillar	Light to moderate	Bihar, Gujarat, Maharashtra, Punjab
Sporadic pests		
Case worm		Kerala, Odisha, Tamil Nadu
Cut worm		Uttar Pradesh
Grass hop-per		Maharashtra
Thrips		Kerala, Tamil Nadu
Root weevil		Bihar

Source: Chelliah et al., (1989)

When the insect pest scenario on rice in India from 1965-2010 (45 years) is critically examined, it leads to gradual increase in the number insect species. The numbers of insect pests were 3 in 1965, 5 in 1975, 8 in 1980, 9 in 1985, 10 in 1990, 12 in 1995, 12 in 2000 (Pasalu and Katti, 2004). Based on the surveys and information available at CRRI the number insect pest species has increased to 14 by 2010. The list in 2010 includes the insect pests like YSB, BPH, LF, Pink Stem Borer (PSB), GM, WBPH, Green Leafhopper (GLH), CW, GB, Hispa, Thrips, Root weevil, Black bug and Blue Beetle (BB) (Prasad *et al*. 2010).

Pest outbreaks

The intensity of damage by different insect pests vary from moderate to severe in different states of India. Yellow stem borer, GM, LF and BPH are the major pests of rice in the whole eastern and southern region of the country. But eastern India has more insect problems such as WBPH and hispa. Other states like Maharashtra, Gujrat, Haryana and Jammu and Kashmir have leaf folder problem whereas Madhya Pradesh besides LF, has the problem of GM, BPH, GLH, YSB and WBPH. Hispa is a problem in Assam and Himachal Pradesh. In India, BPH outbreaks were recorded in states like Andhra Pradesh, Himachal Pradesh, Karnatak, Kerala, Maharashtra, Odisha, Punjab, Tamil Nadu, Uttar Pradesh and West Bengal during 1954-1990 and WBPH outbreak was experienced in Andhra Pradesh, Assam, Haryana, Himachal Pradesh, Karnataka, Madhya Pradesh, Manipur, Odisha, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal during the period 1956-1986 (Senapati, 2004). High YSB incidence was observed in Rabi rice of coastal Odisha during 2010-12 indicating vulnerability of rabi crop to this pest in coastal Odisha. Recently, in April 2012 outbreak of YSB recording as high as 99.4% damage was reported in Chinsurah block of Hoogly district, West Bengal by the joint team from RRS, Chinsurah and NCIPM, New Delhi. Some more recent reports of outbreak of insect pests in different states are listed in Table 3.

Table 3. Years of insect pest severity in India during 2001-2009

Year	Insect species	-	States affected
2001	BPH WBPH LF CW Mealy bug Termite	- - - - - -	Andhra Pradesh, Punjab Punjab Andhra Pradesh, Haryana, Odisha Gujrat, Odisha Odisha Haryana
2002	No severity		
2003	BPH	-	Tamil Nadu
2004	BPH	-	Tamil Nadu
2005	White grub Swarming cater- pillar BPH Hispa Gundhi bug Leaf folder Black bug	- - - - - - -	Uttar Pradesh Odisha, West Bengal, Tripura Odisha, Karnatak, Tami Nadu Tripura Tripura Tripura, AP Tamil Nadu

Year	Insect species	-	States affected
2006	Stem Borer BPH WBPH Gall midge Hispa Army worm/ Swarming cater pillar Termite	- - - - - - -	Jharkhand AP Haryana, Tripura Jharkhand Odisha Odisha Haryana
2007	Stem borer LF BPH WBPH Hispa Case worm	- - - - - -	Puduchery, Uttarakhand Arunachal Pradesh, A.P. Haryana Haryana, Uttarkhand Haryana , Odisha Jharkhand
2008	Stem borer LF BPH WBPH GLH Gundhi bug	- - - - - -	A.P., Chattishgarh, Jharkhand, Puducherry, Uttarakahand Jharkhand, Puducherry, Tamil Nadu, Tripura, Uttrakhand Haryana, Uttrakhand Uttarakhand Puducherry Jharkhand
2009	Stem borer LF BPH GM Swarming cater- pillar	- - - - -	A.P., Puducherry A.P., Puduchery, Tripura Karnatka Jharkhand Odisha

***Source**: Production orientation survey report, Directorate of Rice Research, 2001-2009*

The data revealed a gradual increase in the number of pests year after year. Each one of the insects has shown its severity once or many times during different years indicating that any one of them can assume the major pest status whenever the environment was favourable. In addition to the increase in pest species, there are also variations within the same insect with various species. Among stem borers, yellow stem borer (*Scirpophaga incertulus* Walk.) was the major dominant species in past and also it has the same status till today. Other 6 species, namely: white stem borer (*Scirpophaga innonata* W.) Pink stem borer (*Sesamia inferens* W), Dark headed borer (*Chilo polychrysus* M.) Striped borer (*Chilo suppressalis* W), Gold fringed (*Chilo auricillus* D.) and spotted borer (*Chilo partelus* S.) are existing in rice crop. But there was a gradual change in the status of pink and white stem borers in north-eastern regions during 2001-03. Similarly gall midge, which was confined to 3 biotypes during 1970-83, formed another biotypes (4) during 1986. Since to 2004, another 2 biotypes, i.e. biotype 5 and 6 has been originated (Pasalu *et al*, 2004). Thus, at the national level besides YSB, PSB and WSB emerged as important stem borer, newer biotypes of GM evolved; leaf folder emerged as a major pest while planthoppers invaded new areas.

Change in pest status and infestation pattern

Five insect pests viz. YSB, GM, BPH, WBPH and LF have been considered to be of national importance (Pasalu *et al*., 2008). The present scenario of pest status shows that YSB has continuously remained as the major pest of paddy. Brown plant hopper which was having major pest status during early 1970s to mid-1980s, remained inconspicuous up to late 1990s and again assuming the major status in most of the rice growing tracts of India from 1998 onwards. White backed plant hopper which was infesting the kharif rice in early growth stage is also infesting at late growth stage and rabi rice. In most of the cases, this pest is occurring as a mixed population with BPH. Whorl maggot and thrips, which were not recorded in Odisha up to early 1970s, are presently occurring almost regularly in most part of the state at early growth stage of the crop. Gall midge which was also a pest of dry season rice during 1968, gradually shifted to kharif season (Prakasa Rao *et al.*, 1968). Infestation has decreased considerably due to its late occurrence and also cultivation of resistant varieties. Other insect pests which have changed their status from minor to the pest of concern are the leaf folder, *Cnaphalocrocis medinalis*, rice hispa *Dicladispa armigera* and rice case worm *Nymphula depunctalis*. Outbreak of swarming caterpillar is more often during the present decade, i.e. from 2006 onwards. The surti caterpillar, *Nisaga simplex* has appeared as a serious pest of paddy in medium land of Odisha (Senapati 2004). Outbreaks of swarming caterpillar in Odisha during 2007, 2008 and 2009 appears to be an indication of climate change for which a period of dry spell after early rains may be the cause. Increasing incidence of rice mealy bug and rice hispa in Odisha, Jharkhand and West Bengal during 2003-2008 are unusual as Assam was reported earlier as the endemic state. Upsurge of WBPH during 2008 and 2009 in Punjab and Haryana is also unusual. Period of occurrence of GLH has been delayed due to late commencement of winter in Odisha and West Bengal (Prakash *et al*., 2009)

At the regional level also there was a change in insect pest scenario with rice hispa becoming a major pest in north eastern, eastern and central India. Mealy bug became an important pest in upland and dry areas of West Bengal. White grubs emerged as a serious pest in Kumaon region of Uttaranchal under rainfed condition. Some of recent report of insect pest incidence on rice in different states of the country reflect the change in pest status.

Himachal Pradesh

The incidence of insect-pests and diseases of paddy was recorded during 1999 to 2009 in major rice growing districts of Himachal Pradesh. It was observed that the insects and diseases (whorl maggot, chaffer beetle, bacterial leaf blight), which were not prevalent in rice growing areas of Himachal Pradesh are the major pests now. Hoppers, which were not causing any damage to rice crop in the state, became very severe in 2007 in Kangra district leading to hopper burn. In major rice producing districts like Kangra and Mandi, leaf and neck blast were observed to be the most predominant diseases attributing to crop losses during the decade whereas other rice diseases appeared in low to moderate proportions. Whorl maggot during 2001-2002 in Mandi and Kangra districts appeared in low to moderate intensity especially on late transplanted rice crop (Sharma *et al*., 2012).

Madhya Pradesh

Recent survey in farmers' field during wet season in north eastern Madhya Pradesh indicated 12 insect pests on rice out of which gundhi bug, white backed planthopper, grasshoppers and stem borers proved to be regular occurrence in descending order while armyworm, case worm and rice hispa were sporadic pests (Mishra *et al.,* 2010).

Bihar

Studies undertaken at Pusa, Bihar on Boro rice during 2001-02 indicated severe YSB damage which could be due to large number of moths emerging from diapausing population from the stubbles of transplanted rice grown during the main season (Mishra *et al*. 2005).

Jharkhand

Pest survey and surveillance conducted for a decade (2002-2011) in different regions of Jharakhand state revealed that more than a dozen insect pests occur on rice (Parasad *et al*., 2012). The prevalent pests were YSB, LF, CW, WM, grasshoppers, termite, GLH, BPH, WBPH, GM (biotype 3), swarming caterpillar, ear cutting caterpillar and gundhi bug. Out of these YSB, LF, CW, hispa, GLH, GM and gundhi bug are major pests. Rice leaf folder was a minor pest before 1980. During 2011 there was a severe outbreak of case worm and in medium and lowland as well as late planted crop. There was also outbreak of GM during 2011 in several blocks of Hazaribagh, Jharkhand which are not the identified endemic areas. During 2009 there was a dry spell and a severe unprecedented outbreak of swarming caterpillar (*S. mauritia*) took place in seven western districts causing 40-100% damage at early stage of the crop.

Assam

Stem borer complex of rice at Jorhat, Assam comprised of five species viz. *Scirpophaga innotata* (Wlk.), *S. incertulas* (Wlk.), *Chilo suppressalis* (Wlk.), *C. polychrysus* (Meyrick) and *Sesamia inference* (Wlk.). *S. innotata*, the white stem borer was the predominant species at all stages of crop growth during both the seasons, Ahu and Sali (Pujari *et al.* 2008) whereas *S. incertulas* was reported earlier as the dominant stem borer species of Assam (Bora, 1993). Based on the analysis of rainfall pattern it was concluded that that the predominance of white stem borer could due to decrease in total rainfall over the years as *S. innotata* is dominant in regions with distinct dry and wet seasons.

Uttarakhand

Blast is the major disease of rice in Uttarakhand and contributes to significant crop loss up to 65% in North West Himalayan hills. Among the insects, loss due to stem borer is the highest. Under upland conditions loss due to white grub is up to 30% and occasionally results in total crop failure. Rice planthoppers are of minor importance under hill conditions till now. The incidence of BPH and blight are reported of late in low hills and likely to increase. The changes in insect pest incidence are extended up to an altitude of 1000 meters in hills (Stanley *et al.*, 2009).

Karnataka

More than 28 insect species have been reported on rice as pests from the state. Among them, BPH, YSB, LF (*Cnaphalocrocis medinalis* (Guenee)) and GM are major ones (Gowda & Gubbaiah, 2011). A study was conducted on the status of paddy pests under rainfed ecosystem in Uttara Kannada district of Karnataka during 2008-2009. The roving survey revealed that only the ear head bug population crossed economic threshold level in most of the taluk's during both the seasons at reproductive phase of the crop. The considerable incidence of yellow stem borer and leaf folder was noticed only in Mundgod, Haliyal and Honnavar talukas. Heavy incidence of blue beetle and green leaf hopper were recorded in Mundgod taluk (Kulagod, 2009).

Odisha

The rusty plum aphid *Hysteroneura setariae* Thomas has been reported long back from south India and Cuttack, Coastal Odisha (David *et al*., 1967 and Dani, 1986) as a minor pest of rice. Recently it has been reported from North-Eastern Ghat Zone of Odisha for the first time indicating its spread to interior districts (Mishra *et al*., 2010).

With a view to conserve natural resources, environment and increase the productivity several production practies are being developed and refined. These practices of rice cultivation may also influence the pest scenario besides the changing climatic conditions. Due to present difficulties in labour force for engagement of different agricultural operations, direct seeded rice (DSR) is getting popular among the farmers. Impact of DSR and newly emerging genetically modified rice plants on insect pest scenario needs to be investigated.

Organic rice

Organic farming is useful for the preservation of environment. It is of special importance for cultivation of export quality aromatic rice. Investigations made at CRRI, Cuttack from 2004-2006 with seven treatments revealed that the population of planthoppers was more in plots treated with FYM alone whereas the least population of hoppers was observed in the plots where FYM + GM were applied. Therefore, appropriate organic nutrient source should be standardized as this also affects pest build up. Studies on the effect of application of organic and inorganic fertilizers on the YSB incidence indicated that incidence was least where *Sesbania aculeata* was applied (Chakraborty, 2010). The minimum incidence of YSB and egg masses were observed in plots fertilized with 2.5 t vermin-compost alone. Katti *et al*. (2006) found vermi-compost and FYM treatments to be superior showing relatively less dead heart damage due to yellow stem borer.

Aerobic rice

Aerobic rice is a way of growing rice in aerobic soils with intermittent irrigation. It is a system of growing high yielding rice in non-puddled and non-flooded aerobic soil. Rice cultivation in aerobic conditions may lead to unknown challenges with respect to productivity, weed infestation pest and disease incidence (Singh *et al*., 2002). Termites (*Odontotermes obesus* Rambur) occur as pests in light soils and areas of marginal rainfall and drought. Aerobic rice cultivation in such areas is affected by this pest.

Hybrid rice

In certain localized areas in Jharkhand hybrid rice varieties were severely affected by mixed population of BPH and WBPH during 2011. Prasad *et al*., 2012). Rice hybrids have larger total biomass and are more responsive to fertilizer. Hybrids also have a high tillering capacity and are genetically uniform. Investigations were undertaken at Central Rice Research Institute, Cuttack and in farmers' field to assess the magnitude of pest problem on hybrid rice. Stem borer, gall midge, whorl maggot, leaffolders, BPH &WBPH, bacterial blight and sheath rot were the major insect and disease problems. Incidence of silver shoot was more on hybrids compared to either of their parents. However, incidence of gall midge has been very low in recent years. Gundhi bug was also observed during both the seasons. Incidence of diseases was more in wet season. At the initial stage of hybrid rice development, increase of yield was the major objective. Recent experiences indicated that it would be better to incorporate insect and disease resistance in hybrid rice.

System of rice intensification (SRI)

Results of experiments undertaken on SRI revealed that stem borer damage was significantly lower under SRI during vegetative phase while at reproductive stage it was at par with conventional method of cultivation. The incidence of whorl maggot and case worm damage were lower under SRI (Karthikeyan *et al*., 2010). Similar observations were also made by Behera (2012) except that white ear head damage was less under SRI. The change in pest status on SRI could be due to alternate wetting and drying, application of FYM and wider spacing of 25 cm x 25 cm which is unfavourable to the pests.

New plant type

Green revolution was mainly due to the release of improved high-yielding varieties (HYV) with the characteristics of high response to nitrogen fertilizer and high tillering ability. However, canopy structure of modern varieties with luxuriant vegetative growth and dense foliar canopy has also created lodging and disease and pest problems (Mew 1991). To increase the yield potential of rice further, a new plant type was conceptualized and IRRI scientists proposed further modifications of plant architecture, with the characteristics like; low tillering, no unproductive tillers, dark green, thick, and erect leaves, vigorous and deep root system (Khush, 2007). The potential impact of erect leaves in the canopy and insect abundance need to be investigated as the microclimate would be changed. As regards insect pests, especially planthoppers infesting at the base of the hill such penetration of solar radiation would result in reduced population. In the rice field there are a number of habitats in terms of a vertical stratification in which insects live.

The geometrical structure of a rice canopy has been investigated for optimization of light penetration, light receiving efficiency, photosynthesis activity and yield in relation to breeding programs by the use of modern tools and computer based modeling, but aspects of insect abundance in relation to canopy structure are lacking. It seems possible that, besides susceptibility of a cultivar, canopy structure and its climatic factors could influence insect abundance on rice plants. Intensive study in this regard is necessary for better understanding of the interaction among host plant, insects and environmental factors (Prakash & Behera, 2008).

Biotypes

Gall midge

Breeding resistant varieties and their cultivation has been the main approach to manage damage due to GM. However, the breakdown of resistance conferred by the major genes, deployed one at a time, through evolution of virulent biotypes has become a major setback to this approach. However, the choice of resistance genes needs to be made with a better understanding of the virulence composition of the pest populations in the target area and the genetics of plant resistance and insect virulence. Results on biotype composition showed heterogeneous pest populations in all the tests and at all the locations. Tests at Warangal repeated after 8 years showed a rapid increase in frequency of the virulence allele conferring adaptation to the plant resistance gene *Gm2* as compared to that of the allele for adaptation to the resistance gene *Gm1*. This is probably the first direct measurement of a durability parameter of plant genes conferring insect resistance (Bentur *et al*., 2008).

Brown planthopper

Six biotypes of BPH have been reported from all over the world. Indian biotype of BPH is different from all other biotypes and is designated as biotype 4 (Khush and Brar 1991). Three genes such as *bph-5, Bph-6* and *bph-7* confer resistance to biotype 4 only. Several resistant varieties are available against BPH in India which in due course of time may induce development of biotypes although so far Pantnagar population is identified to be somewhat different from other areas.

Molecular characterization of insect populations

Rapid gene flow among migratory insects like hoppers (BPH, WBPH & GLH) may lead to high degree of genetic diversity. Assessment of genetic variability using random primers among BPH populations from 4 locations in Odisha and 5 locations in Andhra Pradesh resulted in amplification of 137 bands. Genetic variation exists between BPH populations at molecular level and the BPH population from Pipili, Odisha was found to be different from others (Mohanty *et al*., 2011). Thus molecular characterization of prevalent insect pests may indicate future possibilities of their adaptation and distribution in specific locations.

Influence of climate change

Increase in global temperature is associated with increase in atmospheric carbon dioxide and other green house gases. Global increases in CO_2 along with other bio- and anthropogenic trace gases such as methane and nitrous oxide trap, out going thermal radiation leading to enhanced temperature on earth's surface. This rise in temperature is expected to influence insect feeding and breeding behaviour and other biological events of insect pests associated with rice.

Weather conditions that affect insect incidences are temperature, humidity, rainfall, sunshine, wind velocity and natural calamities like cyclone, flood, drought, tornado etc. Temperature is considered to be the single most important environmental factor which mostly influences the insect behaviour, distribution, development, survival and reproduction. It was believed that the effect of temperature on insects largely overwhelms the effects of other environmental factors.

Temperature alone can become a key factor for insect emergence and predominance in dry season rice. But in wet season, all the weather parameters like temperature, rainfall, humidity, sunshine hours and wind velocity work together for increase or decrease of the insect population and extent of damage.

Yellow stem borer

Extremely high or low temperature kills insects effectively. However, within their survival range the population increases at a higher rate with higher temperature. The larva of YSB passes through four to seven instars with a total duration of 35-45 days. At high temperature development is accelerated with a minimum of four stadia (Senapati & Panda, 1999). The YSB undergoes diapause when there are changes in the day length and temperature. In India this phenomenon is observed from November to January. The hibernation is broken on prevalence of warm weather. Thus with global warming the termination of diapause in YSB may be earlier than usual and its seasonal activity may be prolonged. Analysis of long term light trap data from 1973 to 2008 vis-à-vis average annual maximum temperature and minimum temperature at CRRI Cuttack indicated that the average maximum temperature has decreased over the years while the average minimum temperature has increased. This has resulted in increase of YSB population and decrease in population of *Chilo.* Increasing trend of YSB population could be due to increase in average minimum temperature, which in turn could negatively influence diapause and thus helped in population increase**.** In view of the global warming, average monthly YSB moth catch from 1973-1985 and 1995 to 2008 was analyzed separately along with maximum and minimum temperature during the period of study. During the first period there were two peaks in a year where as there were 3 peaks in period two of higher magnitude indicating the change of trend and severity of the pest.

The emergence pattern of YSB for 10 years (2001-2010) during dry season revealed that peak emergence of YSB was always related to the temperature. The suitable range for peak was found to be maximum temperature from 24.2-30.3^{0}C and minimum temperature of 14.8-19.2. The early broad emergence of YSB during 1st week of January, 2009 followed by successive brood and continuity of insect upto April shows that with increase in minimum temperature and maximum temperature remaining within 28-30^{0}C insect like YSB can infest the dry season rice crop for a longer period necessitating more management strategies. (Jena, 2009).

Gall midge

Gall midge proliferates at a higher humidity or precipitation. Percent increase of silver shoot correlated with 10 days lag period weather parameters indicated that contributions of minimum temperature (52.7%) and rainfall (39.7%) were important (Behera *et.al.*, 2002). Due to global warming there may be more rain in some places and less in other places. Gall midge incidence and severity will be more in areas of higher precipitation, where it was not noticed in earlier years. Similarly in some areas its activity may be reduced when there is no adequate rain.Research findings indicated that when monsoon rains started early on March-May, the peak of gall midge activity reached on July. But when monsoon rain started late, *i.e,* in 2nd fortnight of June, the peak activity was reached in September. Gall midge peak period was recorded within the maximum temperature range of 31.8^{0}C and 30.5^{0}C with an average of 31^{0}C. The minimum temperature being within 21.9^{0}C to 19^{0}C with an average of 20.2^{0}C. Analysis of historical data on GM incidence at Cuttack indicated that early monsoon and years of good rainfall were good for GM infestation.

Leaf folder

Light trap catch analysis at CRRI, Cuttack from 1990-2009 was analyzed to study the population trend of the pest over the years. The mean annual leaf folder population from 1990 to 1999 and 2000 to 2009 indicated that over the years the magnitude and number of peaks have increased. Earlier (1990-1999) there were two peaks of LF population in dry season and grossly two peaks in wet season, whereas in recent years three small peaks in dry season and four peaks in wet season were evident (Behera *et al*., 2010). The leaf folder, *Cnaphalocrocis medinalis* needs temperature of 25-32^{0}C and high RH of 83-90% for its better development.

Among the three species of leaffolders prevalent on rice in India, activity of *Brachmia arotraea* is restricted to colder months of the wet season rice crop; where as *Cnaphalocrocis medinalis* is widely prevalent and active during warmer months in the wet season as well as throughout the dry season (Mishra *et al*. 1999). The other species *Marasmia exigua* is observed to be active mostly during wet season, thus increase in the temperature may restrict its prevalence to a limited duration in the season. Thus the leaffolder species *Cnaphalocrocis medinalis* may continue to be the dominant one in future also. The effect of increase of CO_2 concentration in the atmosphere is likely to influence the feeding behaviour of leaf feeders like leaffolders and skippers of rice. With increase in temperature the leaves tend to have a lower protein concentration. Thus leaf feeders must consume more foliage to survive on plants grown in a high CO_2 environment (Wolfe, 1993). Thus severity of these pests may increase with increase in environmental temperature.

Pest incidence on five aromatic rice varieties was studied during wet seasons of 2001-2006 at Cuttack. Analyses of weather parameters indicated that they play a major role in creating variation in pest prevalence. High rainfall during June- July, with low sunshine hours in August followed by gradual decrease of rainfall with increase in sunshine hours towards September and October resulted in more pest incidence (Jena *et al.*, 2009). Hot and high humid conditions during July, August, September with low sunshine hours supports hispa and case worm population. Swarming caterpillar becomes a menace after heavy rainfall and flood. There are some pests which required low humidity and rainfall. Mealy bug can prevail up to 40^0C but no standing water should there in the field. Termite occurs in drought and low soil moisture. So, it is a serious pest of upland rice ecosystem. Whorl maggot needs low standing water. Thrips become more prevalent during the year of delayed monsoon and low rainfall during June and July.

Insects have a wide genetic base and it seems possible that incipient population in nature, with an ability to withstand higher temperature regime and changed climatic conditions may get selected over time with gradual increase in temperature and get adapted to the changed environment without much hazard (Behera *et al.*, 2005).

Irrespective of increase in number of insect pest species of economic importance and infestation in new areas over the years the estimated/avoidable yield loss remains fairly constant around 25% (Pathak and Dhaliwal, 1981) to 28.8% (Pasalu *et al*., 2008). This could be due to efficient insect management technologies available in the recent years. The changes in status of rice insect pests appear to be a continuous process as the climate changes, new rice production technologies are developed and adopted by farmers over large areas and since the insects as a group are highly adaptive and dynamic, their pest status on rice also changes across the regions and seasons. This situation will demand more management strategies and more pesticide application resulting in significant economic costs for growers and environmental cost for the society.

Emerging diseases of rice

Extensive areas of rice monoculture and intensive cropping of rice increased severity of the diseases and several major diseases became even more severe and minor diseases appeared in epidemic form. The severity of is mostly governed by the cultivation practices and the prevalent climatic conditions in the area. The diseases like sheath blight, sheath rot and rice tungro disease were insignificant or unknown prior to introduction of exotic varieties. The occurrence of diseases in each ecosystem during the last decade of 20th century is given in Table 4.

Table 4. Prevalence of diseases in different rice eco-systems

Name of disease	Prevalence of diseases (%)			
	Rainfed upland	Irrigated	Rainfed favourable Shallow lowland	Rainfed lowland including deep water
Blast	28	14	12	49
Brown spot	18	-	12	-
Sheath blight	18	14	12	63
Sheath rot	09	07	-	-
Stem rot	-	07	-	64
False smut	-	7	8	-
Bacterial blight	-	22	20	57
Bacterial streak	18	7	12	-
RTD	-	22	12	49

Source: Pathak et al., 1998

Recently among rice diseases, blast, bacterial leaf blight, sheath blight, brown leaf spot and false smut were recorded to be the significant ones. Of these, the sheath blight and the false smut became important only after the green revolution (Chander *et al*., 2003). False smut disease of rice was considered as the sign of good harvest, for example in Tamil Nadu once a minor disease is now regarded as a serious disease.

Although around 70 diseases of rice are reported, 2 most destructive diseases are Blast and Bacterial Blight. Over a period of 30 years, following variations are observed. Diseases becoming the major constraint for yield are Sheath blight, False smut, Brown spot and *Fusarium* spp. Some of the diseases that appeared in pockets may become major constraints in future are Fungal sheath rot, Bacterial sheath rot, Seedling mortality by *Sclerotium rolfsi*. Primary source of inoculum are internally seed borne**,** Bacterial blight (BB), Blast, Brown spot, Sheath rot (fungal and bacterial), Seedling elongation, foot rot, seedling rot by *F. moniliforme*; externally seed borne or as admixture in seed are Sheath blight, False smut, seedling blight by *Sclerotium rolfsi.* Some of the soil borne diseases are Seedling elongation, Foot rot, Seedling rot by *F. moniliforme*; Sheath blight, False smut, Seedling blight by *Sclerotium rolfsi*. Besides the above, all the diseases may spread through collateral host / stubbles of infected plant / diseased plant parts left in field.

Sheath blight disease caused by *Rhizoctonia solani* Kuhn was first recorded as a minor disease of rice in West Bengal (Roy, 1978). Later the disease was referred to as a major one in West Bengal, second only to blast in its crop damage potential (Biswas, 2000). Yield losses due to this disease is reported to range from 5.2 to 50%, depending on environmental conditions, crop stages at which the disease appears, cultivation practices and cultivars in India (Rajan, 1987).

Over the years minor diseases have become major ones. Bengal Famine of 1943 was the result of crop failure due to brown spot of rice caused by *Bipolaris oryzae* but afterwards through host plant resistance and by adapting appropriate control measure it was not a yield constraint. Recently Brown spot has again appeared in rice-growing areas. *B. oryzae* caused sever brown spot infection at Cuttack . *B. sorokiniana* basically a wheat pathogen was also isolated from brown spots produced on rice cultivars especially on scented rice cultivars and hybrid rice seeds. Collateral host may play a role as a source of primary and supplementary secondary inoculum resulting in aggravation of the disease.

Brown spot was known to be associated with soils deficient in nutrients whereas rich soils especially with more Nitrogen content favoured false smut. A survey carried out in October 2007 in Chhattisgarh to assess the extent of False smut infestation indicated that more than 600 ha were severely affected by the pathogen. Late-sown rice varieties such as Swarna, Tapaswani, Komal and Culture 64 grown in lowland areas showed unprecedented levels of False smut. Rice variety Tapaswani was the most severely affected. The minimum and maximum temperature ranges recorded in October 2007 were 23–25ºC, respectively. Intermittent rains in September and October (at flowering stage) and the associated increased humidity probably favored the disease. Before 2005, False smut was not considered a major disease of rice in India (Singh and Pophaly, 2010).

The seed discoloration has emerged to be a major constraint in cultivating the photo-sensitive high yielding rice cultivars during the wet season. *Fusarium* was found to be associated with the discolored seeds of long duration high yielding rice varieties and yield losses up to 20% were recorded due to this pathogen in the coastal regions of Odisha. This seed-borne pathogen increased number of unfilled or partially filled seeds. The fungus infects plants through roots or crowns which later become systemic. Significant genetic variability was observed in this seed pathogen collected from the coastal region of Odisha and most of the high yielding rice cultivars were susceptible (Mohanty and Dhua, 2007).

Seedling blight was observed in nursery beds of rice variety Sarala at Cuttack during Kharif 2009. The causal organism for this disease was *Sclerotium rolfsii.* Seedlings were affected in irregular patches. Stem base and roots of affected seedlings turned brown. The growth of infected seedlings was retarded followed by yellowing of leaves and seedling mortality. White mycelia growth and white small round sclerotia were produced on roots as well as on stem bases. It has ability to cause pre-emergence seed rot and post emergence seedling blight. This is a virulent strain of pathogen (Dhua *et al.*, 2010).

Foot and sheath rot of rice caused by *Pectobacterium carotovorum* subsp. *carotovorum* and *Pseudomonas syringae* pv. *syringae* were recently observed on rice (Khoshkdaman *et al.*, 2008). Bacterial sheath rot was observed in a small patch at Cuttack. Pathogen was isolated from the infected sheath samples.

Rice Tungro Disease (RTD), which appeared in north India during 1967, moved to peninsular India in 1977. Tungro outbreaks were discontinuous within a district, state and country over the years. The outbreaks of this disease were restricted to irrigated and rainfed shallow lowlands. Three major epidemics in farmers’ fields during 1984, 1988 and 1990, caused severe quantitative and monetary losses. An epidemic outbreak of tungro during 2001 in three districts of West Bengal caused rice production loss of 0.5 mt. The study demonstrated that tungro epidemics could cause a maximum production loss of 53% in a district, 23% in a state and 2% in the country (Muralidharan *et al*., 2003). However, presently incidence of Tungro is at a minimal level and has acquired minor disease status.

Bakanae, a minor disease occurs in both upland and lowland cultivated rice. The disease is widely distributed in all rice growing areas. The fungus, *Fusarium fujikuroi* is cosmopolitan in distribution and found in all rice growing areas of World. In India it is more prominent in Haryana, Punjab and Uttar Pradesh. Reports indicate that the disease causes up to 20% of yield losses, which may increase in endemic areas with no crop rotation (Sharma *et al.,* 2011).

Why minor diseases have become major ones?

The fields planted with modern varieties develop a distinctly different micro-climate. The cultivation of dwarf varieties, therefore, seems to have brought relative changes in the status of insect pests and diseases. This is confirmed by the fact that several new pests appeared immediately after new varieties were introduced. Because of their narrow genetic base, HYVs are inherently vulnerable to major pests and diseases. Even where new varieties are specially bred for resistance to disease, "breakdown in resistance can occur rapidly and in some instances replacement of varieties may be required every three years or so. (CGIAR, Integrative Report, 1979) Large-scale monoculture provides a large and often permanent niche for pests, turning minor diseases into epidemics; in addition, fertilizers have been found to lower plants' resistance to pests. (Vandana Shiva, 1991).

Unwise farming practices are also to blame for increasing pest and disease problems. Many farmers have planted high-quality varieties not recommended for their areas, with consequent increased attacks by BPH, WBPH, sheath blight, sheath rot, and false smut. *Rhizoctonia solani* Kuhn (Teleomorph: *Thanatephorus cucumeris*), is a widely distributed soil-borne plant parasitic-saprophytic fungus. Sheath blight (ShB) disease caused by *R. solani*, is becoming a major constraint to rice production, especially in the intensified cultivation system (Jayaprakashvel and Mathivanan, 2012). The emergence of *R. solani* as an economically important rice pathogen has been attributed to the intensification of the rice-cropping systems with the development of new short-statured, high-tillering, high yielding varieties, high plant densities and an increase in nitrogen fertilization. These factors promote disease spread by providing a favorable microclimate, due to a denser leaf canopy with an increased leaf-to leaf and leaf-to-sheath contact. Incidence of rice sheath blight disease has increased in recent years, because of the unavailability of resistant cultivars or any other suitable economic disease management measures.

Bacillus spp of bacteria offer an effective control of ShB besides inducing growth promoting effects and systemic resistance (Vijaykrishna *et al*. 2009). Among the fungal bioagents, *Trichoderma* spp are important biocontrol agents that are effective against major soil borne diseases. Application of *T. harzianum* with soil organic amendments such as FYM, wheat straw, dhaincha (*Sesbania aculeata*), saw dust and neem cake worked effectively in managing rice ShB and also in increasing grain yields (Khan and Sinha, 2006). *Bacillus* spp. associated with cow-dung was found to be antagonistic to soil bone pathogenic *Fusarium* spp. and sclerotia of virulent *Sclerotium rolfsi* cause of seedling blight of rice. In earlier period bullock, compost and FYM acted as back bone of Indian agriculture but after green revolution maximum use of chemical fertilizer was observed and it may be one of the reasons for the increased incidence of soil borne diseases.

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Important Socio-economic and Ecological Factors Affecting Rice Production in India

K.V. Rao, B. Shailaja, B. Nirmala and B.C. Viraktamath

Rice is the single largest food source of the country contributing 30 - 76% of calorie requirement to more than 70% of Indian population. India has the world's largest area under rice (44.5 million ha in 2011-12) and is the second largest producer (103.4 million tonnes in 2011-12) next only to China with average productivity of 2.31 t/ha which is lower than world's average productivity of 2.9 tons/ha. It accounts for greater than 25% of global rice area of about 160 million ha and 22% of global rice production (685 million tonnes). Within the country, the crop occupies one-quarter of gross cropped area, contributes 40 to 43% of total food grain production and continues to play a vital role in the national food and livelihood security. India exports more than 6 million tonnes of rice worth about Rs. 12,000 crores (second to Thailand), and accounts for nearly 25% of total agricultural exports from the country.

The crop ranks first in the use of land and water resources (> 50% irrigation water), and inputs (38-40% of fertilizers and 17 – 18% pesticides) and a wide range of crops of varied productivity levels are grown in large areas in sequence with rice. Of the current total fertilizer nutrient use of 28 million tonnes (2011 – 12) major portion (>10 million tonnes) is used for rice production. Among the states, highest per-hectare consumption is in Punjab (210 kg) followed by Andhra Pradesh (200 kg) in 2008. Under rice-wheat cropping system, average per-hectare consumption of nutrients in the IGP exceeded 350 kg/ha. Each ton of cereal removes about 82 kg of plant nutrients out of which 75% is accounted by NPK. Production of about 8-12 tons of grain/ha annually in a cropping system is associated with uptake of 140-330 kg N, 70-120 kg P_2O_5 and 200-390 kg K_2O/ha which however could vary in space and time. Rice consumes about 2500 – 3000 liters of water/kg grain production. At this rate total irrigation water requirement for rice with due consideration to rainfall, soil water storage, total evapotranspiration and losses in different regions, has been

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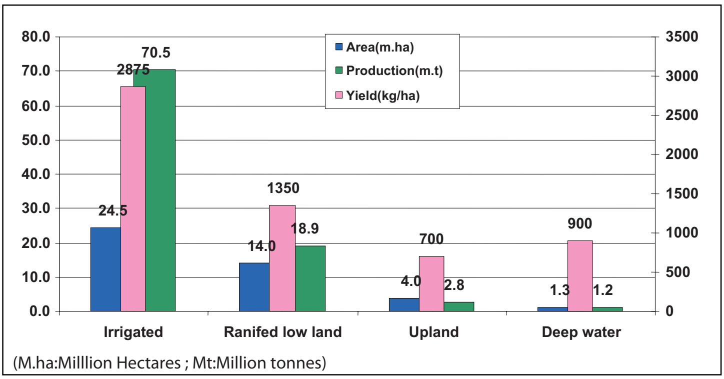
estimated to be about 200 km^3 per year, maximum being in north western (98 km^3) followed by southern (53 km^3) and eastern states (40 km^3) (Frolking *et al* 2006).

While there is a need to further increase the productivity of crops (particularly of rice and wheat) and the system @ 3.0 – 7.5% and bridge the existing yield gaps between the realizable and farm yields, which range from 15 – 70% depending on the rice ecosystem, adoption of situation specific high yielding cultures and precision technologies for efficient management of soil and water resources / nutrients and biotic stresses becomes more relevant in the current production scenario. The issue becomes more complex with the need for increasing cropping intensity and cultivation of varieties with higher yield potential, in view of observed negative impacts of green revolution on soil resource quality and its productivity, and emerging problems associated with climate change on the agricultural system.

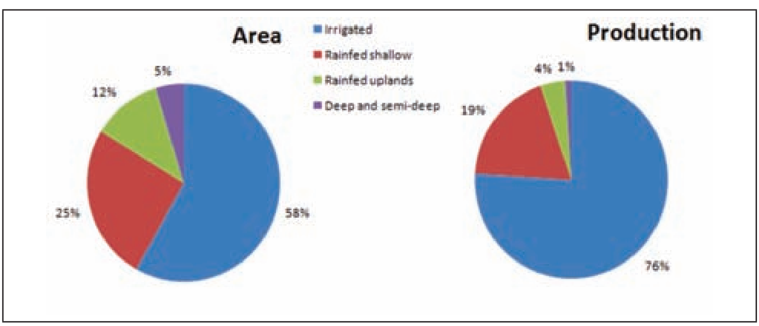
Rice ecologies and productivity

One of the reasons of relatively low productivity of rice in India is that the crop is grown under diverse agro ecological conditions and production systems broadly grouped into irrigated and rainfed systems.

Among these, further sub-systems are usually identified to take location specific variations such as ‘favorable’ or ‘unfavorable’ moisture regimes, temperature, proneness to drought, submergence, growth duration (early, medium, late maturity groups) and low light intensity conditions. The different ecosystems under which rice is cultivated may be broadly classified as (i) irrigated (ii) rainfed lowland (iii) rainfed upland and (iv) Deep water rice (Shobha Rani *et al*., 2010). Irrigated system is considered most favorable accounting for the largest area (> 25.5 M ha) and contributes highest production (~75.0 Million tonnes) and productivity (2.9 t/ha). Rain fed system is classified into a wide range of subsystems like shallow, medium deep and deep water lowlands and uplands with varied productivity levels. Rain fed shallow (up to 30 cm, considered favorable under rainfed system, productivity 1.7 t/ha) and medium lowlands (30 – 50cm) cover about 13.5 Mha, rainfed uplands ~ 4.2 Mha and semi deep to deep water rice ~1.3 M ha (DRR Vision, 2030). Based on available figures, out of 563 rice growing districts, 115 districts (20.4%) in the states of Andhra Pradesh, Tamil Nadu, Punjab and Haryana are predominantly irrigated with an average rice yield of 3.2 t/ha (2009-10). Likewise states of Uttar Pradesh, Bihar, West Bengal, Orissa, Jharkhand, Chattisgarh and Assam have predominantly rainfed shallow lowland system (considered favorable under rain fed ecology). Rain fed uplands which form the low productive system with average yields of 0.8 t/ha. Rest of the rice area is deep and semi-deep water with low productivity of 0.5 t/ha. Depending on the rainfall distribution, rice is cultivated as rainfed upland crop in southern Bihar (present Jharkhand), eastern Madhya Pradesh (present Chhattisgarh), Western Orissa (Jeypore) and parts of West Bengal (Purulia and Bankura regions). On the other hand, it is also grown in shallow (up to 30 cm), semi-deep (30-100 cm) and deep water (>100 cm) ecosystems in eastern Uttar Pradesh, Bihar, West Bengal, Assam and Orissa.



Ecosystem wise rice area, production and yield in India 2006-07



Relative contribution (%) of different rice ecologies in terms of area and production

Rice area, production and productivity in India have undergone a significant change during the last six decades. Area increased by 45% from 31 M ha in 1950-51 to about 45 M ha in 2008 at an average decadal growth of about 6 – 7% (up to 2000) more prominently in the northern and north eastern region and a decline in the southern (Kerala and Tamil Nadu) region. Among the states Uttar Pradesh tops the list in area (5.92 M ha) followed by West Bengal (5.68 M ha), Orissa (4.5 M ha), Andhra Pradesh (3.97 M ha) and Chhattisgarh (3.72 M ha). Production of rice during the same period increased by five times at an annual growth of 2.2 – 5.2% maximum being during 1980s and more prominently in Punjab, Haryana, Andhra Pradesh, Uttar Pradesh, West Bengal, Gujarat, Karnataka and Orissa. In Kerala, Mizoram and Rajasthan there was a decline in production by almost 50 percent. Productivity of rice increased from 0.67 t/ha (1950-51) to 2.3 t/ha in 2011-12, an increase of 245% largely due to cultivation of HYVs (currently ~85%), improved management practices, spread of mechanization and expansion of area under irrigation. State wise, highest productivity was recorded in Punjab (3.86 t/ha) followed by Tamil Nadu (3.42 t/ha), Haryana (3.32 t/ha) and Andhra Pradesh (2.98 t/ha).

Rice soils in India

More than 15 major soil groups of diverse characteristics are cropped to rice under different ecosystems (rain fed upland to deep water and irrigated), and agro climatic conditions. The crop is grown in 11 out of 15 agro climatic zones in west and eastern Himalayas, IGP, major portion of southern and eastern plateau region, eastern and western coastal region and the islands of Indian Ocean. Major soil types that are cropped to rice and rice based cropping systems; suggest that predominantly alluvial soils, red and yellow loams, shallow to deep black soils and lateritic soils are cultivated to rice in about 44 M. ha. The soils cropped to rice have characteristics which vary widely from sandy loam to clay in texture; soil pH from 3.0-10.5; organic carbon from 0.2 to > 2.0%; cation exchange capacity (me/100g soil) from < 10.0 – 50.0; and very low to high available nutrient status. Barring about 5.0 M ha of upland rice, the crop is cultivated under wet / flooded conditions, a unique system followed exclusively for specific benefits of crop establishment and growth, weed control and crop nutrition. The system is not without constraints due to *in situ* soil problems and biotic stresses that influence agricultural production including rice but also due to the physico-chemical changes brought about by flooding the soil which can adversely affect the crop (Rao *et al*., 2010)

Future rice demands

There have been several projections of demand of food grains and rice based on per capita consumption of rice and projected population which is likely to be 1.45 billion by 2030 from the current population of 1.17 billions. This would lead to a progressive decrease in per capita land area available for farming to about 0.25 – 0.35 ha assuming no diversion of farm land to non-agricultural use or not affected by physicochemical degradation. About 120 million rice farm holdings each of < 0.5 ha have been reported. Food grain production needs to be increased to 300 M. tons by 2025 at low food demand, 338 M. tons for a medium demand and 423 M. tons for high food demand. To achieve the estimated food grain demand of at least 300 M tons by 2025, the country would be requiring about 45 M. tons of nutrients which includes about 2.5 Mt of Zn and S and 15 Mt for production of commercial crops (ICAR 2008).

Annual growth rates in production have been the criterion for such estimates of rice requirement. Considering a marginal decline in the per capita consumption of rice to about 73 kg per annum (Mittal, 2008) the demand for domestic consumption has been projected to be about 107 million tons (Mt) after accounting for 12.5% seed and feed demand, industrial use and wastage. Earlier study had projected the demand of rice to be 142.2 Mt for 2030 (Kumar 1998). Goyal and Singh (2002) estimated a demand of 146 Mt of rice (taken as 50% of total cereals), while a third projection by ICAR, 2010 puts rice demand to be 156 Mt by 2030. It is very clear that India needs to produce about 2.0-2.5 million tonnes additional rice per year to meet the projected demands. Keeping in view the estimated growth and contribution of different rice ecologies to total rice production and with least change in the rice area, the projected demand of rice can be met with emphasis on productivity enhancement of irrigated and rainfed low land ecosystem by 1.2-1.5 t/ha and 0.7-0.8 t/ha, respectively and with sustenance.

Constraints in rice production: abiotic constraints

Depending on the location specific variations in rainfall intensity and distribution, temperature regimes and light intensity sub ecosystems of rainfed rice are exposed to various levels of moisture stress like drought and submergence, cold and heat stress during early and late stages of boro rice, and low light intensity conditions in the coastal, eastern India and hill regions. Water, labor and land are the major constraints in productivity enhancement. Water availability for rice cultivation, which requires about 2,500 to 3000 liters of water per kg of grain production, is declining at an alarming rate. Rice alone consumes more than 50% of share of water for agriculture purpose and feasibility of water saving in other crops is less. Labor shortage is another major limitation in view of migration of rural poor to urban areas. Further fragmentation of land will limit effective management. It is estimated that the average size of holding in India would be mere 0.68 ha in 2020, and would be further reduced to a low of 0.32 ha in 2030 (ICAR 2010).

Rice cultivation is also becoming less and less remunerative to the cultivators. Cost of cultivation of rice, which varies from region to region depending on the rice ecology and production potential, range from Rs. 16,700 in Himachal Pradesh to Rs. 45,300 per ha in Punjab and from Rs. 6,480 per ton in Bihar to 15, 550/t in Maharashtra in 2008-09. This has been increasing year to year and has implications on productivity growth and sustainability of the production system. The net returns over paid-out costs for rice farmers have also shown a declining trend @1.15% per annum in real terms over the last 20 years (Mahendra Dev and Rao, 2011). Timely availability of inputs like improved seeds, fertilizers and credit and lack of awareness of modern cultivation practices are also contributing to the poor production environment.

Further, intensive agriculture that realized self sufficiency in food supply, is now becoming the cause for severe degradation of soil and its quality, nutrient depletion, multi-nutrient deficiencies and toxicities, and declining crop growth rates questioning the very capacity of the system. The projected demand to produce food at more than 2.5% has to be met under conditions of diminishing per capita arable land and water resources of decreasing quality, and expanding abiotic and biotic stresses. In other words the demand for food and other commodities has to be met through higher productivity per unit of land, water, energy and time. Given the situation on food front, over exploitation and mismanagement of soil and water resources and fertilizer inputs for immediate gains without regard to long-term sustainability of soil productivity have led to different kinds of degradation processes resulting in at times irreversible soil conditions. Available information on loss of productivity due to soil degradation indicates that it is higher in red soils compared to black and alluvial soils (Velayutham and Bhattacharya, 2000). Extent of loss of yield due to high pH (9.5 and above) and soil acidity (pH 3.5 – 4.5) could be 25-50 per cent.

Rice and rice based cropping systems (RBCS) (27.9 M.ha) are the major systems contributing to food production and also consuming major portion of all resources and inputs. Important rice-based cropping systems under different agro-climatic zones of India are rice-wheat (9.80 M.ha), rice-rice (5.9 M.ha.) and rice–fallow (4.4 M.ha). Future gains in food production have to come from RBCS which are already intensively cultivated with substantial nutrient flows. The crop and the cropping systems are grown under most diverse soil and agro climatic conditions including large tracts of soils with *in situ* problems and management induced constraints. While the unique system of wetland rice cultivation provided many beneficial effects to the crop in terms of nutrient supply, weed and water control, and tolerance to specific soil stresses, the system also created problems of soil salinization and water logging of many fertile lands in the canal commands because of sharp rise in the water table. Similarly in the areas of high productivity potential deficiency of many nutrients (Zn, Fe, S, K), have been reported after high intensity rice crop systems and high yielding varieties were introduced, which is further compounded by imbalanced and indiscriminate application of fertilizers nutrients. Imbalanced use of fertilizer nutrients has resulted in a negative nutrient balance in the system particularly of potassium at an alarming deficit level of 18 M. tons of K. The impact on the productivity of the soil system has been perceptible with wide spread occurrence of multi-nutrient deficiencies and toxicities some of which are specific to rice systems such as Fe, sulphide and boron. The low nutrient use efficiency and factor productivity in rice crop systems have resulted in significant decline in growth rates of the crops under intensive agriculture. Analyzing the long term studies in India and neighboring countries (33) in rice – wheat cropping systems Ladha *et al*., (2003) reported that even with recommended practices, the productivity of rice and wheat stagnated (72 – 85% experiments) or significantly declined particularly of rice mainly attributed to nutrient mining. Similarly there was perceptible decline in productivity growth, decreased responses to applied nutrients and declining soil quality in rice - rice system under intensive cropping (DRR, 2010).

Compounded by this discouraging situation is the emerging problem associated with climate change which influence agricultural productivity through its impact on land use, its quality, availability of irrigation water and use efficiency of resources and inputs (fertilizer, irrigation, tillage), pollution of surface and ground waters, and emission of greenhouse gases (GHGs) from the soil / terrestrial / aquatic ecosystems besides direct effects of increasing temperature, CO_2 and low light intensity etc influencing crop growth, productivity and input efficiency. Water shortage in future is likely to threaten agriculture in general and conventional rice cultivation system in particular warranting a re-look into the current practices and design strategies for enhancing resource quality and water productivity.

Major soil and management related constraints observed in rice are increasing area under salt affected soils (8-10 M ha) due to improper irrigation and drainage facilities - major portion of which is cropped to rice, Large area under acid soils are associated with toxicity of Fe, Al, H_2S, Mn, As, deficiency of K, Ca, Mg, B, Si, and high P fixation, nearly 8.0 M. ha of rice area is zinc deficient. Nutrient depletion (N, K, S, micronutrients) and loss of soil organic matter is prevailing in intensive cropping systems, Mn deficiency is observed in 3.0 M ha in northwestern states under rice-wheat cropping system. Depleting ground water reserves and deteriorating soil quality and blanket fertilizer management / recommendations over large domains have resulted in stagnation or deceleration of growth in productivity of crops and cropping systems

Biotic stresses

Five insect pests *viz*., rice yellow stem borer, gall midge, brown plant hopper, white backed plant hopper, and leaf folder have been recognized as major pests responsible for significant decline in yield of rice in different cropping zones. Other pests like whorl maggot, rice hispa and green leafhopper in wetlands, gundhi bug and climbing cutworm in upland rice have been considered as of regional significance. Emerging pests of concern are rice thrips in southern region, mealy bug and caseworm in eastern region, leaf and panicle mites and nematodes in southern states. Among the rice diseases bacterial leaf blight, blast, rice tungro disease, sheath blight and sheath rot in wet lands, brown spot in uplands have been reported as of economic importance causing substantial crop losses (Pasalu *et al*., 2004).. The average yield losses in rice have been estimated to vary between 20 to 50 percent. Analysis of multi-location data under AICRIP revealed that avoidable losses due to insect pests averaged 29 percent in rice crop. India has also been a witness to many pests out breaks resulting in extensive loss in yield. Puri (2000) reported that brown plant hopper, gall midge and yellow stem borer were the key pests in rice causing 10 to 70%, 15-60% and 25-30% loss, respectively.

The country has diverse soil and agro climatic environments which provide opportunities for supporting growth of wide range of crops. While technological advancements, currently available, have the potential to correct and / or alleviate soil and nutrient related problems and manage major biotic stresses, provided they are implemented in the right perspective with the objective of sustaining productivity of the soil system on a long term basis. There is a need to diversify agricultural systems on wetland soils to improve daily diet and to meet socioeconomic and environmental necessities for sustainable production like rice-based cropping and farming systems involving vegetables, plantation crops, livestock, poultry, and fish. Thus, the basic objective of sustainable development is to increase production per unit area, time and input, and enhance quality of natural resources (soil, water and atmosphere). Development of suitable Integrated Pest Management strategies promoting natural, economical and sustainable farming techniques involving pest resistant cultivars, suitable cultural practices, use of eco-friendly pesticides, conservation of *in situ* biological control agents and other novel pest control techniques like pheromones etc. is essential to overcome the biotic constraints mainly, pests and diseases for realizing yield potential of rice in rice based production systems. The effort also requires addressing few issues connected with cataloguing of available information on ecology related problems and their distribution more systematically using modern tools of remote sensing and GIS which provide opportunities to integrate crop commodity based information for effective management of the field problems and dissemination of information. Important strategies to minimize the existing biotic and abiotic stresses and sustain productivity growth without deteriorating the growing environment are essential.

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Rice Factor Productivity in India: Economic Implications

M.G. Chandrakanth, L. Ranganath and T.N. Prakash

The performance of rice research in India has been highly satisfactory during and after the green revolution period. During the late 1960s on and average about 30 new rice varieties were released in developing countries annually. This increased to 76 varieties by the late 1980s and with the result the productivity of rice increased by 2 percent per year from 1969 to 1995. The world price of rice is at least three times that of wheat and the total value of rice produced is also at least three times that of wheat. Rice being a high value crop compared with wheat, it becomes the key to invest in rice research. Since 1965, there has been an impressive growth in productivity of cereals, due to increase in land productivity, more efficient use of inputs, market infrastructure and supportive government policies. There was also a significant investment in research and irrigation.

In recent times the decrease in the growth rate of productivity of rice in the intensively cultivated lands has been observed. This is attributed to 1) degradation of the land due to intensive cultivation; 2) reducing investment on infrastructure and research and 3) the increasing labor wages. Therefore, further rice productivity growth depends on substantial research investment to shift yield frontier of rice and rice profitability through more efficient use of inputs.

Performance of rice with sources of growth

The rising land values due to increasing land scarcity and adoption of crop intensification technologies are responsible for rice productivity growth. For India, output growth rate of rice increased by 2.02% between 1956 and 1995, 1.41% between 1956 and 1965, 2.25% between 1966 and 1975, 2.79% between 1976 and 1985 and 3% between 1986 and 1995. India experienced low labor productivity and moderate land productivity in rice in 1985, while South Korea, Japan and Malaysia experienced both high labor productivity and high land productivity. China experienced

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moderate labor productivity, but high land productivity. The rate of growth in rice productivity is substantially lower than the rate of growth in fertilizer use over the past three decades. This reinforces the importance of inputs to be used more efficiently for intensive rice production. The area under High yielding varieties has been the largest source of TFP growth in rice between 1967 and 1977 in both irrigated and rainfed districts of India (Table 1A). Irrigation has relatively not contributed substantially to total factor productivity growth in rice.

Table 1A. Annual growth as influenced by various sources in India

Sources of growth in rice in Irrigated areas	Annual growth
1956-1965	
HYV area	0
Literacy	2.55
Irrigation	0
1967-1977	
HYV area	19.58
Road density	3.94
Literacy	2.05
Irrigation	0.12
1978-1990	
HYV area	3.38
Road density	2.87
Literacy	2.29
Irrigation	1.20
Sources of growth in rice in rainfed areas in 1956-1964	
HYV area	0
Road density	2.6
Literacy	2.44
Irrigation	0.93
1967-1977	
HYV area	20.41
Road density	5.45
Literacy	1.90
Irrigation	3.64
1978-1990	
HYV area	4.92
Road density	3.3
Literacy	1.91
Irrigation	3.29

Source: Fan and Hazell (1997)

Area, production, productivity of rice

The area under rice cultivation has been increasing since 1950-51 till 2008. A significant fall in area by 3 million ha and fall in production by around 10 million tonnes from 2008 to 2009 and fall in area of 3 ml ha leading to a fall in production by 8 million tonnes from 2010 to 2011 are crucial aspects which needs attention. The rice productivity has been showing rising and falling moments since 1950s leveling at around 2200 kgs per ha. The proportion of rice irrigated area is increasing since 1950 from 32 percent in 1950 to almost 60% of the total rice area by 2010 (Table 1B).

Table 1B. Area, production and productivity of rice in India

Year	Area (Ml ha)	Production (Ml tonnes)	Yield (kgs/ha)	% of Rice area irrigated
1950-51	30.81	20.58	668	31.7
1955-56	31.52	27.56	874	34.9
1960-61	34.13	34.58	1013	36.8
1965-66	35.47	30.59	862	36.5
1970-71	37.59	42.22	1123	38.4
1975-76	39.48	48.74	1235	38.7
1980-81	40.15	53.63	1336	40.7
1985-86	41.14	63.83	1552	42.9
1990-91	42.69	74.29	1740	45.5
1995-96	42.84	76.98	1797	49.9
2000-01	44.71	84.98	1901	53.6
2001-02	44.90	93.34	2079	53.2
2002-03	41.18	71.82	1744	50.2
2003-04	42.59	88.53	2077	52.6
2004-05	41.91	83.13	1984	54.7
2005-06	43.66	91.79	2102	56.0
2006-07	43.81	93.36	2131	56.7
2007-08	43.91	96.69	2202	56.9
2008-09	**45.54**	**99.18**	**2178**	**58.7**
2009-10	**41.92**	**89.09**	**2125**	**NA**
2010-11*	**42.56**	**95.33**	**2240**	**NA**
2011-12**	**39.47**	**87.10**	**2207**	**NA**

Source: Directorate of Economics and Statistics, Department of Agriculture and Cooperation.

Percapita availability of rice, foodgrains

The per capita availability of rice has been increasing from 159 grams per day per capita to 221.7 grams in 1991 (the highest in the history) and is gradually falling to around 185 grams per day. However the percapita availability of cereals has risen from 334 grams in 1951 to 407 grams per day in 2010. The percapita availability of cereals has fallen in 2012 when compared with 2004. The percapita availability of pulses has been showing a falling trend since 1951 from 61 grams to 32 grams. The total food grains per capita availability has increased from 395 grams to 439 grams (Table 1C).

Table 1C. Per capita availability of rice, cereals, pulses in grams per day in India

(Grams Per Day)

Year	Rice	Cereals	Pulses	Food Grains
1951	158.9	334.2	60.7	394.9
1971	192.6	417.6	51.2	468.8
1981	197.8	417.3	37.5	454.8
1985	188.8	415.3	38.1	453.4
1990	212.1	431.5	41.1	472.6
1991	221.7	468.5	41.6	510.1
1995	220.0	457.6	37.8	495.5
2000	203.7	422.7	31.8	454.4
2001	190.5	386.2	30.0	416.2
2002	228.7	458.7	35.4	494.1
2003	181.4	408.5	29.1	437.6
2004	195.4	426.9	35.8	462.7
2005	177.3	390.9	31.5	422.4
2006	198.0	412.8	32.5	445.3
2007	194.0	407.4	35.5	442.8
2008	175.4	394.2	41.8	436.0
2009	188.4	407.0	37.0	444.0
2010 (P)	184.8	407.0	31.6	438.6

Source: Directorate of Economics and Statistics, Department of Agriculture and Cooperation.

Gradual fall in demand for cereals in rural areas

The data in Table 1C needs to be corroborated with data in Tables 2 and 3. It is not just the productivity and net per capita availability of food which counts, but also the effective demand for food grains which decides the rice economy, since 90% of the cereals consumed in India is rice and wheat. Accordingly in rural areas, in 1970, the percapita cereal consumption per month was 15.35 kgs which is gradually fell to 15.25 kgs in 1977, onto 14.06 kgs in 1990, on to 12.72 kgs in 1999-2000 and 11.76 kgs in 2007. The situation is similar even considering all the monthly per capita consumption expenditure classes. One of the reasons for the fall in cereal (rice and wheat) consumption in India is the operation of Engel's law of expenditure. The other reason is the provision of rice at subsidized prices to BPL families which constitute about 30 percent of the population.

Operation of Engel's law

With the increase in (real) incomes, the expenditure on food grains including rice is falling, while that on vegetables, milk, and non vegetarian food is rising in India.. For instance the consumption of rice per capita per month has fallen by 10 percent between 1993 and 2009, that of coarse cereals by 63 percent, all cereals by 15 percent, and meat by 33 percent (Table 3)

Table 2. Per capita cereal consumption in rural India (1970-2008; kg/month)

Year	PCCC	Year	PCCC
1970-71	15.35	1989-90	14.00
1972-73	15.26	1990-91	14.06
1973-74	15.09	1991-92	13.50
1977-78	15.25	1993-94	13.40
1983	14.80	1999-2000	12.72
1986-87	14.28	2004-05	12.11
1987-88	14.47	2007-08	11.76

Source: Various NSS reports available at http://mospl.gov.in

Table 3. Change in quantity of rural per capita consumption of rice, cereals, fruits, vegetables, meat in India (1993 to 2009)

Commodities	Year	Monthly Qty. consumed	Yearly Qty. consumed	% change in monthly consumption
Rice Kgs	1993-94	6.79	82.61	
	2009-10	6.14	74.70	-9.57
Coarse cereals(kg)	1993-94	2.29	27.86	
	2009-10	0.85	10.34	-62.88

Commodities	Year	Monthly Qty. consumed	Yearly Qty. consumed	% change in monthly consumption
All cereals (kgs)	1993-94	13.40	163.03	
	2009-10	11.35	138.08	-15.31
Edible oil (kg)	1993-94	0.37	4.50	
	2009-10	0.64	7.74	71.89
Banana (No.)	1993-94	2.20	26.77	
	2009-10	3.86	46.96	75.45
Mango Kgs	1993-94	0.06	0.73	
	2009-10	0.11	1.31	80.00
Apple Kgs	1993-94	0.03	0.37	
	2009-10	0.05	0.55	50.00
Groundnut Kgs	1993-94	0.03	0.37	
	2009-10	0.05	0.61	66.67
Vegetables Kgs	1993-94	2.71	32.97	
	2009-10	4.04	49.14	49.04
Milk (litre)	1993-94	3.94	47.94	
	2009-10	4.12	50.09	4.49
Fish (kg)	1993-94	0.18	2.19	
	2009-10	0.27	3.27	49.44
Mutton (kgs)	1993-94	0.07	0.85	
	2009-10	0.05	0.57	-32.87
Chicken (kg)	1993-94	0.02	0.24	
	2009-10	0.12	1.50	515.00

Source: Directorate of Economics and Statistics, Department of Agriculture and Cooperation.

Prospects for further productivity growth

Future growth in rice output could be achieved by increasing the productivity per unit of land since opportunities for area expansion are limited. Already rice productivity has plateaued due to 1) lack of an exploitable yield gap 2) unfavorable relative prices and 3) the degradation of land base. Real prices of cereals in the world are falling and are also responsible for shift in land use towards more profitable crops. This has also resulted in slowdown in investment in rice research and irrigation infrastructure. In Punjab, average rice yield is 5 tons per ha. In irrigated rice areas, exploitable yield gap is small. With the existing technology and relative price levels, farmers find it not profitable to bridge the gap further. Therefore rice yields have leveled off. And with only new rice varieties with substantial yield improvement, shifts in productivity are possible. With rice monoculture, it is becoming difficult to sustain long-term productivity even with the best management resulting in declining productivity

Prospects for shifting the yield frontier

Even with improvements in pest resistance, quality grain, reduction in crop duration, rice productivity has marginally increased. Hybrid rice has proven yield increases to the tune of 20%. The prospect of C4 rice (Super rice) is in the 'hope' and is not yet a reality. This also requires further irrigation infrastructure, intensification of input use, changes in timing and method of application of fertilizers to reduce loss in nutrients due to volatilization and seepage. There has been modest impact of insecticides in rice production and hence IPM is showing signs of hope. Increasing wage rates would lead to shift from rice transplanting to direct seeding. Increasing water scarcity may lead to use of herbicides. However, technologies should aim at capacity building and mechanization.

Why water saving innovative technologies in rice cultivation are not becoming popular

Research on water saving technologies in rice are in the form of (1) SRI (system of rice intensification), (2) aerobic rice cultivation (3) Marker Assisted Selection (MAS) in rice. The water saving achieved is to the tune of 40 percent. Considering 40 acre inches of water per acre as the consumptive use in paddy, the value of groundwater saved at the rate of Rs. 300 per acre inch is on per acre basis is Rs. 4800, while that of surface water saved at the rate of Rs. 12 per acre inch, is Rs. 480. Though the savings range from Rs. 500 to Rs. 5000 per acre depending upon the source of water, the rate of adoption of water saving technologies in rice is far lower compared with the rate of adoption of water saving technologies in crops such as vegetables, fruits. The value of water savings in rice is appreciable compared with the value of plant protection chemicals saved in cotton because of the use of Bt cotton variety. The spread of Bt cotton variety is almost 95 percent of the cotton area, while that of SRI / Aerobic rice is not even 0.1 percent of the rice area. The reason for slow or even non adoption of technologies pertaining to water saving is that water is not a priced resource. But in the case of plant protection chemicals as used in Bt cotton, since farmers are able to actually save their investment while in the case of rice, the saving in water is notional, as surface water for irrigation is still not an economic good, though groundwater for irrigation has become a partially economic good as farmers invest in irrigation wells. Accordingly groundwater saving technologies are relatively adopted (through drip irrigation, sprinkler irrigation) compared with surface water saving technologies.

Can millets offer a solution?

Ever since the green revolution, with the policy support to rice and wheat, and the associated rise in real incomes of farmers, small millets (fox tail millet, little millet, proso millet, kodo millet), were rendered inferior goods as their income elasticity of demand became negative and price elasticity of demand positive. India, being the largest cultivator and consumer of millets, the growth rate in area and production are negative. The Table 4 highlights this negative growth in all millets (Jowar, Bajra, Ragi, Barley, Total Coarse Cereals). Rice and wheat contribute 78 percent of the total food grains production while millets contribute to 15 percent. Green revolution virtually wiped out nutritive, healthy, cost effective and low water using millets due to policy support to the expensive and water intensive rice and wheat.

Table 4. Compound growth rates of area, production and productivity of major crops in India

Crop	(as per cent per annum with base TE 1981-82=100)					
	1980-81 to 1989-90			2000-01 to 2009-10		
	Area	Production	Yield	Area	Production	Yield
Rice	0.41	3.62	3.19	-0.03	1.59	1.61
Wheat	0.46	3.57	3.10	1.21	1.89	0.68
Jowar	-0.99	0.28	1.29	-3.19	-0.07	3.23
Bajra	-1.05	0.03	1.09	-0.42	1.68	2.11
Maize	-0.20	1.89	2.09	2.98	5.27	2.23
Ragi	-1.23	-0.10	1.14	-3.03	-1.52	1.57
Small millets	-4.32	-3.23	1.14	-5.28	-3.58	1.78
Barley	-6.03	-3.48	2.72	-1.41	-0.25	1.17
Total Coarse Cereals	-1.34	0.40	1.62	-0.76	2.46	3.97
Total Cereals	-0.26	3.03	2.90	0.09	1.88	3.19
Gram	-1.41	-0.81	0.61	4.34	5.89	1.48
Tur	2.30	2.87	0.56	0.26	1.82	1.56
Other Pulses	0.02	3.05	3.03	-0.34	-0.32	0.02
Total Pulses	-0.09	1.52	1.61	1.17	2.61	1.64
Total Foodgrains	-0.23	2.85	2.74	0.29	1.96	2.94
Sugarcane	1.44	2.70	1.24	0.77	0.93	0.16
Oilseeds	1.51	5.20	2.43	2.26	4.82	3.79
Cotton	-1.25	2.80	4.10	2.13	13.58	11.22

Source: http://indiabudget.nic.in/es2010-11/echap-08.pdf

Even though the Minimum support prices announced for millets are almost on par with those of rice and wheat, farmers are not responding to cultivation of millets due to (1) absence of procurement by State or Federal Government agencies. (2)

Lack of consumer demand due to niche markets, (3) poor value addition in millets. The rice and wheat are procured at huge transaction cost. For instance, Government procures rice at Rs. 1000 per quintal and spends Rs. 1043 per quintal towards procurement and distribution, and wheat at Rs. 1120, spending Rs. 424 per quintal towards procurement and distribution. The transaction cost of rice procurement is 104 percent of rice price, while that for wheat is 38 percent of wheat price. This shows the lopsided support to superior cereals at the cost of millets.

Value addition can reverse engel's law

Value addition and awareness due to technology can reverse the income and price elasticities of demand (as in the case of maize in India). Maize (*Zea mays*), a coarse grain turned out to be a normal and superior good due to value addition not only as poultry feed but also as corn flakes, corn flour, corn oil, corn starch and so on. Similarly, Ragi (*Eleusine coracana)* (a small millet) is turning out to be a superior millet gradually due to value addition, awareness and capacity building explaining its medicinal properties. Thus, value addition in millets can turn them from inferior to normal and superior goods, apart from fetching socio economic, environmental and natural resource benefits with larger social welfare (Fig 1).

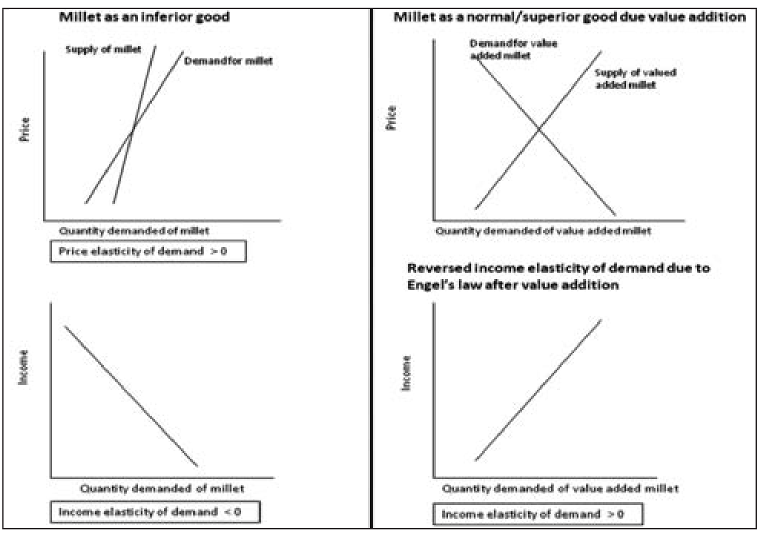

Fig 1: Demonstrating how inferior goods can be normal / superior goods after value addition

Threat to food security

India's food security is currently under threat due to climate change. Rainfed agriculture contributes 40 percent of India's food production where small and marginal farmers who constitute 80 percent of India's farmers are predominant. In addition, they are resource poor, capital poor, and with little or no access to markets and have barely limited livelihood opportunities. Millets are grown on 35.46 ml ha in the world producing 28.52 ml tonnes of which India shares 60 % of area and 65 % of output being the largest cultivator, producer and user of millets. The productivity is 8.76 quintals per ha mainly due to lack of input use, low market prices and lack of demand as a result of faulty policy support to major cereals. Among the grains, small millets, foxtail millet and proso millet outperform cereals such as wheat and rice in their nutritional composition (Table 5). Since millets have higher fiber, they cause for slow release of glucose in the process of digestion. They also prevent constipation and help in lowering blood cholesterol and serve as the best diabetic food due to their low glycemic index. India has the world's largest diabetic population and farmers are increasingly becoming victims of diabetes. The practice of cultivating and consuming millets is relegated and is also responsible for increasing diabetic population. However their production, consumption, value addition is relegated *inter alia* due to imperfect markets, market failure, missing information and lack of policy support.

Table 5. Nutritional composition of millets (per 100 gms)

Food grain	Protein (g)	Carbohydrates (g)	Fat (g)	Crude fiber (g)	Mineral matter (g)	Calcium (mg)	Phosphorous (mg)	Iron (mg)
Finger millet	7.3	72	1.3	3.6	2.7	344	283	3.9
Kodo millet	8.3	65	1.4	9	2.6	27	188	12
Proso millet	12.5	70.4	3.1	7.2	1.9	14	206	10
Foxtail millet	12.3	60.9	4.3	8	3.3	31	290	5
Little millet	7.7	67	4.7	7.6	1.5	17	220	6
Barnyard Millet	6.2	65.5	2.2	9.8	4.4	11	280	15
Wheat	11.8	71.2	1.5	1.2	1.5	41	306	5.3
Rice	6.8	78.2	0.5	0.2	0.6	45	160	

Source: All India Coordinated Small Millets Improvement Project, A Profile, Indian Council of Agricultural Research, University of Agricultural Sciences, Bangalore (undated)

Conclusion

Due to increasing land scarcity, reducing irrigation capacities, in the most intensively cultivated areas, especially with a double or triple cereal rotation, there is slackening in productivity of rice. Agricultural research, human capital, capacity building, infrastructural and market development, and policy reforms have all contributed to driving productivity changes. Long-term declines in world cereal prices and structural adjustment within developing economies have also led to decreases in rice research investments in recent years. India still needs to catch up with developed countries with regard to measurement of factors of production in rice, especially of water. There is virtually no volumetric measurement in any canal irrigated area. Even in groundwater irrigated areas, there is no measurement of water flow to rice fields. This will further reflect the falling productivity of rice to precious water resource. In addition as surface water has still not become an economic good in comparison with groundwater for irrigation, which has become partially economic good, innovations / technologies in savings in surface water use through SRI / aerobic rice / MAS rice are not preferred and remain notional savings.

The needed growth in productivity will also depend upon the increase in investments in agricultural research and education of farmers to increase their marginal return especially to the economically scarce water resource and the economically scarce labor resource. As alternatives, millets such as Bajra, Ragi, and minor millets and sorghum need to be promoted not only from the point of view of reducing water resources, but also from the point of view of provision of fodder for cattle and the imminent effects of climate change. Needless to say that millet fodder is preferred by cattle compared with rice / wheat fodder by the dairy cattle and the dairy income contribute to at least 25% of gross income of farmers.

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Appendix notes and Tables

The decline in per capita consumption of cereals was faster in rural areas than in the urban areas. The survey (of the NSSO 63rd round) conducted countrywide between July 2006 and June 2007 indicated this result. On an average, per capita consumption of cereals declined by 1.9% in rural areas to 11.7 kg from 11.9 kg and by 1.3% in urban areas to 9.6 kg from 9.8 kg, as shown by the comparison of MPCE data of the NSSO's 62nd round and 63rd round

Table 6. PCCC for MPCE classes (Rural India, 2004-05; kg/month)

	NSS	IHDS
0-5	9.88	9.35
5-10	10.87	10.18
10-20	11.33	10.83
20-30	11.70	11.64
30-40	11.98	11.95
40-50	12.16	12.29
50-60	12.37	12.80
60-70	12.61	12.71
70-80	12.77	12.92
80-90	12.72	13.37
90-95	12.77	13.68
95-100	13.50	14.58

Source: NSS report no.508 and author's calculations from IHDS data

Table 7. PCCC for PCI classes (Rural India, 2004-05; kg/month)

Bottom decile	12.29
Bottom quartile	12.10
Second quartile	12.09
Third quartile	12.21
Top quartile	12.12
Full sample	12.13

Source: Author's calculations from IHDS data

Table 8. Per capita Cereal Consumption and per capita Income by occupation Group (Rural India, 2004-05)

Occupation	PCCC	PCI
Cultivation	12.63	634
Agriculture	12.07	416
Non-agri labour	12.06	449
Profession / Pension	11.95	1084
Salaried	11.70	1182
Artisan	11.62	769
Other	11.54	684
Business	11.33	1000
Petty trade	11.19	695
Total	12.13	646

Source: Author's calculations from IHDS data. Occupations ("main source of income") are ranked in descending order of PCCC

Agricultural R&D Investment by India and China: A Comparative Analysis with Specific Emphasis on Rice Production

K.R. Karunakaran

Agriculture Research and Development (R&D) investments through the introduction of improved crops and cropping technologies, labour saving technologies, improved varieties etc are crucial determinants of agriculture productivity. Adequate and continuous investment in agricultural R&D is essential to induce the growth in agricultural GDP that has to be fueled for any agriculturally dependent economy.

Policymakers are now increasingly recognizing that the higher levels of investment in agricultural research is the key factor in increasing agricultural production to the levels required to feed the world's growing population. Furthermore, an additional investment in agricultural research is required to address the recently emerging challenges, such as increasing weather variability, adaptation to climate change, water scarcity, and increased price volatility in global markets. Despite this growing attention to the agricultural sector and the role of agricultural research, many low- and middle-income countries continue to struggle with serious and deepening capacity and funding constraints in their agricultural research and higher education systems. Considering the importance, this paper has been attempted to explore the public and private investments in agricultural R&D by India and China in comparison with other developed and developing countries with the specific emphasis on rice production. Before getting into the topic, an analysis has been attempted to study the present status of rice production by major rice growing countries including India and China besides, exploring the potential and efficiency of rice growing Indian states and the country in rice production. This would help in understanding the research gaps and to formulate suitable policies for Indian rice production system.

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Global rice and food grain production scenario

Rice is one of the important food crops in the world and ranks second in terms of area and production. Rice is the staple food for about 50 percent of the population in Asia, where 90 per cent of the world's rice is grown and consumed. Asia's food security depends largely on the irrigated rice fields, which account for more than 75 percent of the total rice production (Virk *et al*., 2004).

"Rice is life" truly lives up to its meaning in India where its origin dates to 2500 B.C. In Asia, India has the largest area under rice cultivation occupying 29.4 percent of the global area, but India has the lowest yield per hectare. The world cereal production became stagnated around 2200 MT. But the rice growing countries showed increasing trend in rice production during 2000-2010 (Fig 1).

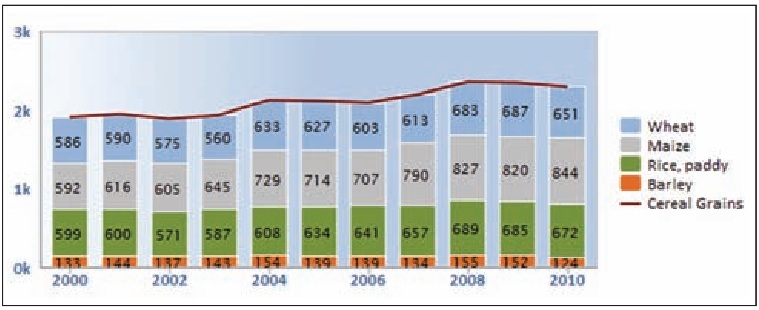


Figure 1. Food grain production of cereals (Miilion Tonnes)

The world food demand has increased considerably, particularly the fruits, vegetables and milk observed a twofold increase in their demand in last 20 years. World per capita consumption is projected to decrease by 3% from 2011 to 2021, whereas global rice demand is still expected to rise by 8% during the period from 443 MT in 2011 to 477 MT in 2021. Therefore, it is recommended to adopt new technologies that will help to increase rice yields in order to meet growing demand. The technologies may include farmers' greater application of improved crop, soil, and water management innovations, and better targeted approaches to crop improvement that are more explicitly focused on adapting to climate change. In India, where rice is already considered an inferior good, will decrease (increase) its per capita consumption by as much as 0.73% (0.61%) in 2021 when income increases (decreases) by 2%. The opposite behavior is expected for the Philippines, where rice is still a normal good (Matriz *et al*., 2010).However, the per capita availability of cereals in Asia particularly wheat, rice and maize were almost remain stable around 64, 77 and 8 kg/capita/year (Figure 2). Hence, the detailed exploration of rice production scenario would help to target our policies to structuring the food basket which can suit to the changing consumption pattern and life style due to growth in economic status of the people.

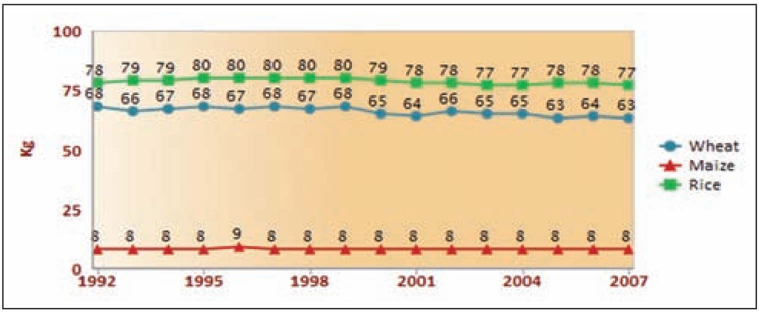


Figure 2. Food supply in Asia (kg/capita/year)

Rice production performance of India and China

India and China are the larger economies (Figure 3) in the world with the GDP of 4 and 10 trillion dollar (ranked 5th and 3rd largest GDP) with the per capita GDP of $3.75 and $7.78 thousand /year in 2005 PPP international $ price in 2006. With reference to arable land, India (ranked 3rd) having the highest arable land resource than China (ranked 4th) where as the supply is almost fixed or even started declining due to expansion of other sectors of land use. India and China supported with 59 % and 66 % of their work force engaged in agriculture. They are classified as low and low middle income countries with 41 and 22 per cent of world poor population. The average fertilizer consumption was 99 kg/ha in India (ranked 43rd) and 256 kg/ha in China (ranked 10th) (http://Knoema.com, 2012).

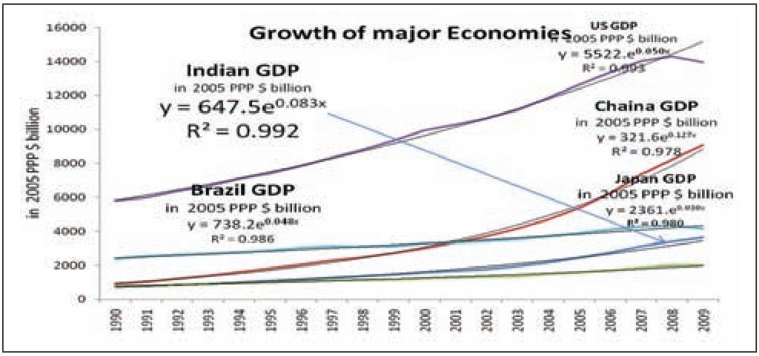


Figure 3. Growth of major economies; author obtained above information from the dataset http://Knoema.com

The annual compound growth rate of India and China's GDP were 8 and 12 per cent during 1990-2010. India and China are the two important countries under rice cultivation and production having a lion's share of rice area of 26 and 19 per cent and producing 20 and 29 per cent of global rice production with an average productivity of 3.29 and 6.56 tons/ha in 2010, respectively. The growth rate analysis (Table 1) revealed that production and productivity of China get stagnated with annual compound growth rate (aCGR) of 0.81 and 0.66 per cent during last decade, while India has scope to further increase the productivity at current growth rate of 1.66 per cent even with the negative growth in rice area (-0.43).

Table1. Performance of rice in India and China

Details	China						India					
	A	%	P	%	Y	times	A	%	P	%	Y	%
1980	34.74	24.29	143.25	37.13	4.12	1.53	40.02	27.98	74.80	19.39	1.87	0.69
1990	33.05	22.42	181.85	35.88	5.50	1.60	42.20	28.62	109.40	21.59	2.59	0.75
2000	31.17	20.22	196.93	33.01	6.32	1.63	44.89	29.11	130.34	21.85	2.90	0.75
2010	29.83	19.05	195.73	28.70	6.56	1.51	40.78	26.05	134.36	19.70	3.29	0.76
aCGR1971-80	0.35		2.73		2.38		0.89		2.49		1.57	
aCGR 1981-90	-0.53		2.15		2.69		0.45		3.96		3.49	
aCGR 1991-00	-0.51		0.97		1.48		0.66		1.86		1.20	
aCGR 2001-10	0.15		0.81		0.66		-0.43		1.23		1.68	

Note: A: Area in million hectare (mha); P: Paddy (with husk) Production in million ton(mt); Y: Rice yield ton/ha, paddy yield has converted in terms of rice by factor 0.66; aCGR: Annual compound growth rate (%)
Source: FAO crop statistics

Though rice area of India and China has stagnated around 41 and 30 mha in 2010, China shifted its production and productivity trend after 1981 (Figure 4), while India has turned it growth trend only after 1990. It could be inferred from the aGCR of rice area, that further increase in area under cultivation of rice is almost restricted in India whereas less scope for expansion of rice area in China (Table 1). In the last 20 years, China recorded two fold increases in productivity of rice when compared to India. India need to look at issues related to yield gaps, hence, the Indian agricultural R&D investment has to be more targeted to enhance the rice productivity & production. India needs to focus on developing productivity improvement technologies, expansion of hybrid rice area, hybrid yield enhancement programme similar to that of hybrid rice programme of China and efforts on adoption of rice mechanization in large scale area (Karunakaran 2010).

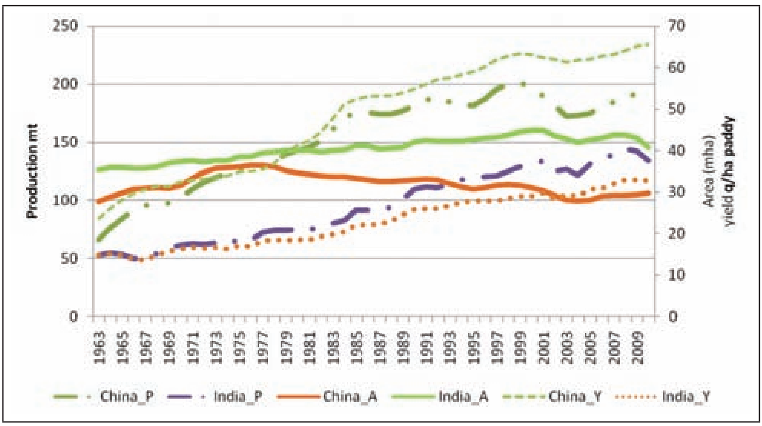


Figure 4.Performance of Rice-paddy in China and India

Food grain and rice production scenario in India

Agriculture is the mainstay of Indian economy. The share of agriculture in the gross domestic product has registered a steady decline from 36.4 per cent in 1982-83 to 18.5 per cent in 2006-07 and now pegged at 17 per cent. Yet this sector continues to support more than half a billion people providing employment to 52 per cent of the workforce. It is also an important source of raw material and demand for many industrial products, particularly fertilizers, pesticides, agricultural implements and a variety of consumer goods. However, in recent years due to weather variability, Indian agricultural sector growth is highly fluctuating. Furthermore, the resource base for rice production system is shrinking due to expansion of area under high value crops, depletion in surface and ground water, irrigation resources. India's annual water resource was 2214 cum in 1996 but is estimated to go down to 1496 cum by 2025 (Apoorva Ozd, 2010) and arable land availability which resulted in a declining trend (negative growth rate) both in food grains area and rice area during the last decade (Table 2, Figures 5 and 6).

However, the production and productivity of food grain as well as rice recorded an increasing annual growth rate of around 3-4 per cent up to 1990 and later showed lesser positive growth rate at 1-2 per cent per year.

Table 2. Area, production and productivity of food grains and rice in India

Year	Food grains				Rice			
	Area (mha)	Prod (mt)	Yld (kg/ha)	Irrigation Share (%)	Area (mha)	Prod (mt)	Yld (kg/ha)	Irrigation Share (%)
1980-81	126.96	123.73	974	29.60	40.02	49.91	1246	41.70
1990-91	127.43	172.45	1353	34.83	42.20	72.78	1725	45.80
2000-01	123.11	203.41	1652	43.23	44.89	86.91	1936	53.27
2010-11	104.42	189.10	1789	46.80	41.45	89.57	2162	56.90

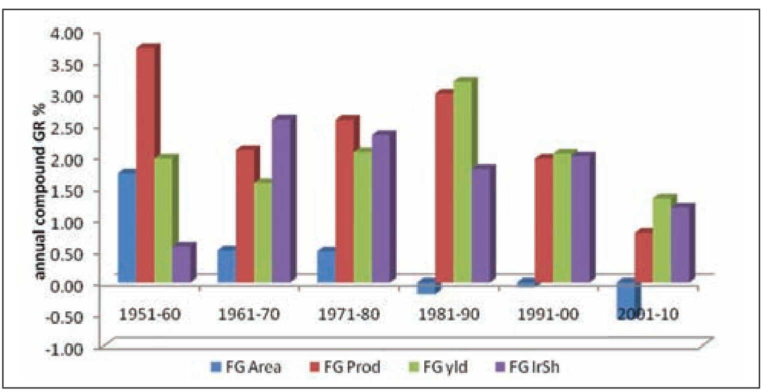


Figure 5. Trend in food grain growth rate (FG: food grain; IrSh: irrigation share)

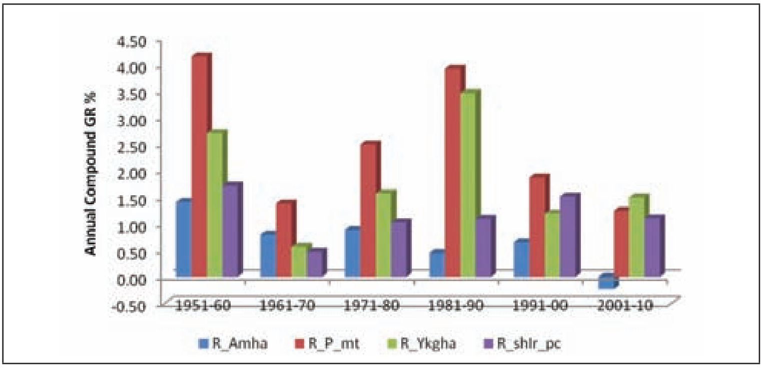


Figure 6. Trend in rice growth rate

With this, the stagnating trend in Indian rice production is clearly expressed (Figure 6a) by pegging the rice production at 90 MT in last 5 years. Though the rice area was almost stagnated at 40 mha. India doubled the rice production from 49 MT in 1980-81 to 90 MT in 2010-11 due to increased productivity from 12.5 q/ha to 21.69 q/ha during this period. However, after 2005-06 there was only a little growth in area and productivity of rice resulting in declining trend in rice production in recent years. Further a detailed analysis of regional performance of rice growing states in India would help to formulate specific policies.

The stagnation in both food grain and rice production was observed at 3, 2, 1.5 per cent for food grain and 3.5, 1 and 1.1 per cent for rice in last three decades, respectively.

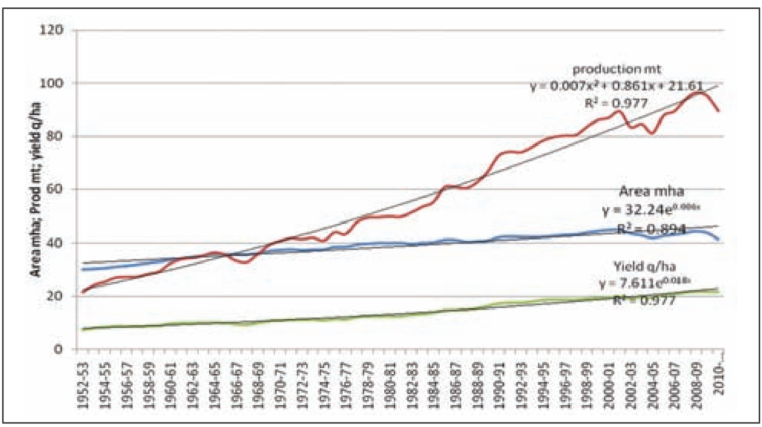


Figure 6a. Trend in rice production in India

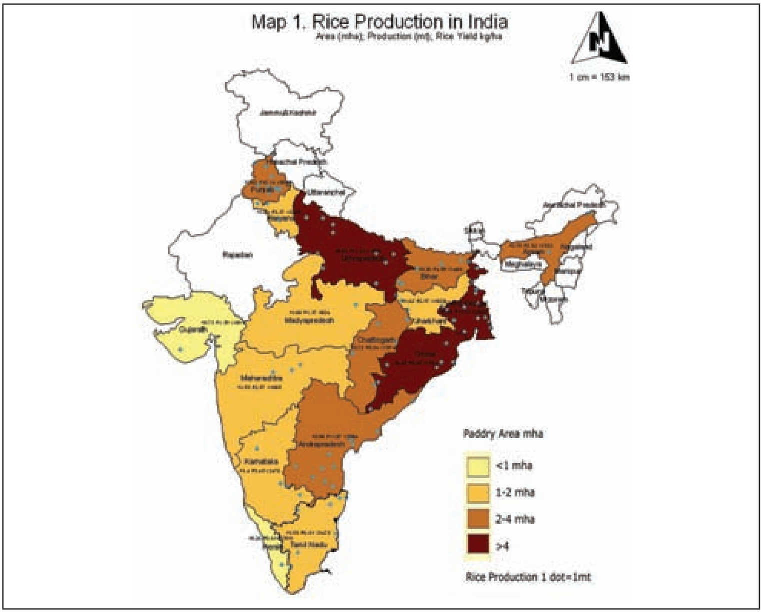
Rice production in different states of India

In order to explore the production potential of the major rice growing states, the area, production and productivity of rice in each state was analyzed and the results are presented in Table 3 & 4. The results revealed that West Bengal, Andhra Pradesh, Uttar Pradesh, Punjab and Orissa are the major rice producing states in India which constitute half of national rice production and rice area (58.59%) (Map1).

Table 3. Major rice producing states in India (TE2009-10)

States	Group	Area		Production		Yield (kg/ha)
		mha	%	mt	%	
Andhra Pradesh	HH	3.94	8.99	12.70	13.37	3.22
Uttar Pradesh	Area >7.5%	5.64	12.89	11.89	12.52	2.11
West Bengal	Yield >2 t/ha	5.76	13.16	13.13	13.82	2.55
Karnataka	HL	1.47	3.36	3.74	3.93	2.54
Punjab	Area<7.5%	2.72	6.20	10.91	11.48	4.02
Tamil Nadu	Yield >2 t/ha	1.86	4.24	5.30	5.58	2.86
Bihar	LH	3.43	7.83	4.54	4.78	1.32
Chhattisgarh	Area >7.5%	3.72	8.49	4.64	4.89	1.25
Orissa	Yield <2 t/ha	4.42	10.10	7.09	7.46	1.60
Assam	LL	2.43	5.56	3.89	4.09	1.59
Jharkhand	Area <7.5%	1.44	3.30	2.77	2.91	1.86
Maharashtra	Yield<2 t/ha	1.52	3.48	2.49	2.62	1.63
Others		5.43	12.41	11.92	12.55	2.10
India		43.79	100	94.99	100	2.17

Source: Derived from various issues of Agricultural statistics in India.



It could be observed from Table 3 that the productivity of rice was maximum in Punjab with state average productivity of 4017 kg/ha during TE2009-10. However, Tamil Nadu produced 5.30 MT of rice from 1.86 mha with the third highest rice productivity of 2.86 tons/ha next to Punjab and Andhra Pradesh (3210 kg/ha). Similarly, Orissa, Chhattisgarh and Bihar are the other larger rice growing states with the average rice productivity of around 1.5 t/ha which is less than the national average productivity of 2.17 t/ha in terms of rice (de-husked).

Table 4. State wise annual CGR of area, production and yield

State	State group	CGR of Area in last (%)		CGR of production in last (%)		CGR of yield in last (%)	
		10 yrs	5 yrs	10 yrs	5 yrs	10 yrs	5 yrs
Andhra Pradesh	HH	0.36	4.46	1.99	6.54	1.66	1.87
Uttar Pradesh	Area >7.5%	-0.41	0.55	-0.47	2.4	-0.04	1.9
West Bengal	Yield >2 t/ha	-0.22	-0.11	-0.06	-3.23	1.27	0.21
Karnataka	HL	0.53	3.03	2.03	-2.56	1.48	-4.85
Punjab	Area<7.5%	0.6	0.68	2.71	1.84	2.1	1.15
Tamil Nadu	Yield >2 t/ha	-0.9	0.56	-2.64	3.27	-1.63	2.84

Bihar	LH	-2.59	1.35	-3.96	6.88	-1.47	5.79
Chhattisgarh	Area >7.5%	-0.2	-0.3	6.65	-1.14	6.88	-0.84
Orissa	Yield <2 t/ha	-0.08	-0.3	4.33	1.69	4.44	1.99
Assam	LL	-1.26	-0.04	-1.08	1.66	0.15	1.65
Jharkhand	Area <7.5%	0.44	3.15	7.45	13.37	6.74	9.57
Maharashtra	Yield<2 t/ha	0.18	0.14	1.65	-0.06	1.44	-0.27
Others		-2.71	0.39	1.91	6.09	1.30	0.85
All India		**-0.15**	**0.79**	**1.33**	**2.35**	**1.49**	**1.55**

Orissa, Bihar, Chhattisgarh and Assam having more rice area (more than 2/3 of country's rice area) are producing only one fifth of national rice production due to their low productivity of 1.5 t/ha (Table 3). Already larger rice area contributors like UP, West Bengal, Orissa, Bihar, Chhattisgarh recorded negative growth in rice area, resulting in decline in production either due to decline or stagnation in their rice productivity. This situation clearly warrants special strategy in agricultural R&D investment particularly in rice research, marketing and distribution.

Declining rice production in India: a state level analysis

Well acclaimed rice bowls in several parts of India are facing a decline in area, production and productivity. To ensure food security, it is required to double the production by 2025 and, this additional yield will have to be produced on less land with less usage of water, labour and chemical (Zeng *et al.*, 2004). But, the current trend in rice production is not attracting particularly after 2000 in major rice growing states. Area, production and yield of rice has increased steadily from 1950-51 onwards till present but the growth rate (%) has been fluctuating in all three aspects. In the last decade, there has been negative growth rate observed in major rice growing parts in terms of area.

Considering the variability, the rice growing states are classified into four groups based on the area and productivity. They are i) HH- Higher area and high productivity (>2t/ha) states (AP, UP, WB); ii) HL- higher (>7.5% national rice) area with low (<2t/ha) productivity states (Bihar, Chhattisgarh, Orissa); iii) LH-less area with high productivity sates (Karnataka, Punjab and Tamil Nadu) and iv) LL- Low area with low productivity (Assam, Jharkhand, Maharashtra).

The strategic research and development plans have to be designed separately for these rice growing category states in order to prioritize and address the problems. Besides, that the present cultivation cost, profit and cost of production per ton of paddy are derived for each state under these categories using published CACP data. To this cost and profitability data of rice in each state is going to be a price factor in adoption of any new technology developed through the rice research and development system.

The cost of cultivation in high productivity states range from 30-37 thousand/hectare while in low productivity states (except Maharashtra Rs 30 thousand/hectare) the cost of cultivation vary between 15-20 thousand/hectare with the average profitability over cost C2 at Rs 3-5 thousand/hectare. Punjab recorded the highest profitability (28 thousand/hectare) due to higher productivity. The policy needs to be framed to enhance the productivity for better exploitation of yields in suitable areas.

However, the cost of production is highly variable among states under HL group, which may be due to variation in their input use level and related cultivation expenses. While the cost of production for all other groups was around 6 thousand rupees per ton against the minimum support price of 11000 rupees per ton, leaving a margin of Rs 5000/ton of output produced in these regions. The increase in productivity further in HH states like AP, UP, Karnataka, Punjab and Tamil Nadu is difficult. Further it is cautioned to note that already Bihar, Tamil Nadu and UP states had experienced a negative growth in rice productivity, which warrant development of cost cutting technologies or labour saving machineries/ technologies in rice for increasing profitability. However, any increase in productivity in HL and LL group states would reduce the cost of cultivation and increase the profitability from current level (loss in case of Maharashtra). The agricultural R&D has to focus on yield improvement programmes to achieve higher yield so as to improve the production in HH and HL on priority basis than in LH and LL states.

Though, varying rice productivity among states is largely dependent upon the resource availability, varietal potential and level of management technology adoption, the yield gap between the maximum yield and state average yield could be further reduced by adopting suitable regional specific varieties and adoption of improved management technologies.

The fore said analysis clearly narrate the need of regional specific attention coupled with investment in agricultural R&D particularly on rice research besides tracing the factors responsible for potential yield gap in low productivity states.

This could be also inferred from the Figure 7 & Figure 8 that the HL states in which rice productivity is below the national average (21.79 q/ha) viz Orissa, Bihar and Chhattisgarh (higher area with low productivity) did not showed any improvement in their productivity over last two decades (1990-99 and 2000-09) Figure 9. This analysis clearly showed that higher area with low productivity states need special attention by introducing high yield varieties and technologies particularly to suit their region so as to trigger the rice productivity growth in this region.

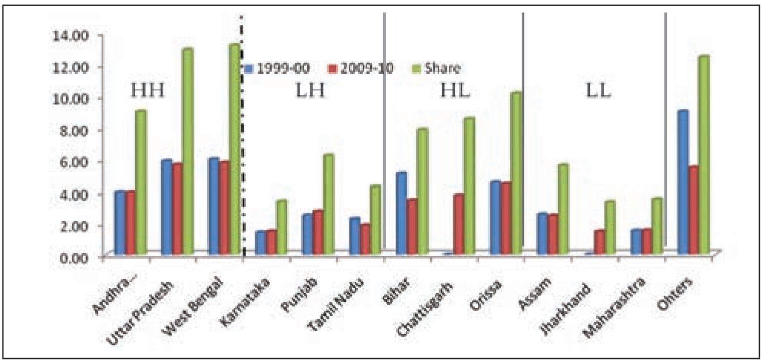


Figure 7. Area under rice cultivation (1999-00 and 2009-10)

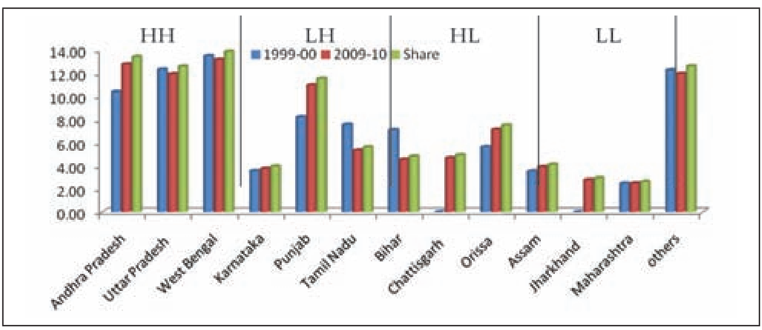


Figure 8. Rice production during 1999-00 and 2009-10

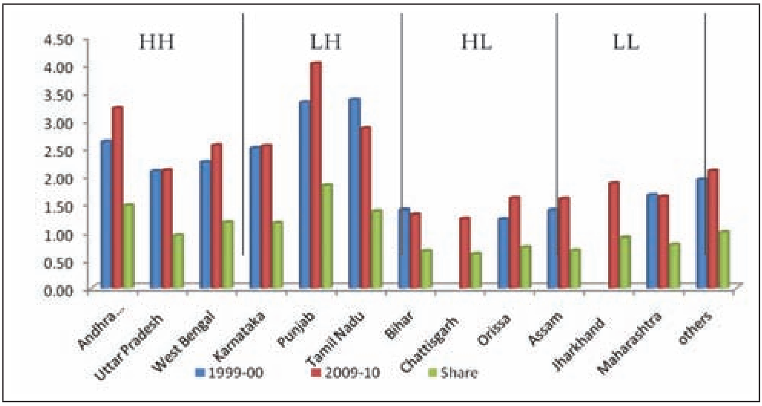


Figure 9. Rice productivity (t/ha) during 1999-00 and 2009-10

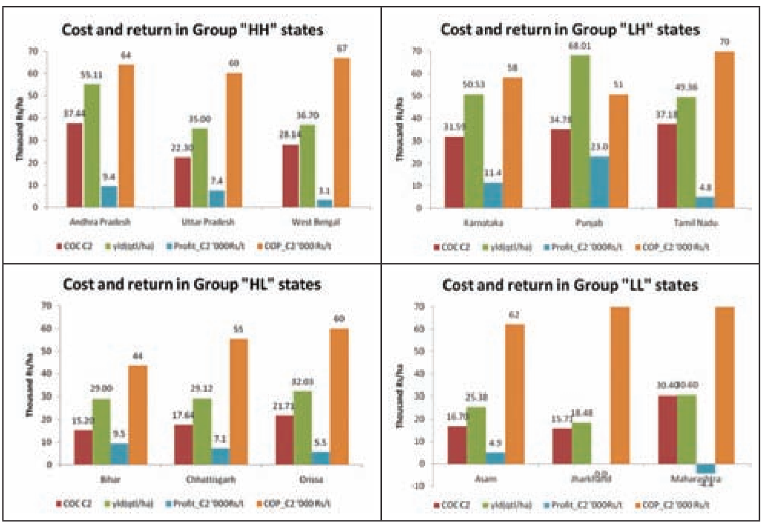


Figure 9a. Cost and return in different groups of rice growing States

Investment in Agricultural R&D

Science is a cumulative endeavor, with snowball effect. Innovations give rise new ideas and furthering it will add to the cumulative stock of knowledge. Data that are improperly documented, inaccessible and effectively exist only in the mind of the researcher are lost from the historical records when researchers retire from science.

India, China, and Brazil have become major forces in the global economy having national GDP of $3639, $ 4066 and 2010 billion PPP respectively with the annual growth rate of 8, 13 and 7 per cent in last two decades. The growth in public agricultural R &D by India was impressive at 25 per cent during 2000-07, but did not keep the pace with China, where they spent almost double the amount during the same period (Table 5). Brazil has one of the most well established and well funded research systems in the developing world. It is interesting to note that the doubling in agricultural R&D investment by China triggered the higher agricultural GDP growth rates of about 6 per cent during 90s and 5.55 per cent after 2000. Where as in India, increased agricultural R&D investment from $1.5 b in 2000 to $2.3 b in 2008 showed only 55 per cent increase in agricultural GDP in 2008 over 2000 and as a catalyst it resulted in 9.25 per cent annual growth after 2001. The three countries accounted for at least half of the developing world's total public investment in agricultural R&D in 2000 (Beintema and Stads 2010).

However, the Asia-Pacifica region is highly diverse in its geography, culture, politics and history and this diversity extends to its economic and agricultural development and consequently to its agricultural R&D systems. In 2002, Japan and South Korea spent $6.2 billion on agricultural R&D in 2005 PPP prices, but China and India accounted for nearly 70 per cent of this total ($3.0 and $1.4 billion, respectively, based on Beintema and Stads 2008s and adjusted data for China from Chen and Zhang 2010) and further they reached to $3.4 billion and $2.3 billion in 2005 price. China's public agricultural R&D spending continued to increase after 2002 in inflation adjusted terms: in 2008 it totaled $ 3.4 billion, which is close to twice its investment in 2000 ($1.3 billion). Japan and South Korea maintained their investment at $2.7 b and $0.7 b in 2005 price respectively in public agricultural R&D.

Table 5. Public agricultural R&D spending and intensity ratio, 2000 and 2008

Country	Spending (billion 2005 PPP prices)		Intensity Ratio ($ per $100 of AgGDP)		AgGDP cgr %	
	2000	2008	2000	2008	1990-00	2001-08
India	1.5	2.3	0.36	0.4	3.85	9.25
Brazil	1.2	1.3	1.86	1.8	-2.33	1.77
China	1.7	3.4	0.38	0.5	5.94	5.55
Australia	0.8	0.6	4.57	3.56	0.004	12.44

Country	Spending (billion 2005 PPP prices)		Intensity Ratio ($ per $100 of AgGDP)		AgGDP cgr %	
	2000	2008	2000	2008	1990-00	2001-08
Japan	2.6	2.7	4.06	4.75	NA	Na
South Korea	0.6	0.7	1.6	2.3	NA	NA

Source: Suresh Pal, *et al* (2012), author estimated the growth rates

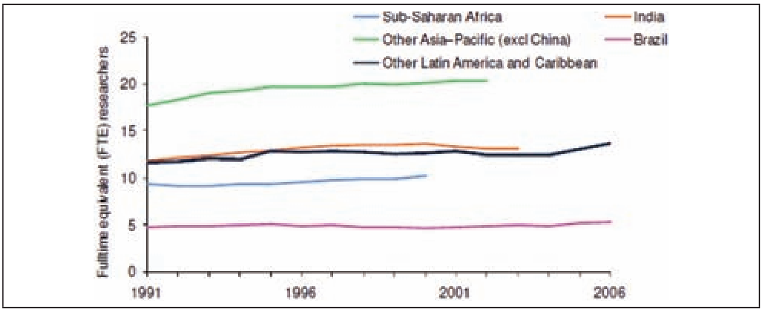


Figure 10. Public agricultural research capacity trends, 1991-2006

The staffing pattern and their qualification in the agricultural research system is an important aspect for achieving desirable results. In general, the Full-time equivalent (FTE) researchers employed in agricultural research in developing countries is erratic (Figure 10). Overall, most low and middle income counties in Sub-sharan Africa, Latin America, and the Asia Pacific have made considerable progress in building their research staff capacity, both in terms of total research number and qualification levels. China has world's largest agricultural R&D system in terms of research staff numbers (Beintema and Stads, 2010).

The most common research intensity inicator is to measure the total public agriculture R&D spending as a percentage of agriculture output (AgGDP). India invested $0.40 for every $100 of agricultural GDP in 2008. Thus is less than the amount invested by China ($0.50), Brazil (1.8), Japan (4.25), for every $100 of their agricultural GDP in 2008; it is also less than the average of $0.56 for developing countries in 2000 (Beintema and Stads, 2010). Higher rate of intensity ratio of agricultural R&D by high income countries like Brazil and Australia had triggered the higher growth in agricultural GDP by 1.77 and 12.44 per cent, respectively. Though China and India were the toppers in agricultural R&D investment, the intensity ratio was higher in developed countries like Japan ($4.06) and Australia ($4.57) in 2000 and further increased to $4.75 and $3.56 in 2008. While in China the intensity ratio was $0.38 in 2000 and it has improved to $0.5 and for India it was increased from $0.36 to $0.4 per every $100 of Agricultural GDP in the above period and they are lacking in terms of research intensity indicators.

Agricultural R&D systems and the investments in India

The bulk of agriculture research in India is in the public domain, which includes the Indian Council of Agricultural Research (ICAR) and State Agricultural Universities (SAUs), and various other government and higher education agencies. Unsurprisingly, staff at SAUs other higher education agencies spend a considerable time on teaching / education (42 per cent). In ICAR institutes, teaching accounts for 3 per cent of total staff time. Research, as well on transfer of technologies, remained the main focus of their work (97%). India spent Rs 33.4 billion on public agricultural R&D system, out of which 17.9 billion towards 94 ICAR institutes and 1.4 billion to 45 SAUs. Fifty five per cent of total research staffs are engaged in SAUs as compared to 34 percent in ICAR (Table 6). The public spending in agriculture R&D in India, in inflation adjusted terms, grew substantially during (1991-2003) at an average rate of 6.4 per cent per year mostly at late 1990 and was only 2.3 per cent during 2000-2003 (Suresh pal *et al.*,2012).

Table 6. Agricultural R&D spending and research staff levels 2009

Type of Agency	Total spending (billion 2005 price)			Total Staffing	
	INR	PPP $	Share %	Number (FTEs)	Share %
ICAR (94)	17.9	1.2	53.7	3816.7	34.0
Other Govt. (12)	3.6	0.2	10.8	1015.0	9.0
SAU(45)	11.4	0.8	34.2	6158.0	54.9
Other higher education (16)	0.4	0.03	1.3	226.8	2.0
Subtotal Public (167)	**33.4**	**2.3**	**100**	**11216.5**	**100**
Private	7.8	0.5	-	na	-
Total	**41.2**	**2.8**			

Development in agricultural R&D staff

Despite the overall decline in research staff capacity building of scientists at ICAR was impressive during 1996-2009. In 1996, 67 per cent of ICAR scientists held a PhD degree; this has increased to 80 per cent in 2003 and further to 86 per cent in 2009. In 2009, 37 per cent of ICAR's agricultural research scientists were between 41-50 years of age, 29 per cent were between age group of 51-60 and 7 per cent were over the age of 60years. PhD qualified researchers were significantly older than MSc qualified researchers.

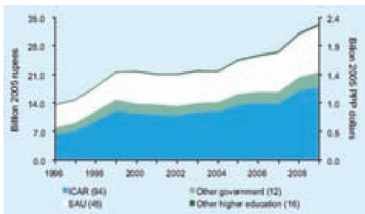


Figure11. Public agricultural R&D investment in India(1996-09)

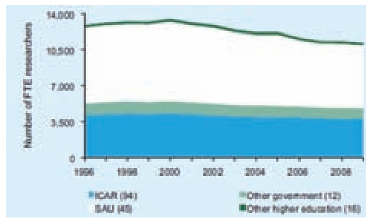


Figure 12. Public agricultural R&D staff (1996-09)

Source: Suresh pal, *et al* 2012

The allocation of research budget towards salaries, operating cost and capital costs influence the efficiency of agriculture R&D. During 2001-2003, the institutes under ICAR spent 50 per cent on salaries, 35 per cent on operating costs and 15 per cent on capital investment, but in SAUs 67, 20 and 13 per cent of the expenditure go towards salary, operational cost and capital cost in 2003 (Figure 13), respectively. The allocation of research budget on various of research programmes is policy decision and reflects priorities for research. The allocation among different items by ICAR institutes and SAUs are presented in Figure 14 (Suresh Pal, *et al*., 2008).

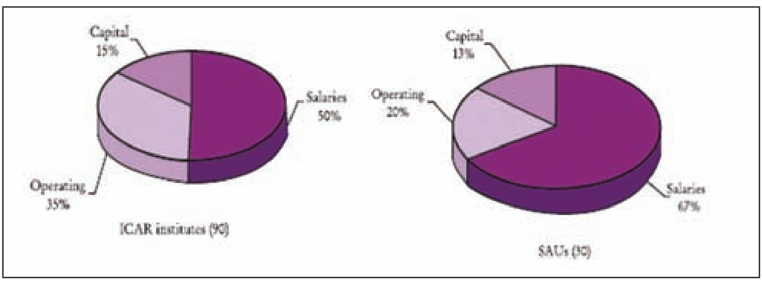


Figure 13. Cost category shares of government agency expenditure, 2001-2003

Source: Beintema *et. al*., (2008)

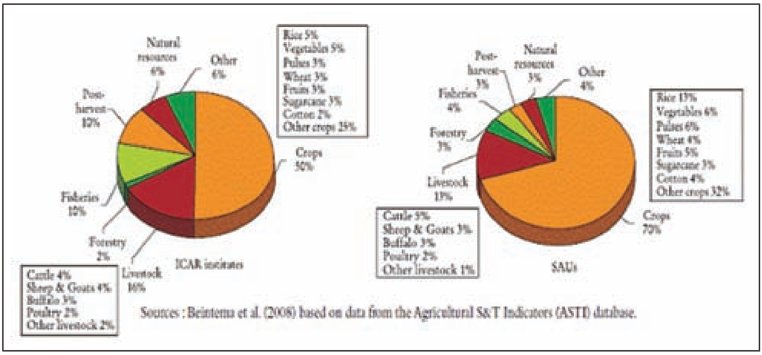


Figure 14. Commodity focuses of professional research staff of ICAR and SAUs, 2003

In last 5 years ending with 2009, even with the positive trend in public agricultural R&D in India, the staffing in agricultural R&D has shown declining trend due to stagnation in recruitment and enhancement in salaries (Figure 11). However, among the research institutes ICAR spent about 50 per cent in crop research while SAU spent 85 per cent in crop and livestock research (Figure 14).

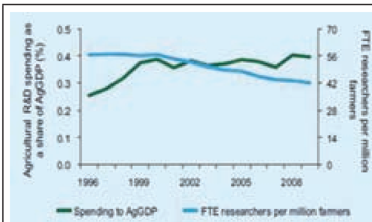


Figure 15. Intensity of public agricultural research spending , 1996-2009

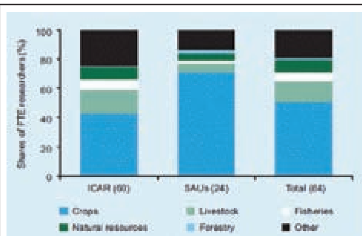


Figure 16. Research focus by major commodity area, 2009

In ICAR system 50 per cent of research time is spent in crop research in 2009 (Figure 16) followed by live stock (16%), fisheries (10%) post harvest (10%). Out of the (50%) crop research, rice and vegetables received greater focus at 5 percent each, followed by pulses, wheat, fruits, sugarcane each 3 per cent, cotton 2 per cent research time. While in SAUs, out of 70 per cent research time in crop research, the research staff time (STE) is distributed in rice (13%), vegetable & pulses (each 6%), wheat (4%), fruits (5%), sugarcane (3%) and cotton (4%). Next to crop research, livestock

(13%), fishers (4%), post harvest, natural resource and forestry received 3 per cent each of research time (Beintima, et. al., 2008). Since the mid 1990s, agricultural R&D spending by the private sector has increased fivefold (Pray and Nagaraj 2012), in 2008-09, the private sector spent Rs 7.8 b or $0.5 b PPP in India.

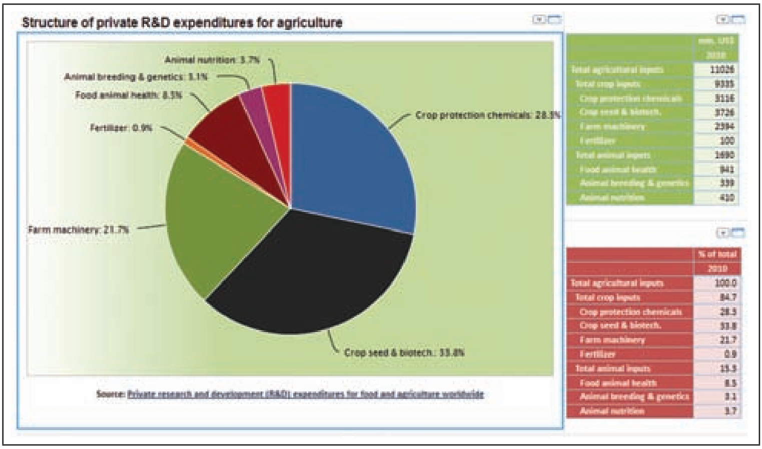
Research funding and donors

Public agricultural R&D is funded by federal Government at large to the ICAR system and by the state govt. to the SAUs. These contributions fall in to two broad categories viz., plan and non plan items. The Plan expenditures pay for new research programmes, and the non plan funds cover Salaries and over head cost. Besides that some agricultural R&D agencies in India generate funds internally through the commercialization of the technologies and by offering contract research and services. Bentman *et al.*, (2008) estimated that only one per cent of total funding of ICAR agencies came from internally generated income during 1998-03 and it was about 6 per cent in SAUs. The National Agricultural Technology Project (NATP, 1998-05) and now National Agricultural Innovation project (NAIP) implemented from 2006 onwards was supported by World Bank loan up to US $ 200 m. Besides that competitive grant scheme by Department of Bio-technology (DBT) and Department of Science and Technology (DST) provide funding support to cover the operating cost for short term research projects.

Private investment in agricultural R&D

To encourage the private sector involvement in agricultural technology development, India has strengthened its IPR regimes in harmonization with international agreements. IPR guidelines by ICAR will geared to stimulate innovation by sharing research benefits with innovations. It was fostering the partnerships with the private sector for the scaling up and commercialization of technologies developed in the private sector.

Private investment in agricultural R&D was relatively low until 2000. Growing world population, global food demand and the lack of extensive factors of production push food and agriculture producers to find a new ways to increase output. According to USDA, private agriculture research and development (R&D) expenditures, increased from $6.9 billion in 2000 to $11 billion in 2010. R&D expenditures on crop improvement & biotechnology, crop protection and farm machinery account for about 85% of total private R&D expenditures in the world.



The Intellectual Property right (IPR) provides ownership rights to innovation which provide incentives to the researcher and organization not only with in the public research system but also helps for new innovation and research ideas from private agencies. French Government began investing in agriculture research in its West African colonies after 1943 and in Britain's central African colonies at the turn of 20th century. Subsequently the participation of private company and organization in agricultural research increased. Particularly in the form of Bio technology, their participation increased. Private sector participation in agricultural R&D is dominated by companies involved in breeding, biotechnology animal health, plant protection and farm machineries. The firm starts with national input companies and gradually diversifies into research. This trend was further stimulated by the participation of large national and multinational companies and their merging and conglomeration during 90s.

Agricultural biotechnology

Biotechnology is one field where more private investments in agriculture were made. For instance, by the end of 2000, over 11500 field trials for transgenic crop technologies had occurred in 39 countries of which 55 in US and 10.7 in Canada, 3.4% in Argentina (Pardey and Beintema, 2001). About 180 crop events involving 15 basic phenotypic characteristics were approved for planting, feed or food use in at least 27 countries and for atleast 14 crops. Successfully modified traits important for the major crops include delayed ripening, herbicide tolerance, insect resistance, modified color or oil male fertility/ fertilizer restoration and virus resistance. Although transgenic crops were grown in eight LDCs by the end of 2000 (compared with only seven developed countries), almost three quarters of the world's transgenic acreage was located in developed rich countries. US alone accounted for two third of world's transgenic acreage. Close to 60 per cent US area is in herbicide resistant soybean (mostly roundup ready) followed by corn at 20 per cent mostly insect resistant and cotton at 18 per cent. Argentina accounts for 24% of world's transgenic acreage followed by Canada (7%), and China (1.2%).

The low rate of transgenic crops acreage in LDCs is due to absence of regulatory approvals for commercial use and lag in getting genetic traits in to varieties that suit to local and desirable traits in crops of significance to poor people. The small amount of money spent on bio technology by government agencies also the reason for low adoption. For example, in 1998, the Consultative groups collectively spent just $ 25 million on biotechnology research. That same year; Monsanto invested $1.26 b in R&D.

Impact of private agricultural R&D investment

The current challenges of the stock holders and policy makers is to provide adequate, accessible quality foods to below poverty line people at reasonable price. The increasing rate of R & D investment would bring positive change in the food prices and GDP. It could be inferred from the Figure17, that with increase in private agricultural R&D, the food price index showed sharp increase after 2005, along with increased share of agriculture in world GDP.

Implication of agricultural R&D investment in agricultural GDP

Agricultural GDP response function for agricultural R&D investment was fitted with staffing as instrument variable. The agricultural GDP response to both 10 year lag and 5 Year lag in agricultural R&D investment were attempted using log linear model and the results are presented in Table 7.

The results revealed that for every additional one dollar investment in agricultural R&D from the mean level would generate 1.07 per cent increase in agricultural GDP in 10 years and 0.94 per cent growth from the current level of Agrl GDP could be achieved with in 5 years after investment using current resource endowment. This indicates the importance for agricultural R&D investment for increasing growth rate in agriculture to meet the growing food demand

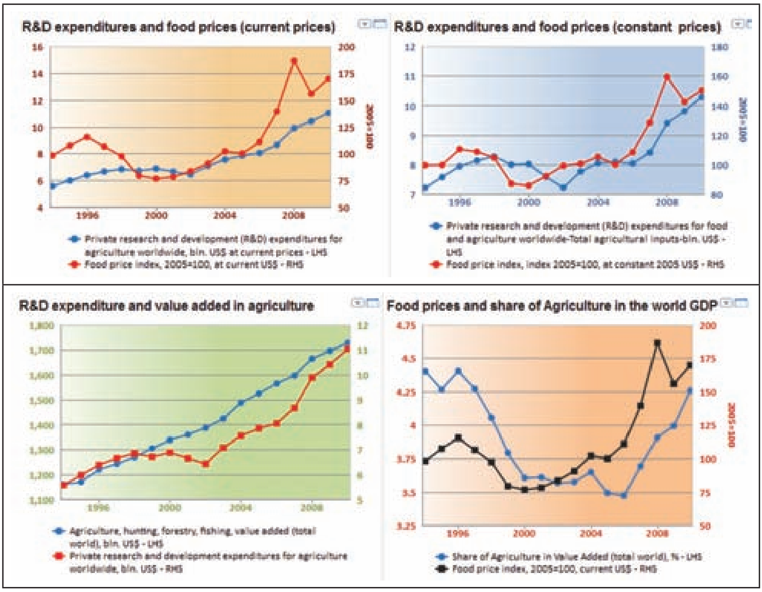


Figure 17. Private R & D food prices

Table 7. Agricultural GDP response function for agricultural R&D

Details	Model 1: 10 years lag R&D		Model 2: 5 years lag R&D	
	Coefficient	t-value	Coefficient	t-value
Constant	5.96***	6.32	6.53***	7.89
Agricultural R&D	1.072***	7.34	0.941***	8.05
Adj R^2 ; F value	0.748	54.42	0.77	62.27

Instrument variable is 5 years lag total numbers of staff in public agricultural R&D

Conclusion

Rice productivity has reached higher level in high area high productivity states (HH) and low area high productivity states (LH). This warrants regional specific research approach to increase the productivity further by hybrid technology or bridging the yield gap through yield boosting technologies

- Many developing and developed countries are having constant or even declining investment in agriculture R&D. Only a few larger and more advanced developing countries, such as India, China, and Brazil are growing substantially in terms of amount spent on agriculture R&D.
- Now, India has ability to produce diverse technologies that have been highly beneficial for the agricultural sector. But, the focus of agriculture research in India is widening and becoming more complex with the need to encompass issues such as sustainable natural resource management, improving food quality and safety and poverty alleviation. This will need a redirection of the country's R&D policy and strategy coupled with sufficient resources.
- Key development challenges for the coming decades are meeting the growing and diversifying food demand, especially for livestock and horticultural products, managing natural resources, sustainability and raising the productivity of rainfed agriculture.
- India's research intensity ratio, measured as public agricultural R&D spending as a share of agricultural output, continue to be relatively low compared to China and Brazil. In its upcoming 12^{th} FYP, the Indian government seeks to address this deficiency by committing one per cent of agricultural GDP to agricultural R&D.
- Though the quality of India's research staff has improved, by declining trend of number of research staff by 8 per cent in recent years due to budget constraints has to be taken care to strengthen the agricultural research.
- Without an effective policy response, the state research capacity will decline further, leading to less spending on research by SAUs.
- A final concern is the fragmentation of SAUs along disciplinary lines. A trend toward greater specialization could hinder integrated technology development and demonstration on farmers' fields.
- The target oriented location specific yield boosting and cost cutting technologies have to be generated and are essential for sustain the rice production system particularly in low productivity higher area states such as Bihar, Chhattisgarh and Orissa.

Note

1 FAO Statistics the production and productive data for converting milled rice term (multiply by 2/3)

2 PPP are synthetic Exchange rates used to reflect the purchasing power of currencies, typically comparing prices among a broader basket of goods and services than do conventional exchange rates.

3 Rice growing state classification criteria (7.5% national rice area and national yield 2 t/ha;

State group	Area 7.5% of national rice area	Yield 2 t/ha	State
HH	> 7.5	>2.5	AP, UP, WB
HL	> 7.5	>2.5	Bihar, Chhattisgarh, Orissa
LH	> 7.5	>2.5	Karnataka, Punjab, Tamil Nadu
LL	> 7.5	>2.5	Assam, Jharkhand, Maharashtra

4 Country International Price level (IPL) is an Index of the costs of goods in one county at the current rate of exchange relative to the cost of the same bundle of goods in numeral country, US, IPL for Japan is 1.57 indicates that average prices in Japan were 57 per cent higer than they were in USA. IPL for Kenya 0.20 means goods worth of $100 to be purchased in USA can be purchased with $20 in Kenya.

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Biotechnological Options for Rice Improvement

R.M. Sundaram, S.M. Balachandran, M.S. Madhav and B.C. Viraktamath

Rice is the world's most important food crop and a staple food for more than half of the world's population. More than 90% of the world's rice is produced and consumed in Asia, where 60% of the people live. In India, rice feeds more than 70% of the population and is the principal calorie source for most of the people. In the last five decades, rice production has steadily kept in pace with the population growth rate in India and elsewhere, mainly due to the gains derived from the technologies of green revolution era and due to the ushering of new technologies like hybrid rice. Of late, rice yield levels are reaching a plateau and no significant increase is being witnessed in productivity levels in the last few years. Keeping in view the annual average population growth rate of 1.5% and estimated per capita consumption of about 250 g of rice per day, the demand for rice is expected to be 100 M tonnes by 2025 and 140 M tonnes by 2025 (http://www.fao.org/rice2004/en/pdf/khush.pdf). This projected demand can be met only if there is a steady increase in productivity and production. Further, the increases in production have to be achieved under conditions of declining and deteriorating land, soil and water resources and at the same time preserving the environmental quality for future generation. It will be indeed difficult to meet these daunting challenges, only through the application of conventional plant breeding techniques and tools. Modern tools of biotechnology, particularly molecular breeding can be helpful to meet the rice production and productivity targets. Application of various tools of biotechnology like molecular markers, genetic engineering and genomics to the process of plant breeding is collectively referred to as molecular breeding (http://en.wikipedia.org/wiki/plant_breeding). The progress of application of molecular breeding tools for rice improvement in India and elsewhere is reviewed in this article along with a road-map for the future.

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Molecular breeding: a new paradigm for rice improvement

Rapid strides in the field of molecular biology during the last two decades as applicable to plant sciences in general and crop improvement in particular have ushered in a new paradigm for rice improvement, i.e. molecular breeding. A judicious, imaginative and pragmatic application of molecular tools of biotechnology in breeding can bring about positive impact in rice improvement efforts. From the point of view of plant breeding, modern plant biotechnology helps to add precision to the process of breeding, making it target oriented and purposeful as compared to the empirical efforts involved in conventional/traditional breeding.

Molecular breeding can help in enhancing breeding efficiency through (Datta; http://www.rkmp.co.in/sites/default/files/ris/research-themes/Rice%20Improvement%20through%20Application%20of%20Biotechnological%20Tools.pdf)

(i) Precise manipulation of target trait without any disruption to non-target sites of the genome [i.e., increasing the efficiency of selection]

(ii) Shortening the breeding cycle considerably by rapid and precise identification of desirable segregant(s), and

(iii) Transfer of economically important traits/genes across species and genera into the rice gene pool [i.e., broadening the genetic base]

Three broad applications of biotechnology and molecular breeding that are expected to contribute both directly and indirectly towards rice improvement are (Sarma and Sundaram 2005):

1. **DNA marker technology** for enhancing selection efficiency and precision in breeding.

2. **Genetic engineering** for transferring agronomically useful traits across species barrier that cannot be achieved by conventional means and

3. **Genomic tools** for identifying new and useful genes/alleles

DNA marker technology

The differences that distinguish one plant from another are encoded in the plant's genetic material, the deoxyribonucleic acid (DNA). Molecular marker is a fragment of DNA sequence that is associated to a part of the genome. These DNA sequences are used to 'flag' the position of a particular gene/QTL of interest and thereby track the inheritance of a particular trait. In a given cross, the trait(s) of interest will usually stay linked with the molecular markers. Thus, individuals in which the particular molecular marker allele is present can be selected without exposing them to the selection pressure as the marker indicates the presence of the desired characteristic.

DNA marker technology refers to the application of DNA based markers in breeding programmes to improve the selection efficiency (Sarma and Sundaram 2005) and the term 'Marker-assisted selection (MAS)' or 'marker-assisted breeding (MAB)' are also used to refer to the application of DNA markers in crop breeding. Many molecular genetic linkage maps have been constructed in rice using molecular markers (McCouch *et al.* 1988; Causse *et al*. 1994; Kurata *et al*. 1994; McCouch *et al*. 2002; IRGSP, 2005) and a multitude of DNA markers have been identified to be linked to traits of agronomic importance in rice (Table -1).

The utility of DNA markers is dependent to a large extent by the techniques that are used to generate DNA polymorphism. DNA markers are classified as hybridization based markers and polymerase chain reaction (PCR) based markers. In the first category are restriction fragment length polymorphisms (RFLPs) which are visualized by hybridization of restriction enzyme digested DNA to a labelled probe of known sequence or origin. However, RFLP markers are not in vogue nowadays due to complexity of protocols. PCR based markers, which utilize the technique of polymerase chain reaction (PCR) are the most useful markers due to their simplicity, robustness and speed of assay. These markers involve *in-vitro* amplification of specific DNA sequence or locus by using either specifically designed or arbitrarily chosen random primers. A plethora of markers are now available for rice improvement. As each of these markers have different advantages, the question of what markers to use depends on the specific purpose. For example, trait introgression, qualitative trait mapping and quantitative trait mapping, germplasm characterization or diagnostics have different technical challenges and demand specific requirements. The suitability of a marker is determined by several considerations such as ease of assay, ability to discriminate between individuals, the frequency of occurrence of the marker (abundance) and more importantly the type of marker – Co-dominant or Dominant. In rice, many PCR based markers like randomly amplified polymorphic DNAs (RAPDs), amplified fragment length polymorphisms (AFLPs), inter-simple sequence repeats (ISSRs) and simple sequence repeats (SSRs) are being used. Among the PCR based DNA markers, microsatellites or simple sequence repeats (SSRs) are highly preferred for gene tagging and mapping efforts due to the high level of polymorphism content and versatility and are preferred due to their reproducibility and amenability for automation (McCouch *et al*. 1997; McCouch *et al*. 2002). More than 20,000 SSR markers have been developed in rice so far and their chromosomal location and polymorphism levels have been determined (IRGSP 2005; http://www.gramene.org). Due to these reasons, SSRs are the markers of choice for rice improvement today for MAS applications.

The availability of the complete sequence of the rice genome has accelerated the process of cloning of many genes. If the functional nucleotide polymorphism, specific for the functional allele of the gene is identified, it can lead to a more powerful, gene-based or functional marker (Andersen and Lubberstedt 2003), which are sometimes referred to as a "perfect marker". Functional markers are now available for a multitude of traits in rice (Iyer and McCouch 2007; Sakthivel *et al*. 2009; Sundaram et al. 2010; Ramkumar *et al*. 2010a; Ramkumar *et al*. 2010b; Hayashi *et al*. 2010).

Of late, a special class of markers called single nucleotide polymorphisms (SNPs) are gaining predominance in those crop species like rice, whose genomes have been sequenced. A single-nucleotide polymorphism (SNP, pronounced as 'snip') is a DNA sequence variation occurring when a single nucleotide — A, T, C, or G — in the genome differs between members of a species or paired chromosomes in an individual. For example, two sequenced DNA fragments from different individuals, AAGCCTA to AAGCTTA, contain a difference in a single nucleotide. Thus for the sequence under consideration, there are two alleles: C and T. Almost all common SNPs have only two alleles (http://en.wikipedia.org/wiki/SNPs). Many SNPs have been identified between *indica* and *japonica* subspecies of rice and information regarding these are available freely online (http://

www.ricesnp.org). Recently, McNally *et al*. (2009) undertook genome-wide SNP variation among 20 diverse elite rice varieties and landraces and observed 160,000 non-redundant SNPs and the entire information is available online (http://www.oryzasnp.org). Even though SNP markers are not widely used for marker-assisted breeding (MAB) in rice, in future it is expected that they will replace SSRs as markers of choice, now that chip based assays are available for their analysis (http://www.affymetrix.com).

Many agronomically important rice genes have been tagged with markers and are readily deployed by breeders in breeding programs (Table 1).

Table 1. Agronomically important genes tagged and mapped with molecular markers in rice

Sl No.	Trait	Name of the gene/ QTL	Chromosome on which the gene is located	Linked marker	Reference
1	Blast resistance	*Pi1*	11	Npb181	Yu *et al*. (1991)
2	Blast resistance	*Pi2*	6	RG64	Hittalmani *et. al* (1995)
3	Blast resistance	*Pi4*	12	RG869, XNpb294	Yu *et al*. (1991)
4	Blast resistance	*Pi9*	6	pB8	Qu *et al*. (2006)
5	Blast resistance	*Pi36*	8	RM5647 & CRG2	Liu *et al*. (2007a)
6	Blast resistance	*Pi37*	1	RM543-FPSM1	Chen *et al*. (2005)
7	Blast resistance	*Pi39*	12	RM27933 and RM27940	Liu *et al*. (2007b)
8	Blast resistance	*Pi40*	6	9871.T7E2b	Jeung *et al*. (2007)
9	Blast resistance	*Pib*	2	R2511	Wang *et al*. (1999)
10	Blast resistance	*Pita*	12	RZ397	Yu *et al*. (1991)
11	Blast resistance	*Pi54* (*Pi-k^h^*)	11	RM206 *Pi54* MAS	Sharma *et al*. (2005) Ramkumar *et al*. (2010b)
12	Bacterial blight resistance	*Xa1*	4	Npb235	Yoshimura *et al*. (1998)
13	Bacterial blight resistance	*Xa4*	11	Npb181	Yoshimura *et al*. (1995)
14	Bacterial blight resistance	*xa5*	5	RG556	Mc Couch *et al*. (1991)
15	Bacterial blight resistance	*Xa7*	6	G1091	Kaji and Ogawa (1995)
16	Bacterial blight resistance	*xa8*	8	RM500 RM533	http://www.gramene.org

Sl No.	Trait	Name of the gene/ QTL	Chromo-some on which the gene is located	Linked marker	Reference
17	Bacterial blight resistance	*xa13*	8	RG136	Zhang *et al.* (1996)
18	Bacterial blight resistance	*Xa21*	11	pTA248	Ronald *et al*. (1992)
19	Bacterial blight resistance	*Xa23*	11	RM254	www.gramene.org
20	Bacterial blight resistance	*xa25*	11	RM254	www.gramene.org
21	Bacterial blight resistance	*Xa26*	11	C481S Y6855RA	Sun *et al*. (2004)
22	Bacterial blight resistance	*Xa33*	7	RMWR7.1 and RMWR7.6	Natarajkumar *et al.* (2011)
23	Bacterial blight resistance	*xa34*	1	RM10929 and BGID25.	Chen *et al.* (2011)
24	Bacterial blight resistance	*Xa38*	4	RM17499 and RM17502	Cheema *et al.* (2008a)
25	Rice tungro spheri-cal virus resistance	*RTSV*	4	RZ262	Sebastian *et al*. (1996)
26	Brown plant hop-per resistance	*Bph1*	12	XNpb248	Hirbayashi and Ogawa (1995)
27	Brown plant hop-per resistance	*Bph10(t)*	12	RG457	Ishii*. et al*. (1994)
28	Brown plant hop-per resistance	*Bph13*	2	RG100 and RG 191	Renganayaki *et a*l. (2002)
29	Brown plant hop-per resistance	*Bph18*	12	RM463, S15552, 7312.T4A	Jena *et al.* (2006)
30	Brown plant hop-per resistance	*Bph20*	4	MS10 and RM5953	Rahman *et al*. (2009)
31	Brown plant hop-per resistance	*Bph21*	12	RM3726 and RM5479	Rahman *et al*. (2009)
32	Gall midge resis-tance	*Gm1*	9	RM219, RM316, RM444	Biradar *et a*l. (2004)
33	Gall midge resis-tance	*Gm2*	4	RG329	Mohan *et al.* (1994)
34	Gall midge resis-tance	*Gm4*	8	F43	Nair *et al. (*1996)
	Gall midge resis-tance	*Gm6*	4	OPM06, RG214, RG476	Katiyar *et a*l. (2001)
35	Gall midge resis-tance	*Gm7*	4	SA598, F8	Sardesai *et al*. (2002)
36	Gall midge resis-tance	*Gm8*	8	AR257 and AS168	Jain *et al*. (2004)

Sl No.	Trait	Name of the gene/ QTL	Chromo-some on which the gene is located	Linked marker	Reference
37	Gall midge resis-tance	*Gm11*	8	RM28706 and RM235	Himabindu *et al.* (200
38	Submergence tolerance	*Sub1*	9	AEX and AEX1R	Septiningsih *et al.* (2009)
39	Tolerance to low Phosphorus levels in the soil	*Pup1*	12	Pup1-K29 and Pup1-K42	Chin *et al.* (2010)
40	Drought tolerance	*Qtl 12.1*	12	RM28048 and RM511	Bernier *et al.* (2007)
41	Drought tolerance	*qDTY1.1*	1	RM11943 and RM431	Vikram *et a*l. (2011)
42	Salt tolerance	*Saltol*	1	RM8094 and RM10793	Thomson *et a*l. (2010)
43	Fertility restoration for WA-CMS	*Rf3*	1	RM10305	Neeraja *et al*. (2007)
44	Fertility restoration for WA-CMS	*Rf4*	10	RM6100	Mishra *et al.* (2003)
45	Wide compatibility	*S5*	6	*S5*MMS	Sundaram *et al.* (2010a)
46	Aroma	*fgr*	8	BADEX7-5	Sakthivel *et a*l. (2009)
47	Grain length/ size	*GS3*	3	DRR GL	Ramkumar *et al.* (2010)

Three important application of DNA markers have been visualized in rice genetics and breeding (Collard and Mackill, 2008). They are:

(i) To determine the allelic status of genes/QTLs (i.e., determining whether homozygous or heterozygous) conferring identical phenotypes,
(ii) Use in marker assisted selection and
(iii) Map based cloning of genes.

Applications of marker-assisted selection in rice

Marker-assisted selection (MAS) refers to the use of DNA markers that are tightly-linked to target loci as a substitute for or to assist phenotypic screening. It is an indirect selection process where a trait of interest is selected not based on the trait itself but on a marker linked to it (Ribaut and Hoisington 1998). The basic premise and assumption here is that the DNA markers can reliably predict phenotype and this depends on the linkage distance between the marker(s) and the gene/QTL of interest controlling the trait phenotype.

DNA markers tightly linked to the gene(s) of interest can be used at any crop stage for testing the presence of the gene(s) without waiting to observe its phenotypic manifestations. In addition, markers which are co-dominant (like SSRs) also help us know the allelic status of a gene (i.e. whether the gene is homozygous/heterozygous) and thus are very helpful in recurrent/backcross breeding programs for introgression of recessive but agronomically important gene(s).

Markers should be deployed only for those traits, which cannot be easily scored for phenotype or those governed by recessive genes. Very tightly linked markers with close linkage (< 1cM) with the gene of interest or markers flanking the gene (<8 cM on either side of the gene) should be used in breeding programs (Biradar *et al*. 2004; Jena and Mackill *et al*. 2008). If these points are taken care of, marker technology can significantly contribute towards increasing the selection efficiency in breeding programs.

Collard and Mackill (2008) have outlined five main considerations for the use of DNA markers in breeding. They are (i) reliability, (ii) quality and quantity of DNA used, (iii) complexity of the technical procedure, (iv) level of polymorphism and most importantly and (v) cost of assay. SSR markers satisfy most of these criteria and hence are considered the most ideal markers for MAS in rice. However, in future, it is expected that the technical procedure for utilization of SNP markers will be simplified and automated and together with SSR markers, SNPs will be the markers of choice in rice breeding.

Marker-assisted breeding (MAB) has the following distinct advantages as compared to conventional phenotypic-selection based breeding (Collard and Mackill, 2008):

(i) MAB facilitates cost effective, time saving and non-destructive assay(s).

(ii) Selection can be carried out at any growth stage from seed to maturity.

(iii) Facilitates differentiation of homozygous segregants from heterozygous ones in backcross, bulk and pedigree breeding methods, thus facilitating early –generation selection of superior recombinants, particularly for those traits controlled by recessively inherited genes.

(iv) Screening can be done even without having the incidence of pests/disease.

There are many areas for application of molecular markers in rice improvement (Sarma and Sundaram, 2005). They include:

- Establishing cultivar identity and assessment of genetic purity
- Assessment of genetic diversity and parental selection
- Prediction of heterosis
- Identification of restorer lines and wide-compatible genes,
- Marker-assisted introgression of agronomically important genes/QTLs into the genetic background of elite cultivars/ parental lines through backcross breeding
- Marker-assisted gene-pyramiding for biotic and abiotic stresses
- Marker-based early generation selection
- Marker-based whole genome selection
- Combined deployment of MAS with phenotypic selection

Some of the success stories related to application of MAS in rice are enlisted in Table 2

Table 2: Examples of MAS applications in rice (adapted from Collard *et al.* 2008)

Sl No.	Target trait	Gene (s) / QTL (s) deployed	Type/name of marker(s) used	Reference	Remarks
1	Bacterial blight (BB) resistance	*Xa4, xa5* & *Xa10*	Gene linked RFLP and RAPD markers	Yoshimura *et al*. (1995)	MAS applied for gene pyramiding
2	Bacterial blight (BB) resistance	*Xa4, xa5, xa13* & *Xa21*	STS for *Xa4* CAPS for *xa5* (RG556+DraI) CAPS for *xa13* (RG136 + HinfI) STS for *Xa21* (pTA248)	Huang *et al.* (1997)	MAS applied for gene pyramiding
3	Bacterial blight (BB) resistance	*Xa21*	STS (pTA248)	Reddy *et al.* (1997)	MAS applied for early generation selection for BB resistance

Sl No.	Target trait	Gene (s) / QTL (s) deployed	Type/name of marker(s) used	Reference	Remarks
4	Bacterial blight (BB) resistance	*Xa21*	STS (pTA248)	Chen *et al*. (2000)	MAS applied for Marker-assisted backcross breeding
5	Bacterial blight (BB) resistance	*xa5*, *xa13* & *Xa21*	CAPS for *xa5* (RG556+DraI) CAPS for *xa13* (RG136+HinfI) STS for *Xa21* (pTA248)	Sanchez *et al.* (2000)	MAS applied for gene pyramiding
6	Bacterial blight (BB) resistance	*Xa21*	STS (pTA248)	Ronald *et al.* (1992)	MAS applied for Marker-assisted backcross breeding
7	Bacterial blight (BB) resistance	*xa5*, *xa13* & *Xa21*	CAPS for *xa5* (RG556+DraI) CAPS for *xa13* (RG136+HinfI) STS for *Xa21* (pTA248)	Singh *et al.* (2001)	MAS applied for Marker-assisted backcross breeding (Target variety: PR106)
8	Bacterial blight (BB) resistance	*xa5*, *xa13* & *Xa21*	CAPS for *xa5* (RG556+DraI) CAPS for *xa13* (RG136+HinfI) STS for *Xa21* (pTA248)	Davierwala *et al*. (2001)	MAS applied for gene pyramiding
9	Bacterial blight (BB) resistance	*xa5*	CAPS (RG556+DraI)	Toennisen *et al*. (2003)	MAS applied for Marker-assisted backcross breeding
10	Bacterial blight (BB) resistance	*Xa4*, *xa5* & *Xa21*	STS for *Xa4* CAPS for *xa5* (RG556+DraI) STS for *Xa21* (pTA248)	Leung *et al.* (2004)	MAS applied for gene pyramiding
11	Bacterial blight (BB) resistance	*Xa7*& *Xa21*	STS for *Xa7* STS for *Xa21* (pTA248)	Zhang *et al*. (2006)	MAS applied for gene pyramiding
12	Bacterial blight (BB) resistance	*xa5*, *xa13* & *Xa21*	CAPS for *xa5* (RG556+DraI) CAPS for *xa13* (RG136+HinfI) STS for *Xa21* (pTA248)	Sundaram *et al*. (2008a)	MAS applied for backcross breeding. In addition to foreground selection using the gene linked markers, background selection was also performed using parental polymorphic SSR markers (Target variety: Samba Mahsuri)
13	Bacterial blight (BB) resistance	*Xa4*, *X17* & *Xa21*	STS for *Xa4* & *Xa7* STS for *Xa21* (pTA248)	Perez *et al*. (2008)	MAS applied for gene pyramiding

Sl No.	Target trait	Gene (s) / QTL (s) deployed	Type/name of marker(s) used	Reference	Remarks
14	Bacterial blight (BB) resistance	*Xa4, xa5, xa13* & *Xa21*	STS for *Xa4* CAPS for *xa5* (RG556+DraI) CAPS for *xa13* (RG136+HinfI) STS for *Xa21* (pTA248)	All India Coordinated Rice Improvement Project (AICRIP) Progress Report. Vol. 1 (2008)	MAS applied for gene pyramiding (Target varieties: Swarna and IR64, some pre-breeding lines in the genetic background of Lalat and Tapaswini possessing BB resistance also developed by the Central Rice Research Institute (CRRI), Cuttack, India and nominated for AICRIP trials)
15	Bacterial blight (BB) resistance	*xa5* and *xa13*	CAPS for *xa13* (RG136+HinfI) STS for *Xa21* (pTA248)	Sundaram *et al.* (2009)	MAS applied for backcross breeding. In addition to foreground selection using the gene linked markers, background selection was also performed using parental polymorphic SSR markers (Target variety: Triguna)
16	Bacterial blight (BB) resistance + Grain quality	*xa13* & *Xa21*	CAPS for *xa13* (RG136+HinfI) STS for *Xa21* (pTA248)	Joseph *et al.* (2004) Gopalakrishnan *et al.* (2008)	MAS applied for backcross breeding. In addition to foreground selection using the gene linked markers, background selection was also performed using parental polymorphic AFLP & SSR markers. Further markers linked to grain quality traits were also used for foreground selection (Target variety: Pusa Basmati 1)
17	Bacterial blight resistance	*Xa21* + *xa13*	STS for *Xa21* and a functional marker for *xa13*	Basavaraj *et al.* (2010)	MAS applied for backcross breeding. In addition to foreground selection using the gene linked markers, a SSR marker RM6100 linked to the major fertility restorer gene *Rf4* was also utilized (Target variety: Pusa6B and PRR78, parental lines of the rice hybrid Pusa RH10)

Sl No.	Target trait	Gene (s) / QTL (s) deployed	Type/name of marker(s) used	Reference	Remarks
18	Bacterial blight (BB) resistance + Grain quality	*xa5, xa13, Xa21*& *Wx*	CAPS for *xa5* (RG556+DraI) CAPS for *xa13* (RG136+HinfI) STS for *Xa21* (pTA248) CAPS for *Wx*	Ramalingam *et al*. (2002)	MAS applied for pyramiding of target traits
19	Bacterial blight (BB) resistance + stem borer tolerance	*Xa21*& *Bt*	STS for *Xa21* (pTA248)	Jiang *et al*. (2004)	MAS applied for pyramiding of target traits into restorer line. *Bt* gene originally introduced into donor line through genetic engineering (Target variety: Minghui63)
20	Bacterial blight (BB) resistance + stem borer tolerance + sheath blight tolerance	*Xa21, Bt* & *Chitinase*	STS for *Xa21* (pTA248)	Datta *et al*. (2002)	MAS applied for pyramiding of target traits. *Bt* gene and *Chitinase* gene originally introduced into donor lines through genetic engineering (Target variety: IR72)
21	Bacterial blight (BB) resistance + Blast resistance	*Xa21* & *Piz*	STS for *Piz*, transgene specific marker for *Xa21*	Narayanan *et al*. (2002)	MAS applied for pyramiding of target traits. *Xa21* gene originally introduced into donor lines through genetic engineering (Target variety: IR50)
22	Bacterial blight (BB) + Semi-dwarfing	*Xa21* + *xa13* & *Sd1*	STS for *Xa21* and *xa13*	Rajpurohit *et al*. (2011)	MAS applied for backcross breeding. In addition to foreground selection using the gene linked markers, background selection was also performed using SSR and ISSR markers. Further markers linked to *Sd1* were also used (Target variety: Type 3 Basmati)
23	Blast resistance	*Pi1, Piz-5, Pi2, Pita*	RFLP markers for *Pi1, Pi2* and *Pita* and a PCR based SAP marker for *Piz-5*	Hittalmani *et al*. (2000)	MAS applied for gene pyramiding (Target variety: C039)

Sl No.	Target trait	Gene (s) / QTL (s) deployed	Type/name of marker(s) used	Reference	Remarks
24	Blast resistance	*Pi1*	SSR and ISSR markers	Liu *et al*. (2003)	MAS applied for backcross breeding (Target variety: Zhenshan 97A)
25	BPH resistance	*Bph1 & Bph2*	STS markers	Sharma *et al*. (2004)	MAS applied for gene pyramiding
26	Thermo-sensitive genic male sterility	*tms2, tgms & tms5*	SSR markers	Nas *et al*. (2005)	MAS applied for backcross breeding
27	Deep roots	*QTLs on chromosomes 1, 2, 7 and 9*	RFLP and SSR markers	Shen *et al*. (2001)	MAS applied for backcross breeding
28	Root traits + Aroma	*QTLs on chromosomes 2, 7, 8, 9, and 11*	RFLP and SSR markers	Steele *et al*. (2006)	MAS applied for backcross breeding
29	Submergence Tolerance + BPH resistance + Bacterial blight resistance + Blast resistance + quality	*Subchr9 QTL, Xa21, Bph and blast QTLs, and quality loci*	SSR and STS	Toojinda *et al.* (2005)	MAS applied for backcross breeding
30	Submergence tolerance	*Sub1-QTL*	SSR	Neeraja *et al*. (2007)	MAS applied for backcross breeding (Target variety: Swarna and Samba Mahsuri)
31	Heading date	*QTLs for heading date (Hd1, Hd4, Hd5 or Hd6)*	RFLP, STS, SSR, CAPS, dCAPs	Takeuchi *et al.* (2006)	MAS applied for backcross breeding
32	Grain quality	*waxy*	SSR	Zhou *et al*. (2003)	MAS applied for improvement of starch properties of grain
33	Hybrid seed purity assessment	--	SSR and STS markers	Yashitola *et al* (2002) Nandakumar et al. (2004) Sundaram et al. (2008b)	Co-dominant deployed for assessment of genetic purity of seed-lots of rice hybrids and their parental lines.

Sl No.	Target trait	Gene (s) / QTL (s) deployed	Type/name of marker(s) used	Reference	Remarks
34	WA-CMS seed purity assessment	--	Mitochondrial STS and SSR markers	Yashitola *et al.* (2004) Rajendrakumar *et al.* (2007)	Markers deployed for assessmenta of genetic purity of seed-lots of WA-CMS lines. The markers can distinguish the WA-CMS lines from their cognate isonuclear maintainer lines.

The role of molecular biologists and rice biotechnologists towards development of rice marker technology notwithstanding, the role of traditional plant breeders in aiding the process of marker development (in terms of developing mapping populations) and utilization of molecular markers in breeding programs in a routine way is vital for the success of marker assisted selection (MAS) programs. In order to enhance cost efficiency in MAS, effort towards cost-economizing MAS through automation, scaling down PCR reaction volumes, simplified procedures of DNA extraction and networking of laboratories are being taken up (Collard and Mackill, 2008). Similar efforts are in progress to simplify and automate the utilization of SNP markers in rice (www.ricesnp.org).

Marker-assisted breeding in rice-an Indian perspective:

Molecular markers are being increasingly deployed in different rice breeding programs across India. Most of these programs have focused on enhancement of biotic stress resistance, particularly disease resistance. The first report of utilization of molecular markers in a rice breeding was by Singh *et al.* (2001), wherein molecular markers linked to the bacterial blight resistance genes *Xa21*, *xa13* and *xa5* were deployed for their introgression into the elite rice variety, PR 106. When evaluated against different isolates of the bacterial blight pathogen from Punjab, the pyramided lines with the gene combination *Xa21* + *xa13* + *xa5* were observed to provide high levels of resistance. Later, Joseph *et al*. (2004), introgressed two bacterial blight resistance genes *Xa21* and *xa13* with the help of molecular markers through backcross pedigree strategy into the genetic background of a ruling Basmati variety, Pusa Basmati-1. Phenotypic selection for disease resistance, agronomic and Basmati quality characteristics and marker-assisted selection for the two resistance genes were carried out in BC_1F_1, BC_1F_2 and

BC_1F_3 generations. Background analysis using 252 polymorphic amplified fragment length polymorphism (AFLP) markers detected 80.4 to 86.7% recurrent parent alleles in BC_1F_3 selections. One of the selected gene-pyramid lines, Pusa 1460-01-32-6-7-67 has been released as a new variety named 'Improved Pusa Basmati 1' for commercial cultivation in India (Gopalakrishnan et al. 2008). Parallel to these efforts, the resistance breeding team at Directorate of Rice Research (DRR), Hyderabad have introgressed three bacterial blight resistance genes *Xa21, xa13* and *xa5* into the elite, high yielding, fine-grain type rice variety, Samba Mahsuri through marker-assisted breeding (Sundaram *et al*. 2008). Foreground selection was deployed for quick identification of the target resistance genes in the backcross-derived plants and background selection was carried out to identify backcross lines possessing maximum recovery of the recurrent parent genome at each generation of backcrossing. Backcrossing was carried out until BC_4 generation. A three-gene pyramid line, RPBio-226 (IET 19046) was identified to possess high yield, good level and broad-spectrum bacterial blight resistance and excellent grain quality. Recently, this line has been released for commercial cultivation as a new variety 'Improved Samba Mahsuri'. A sister line of Improved Samba Mahsuri, RPBio-210 (IET 19045), which has high level of BB resistance, high yield, good grain quality has been recently registered with the National Bureau of Plant Genetic Resources (NBPGR) as a novel germplasm (Sundaram *et al*. 2010b). Recently, Basavaraj *et al*. (2010) introgressed *Xa21* and *xa13* into the parental lines of the elite, Basmati quality rice hybrid, Pusa RH10 demonstrating the utility of molecular markers in improvement of biotic stress resistance of rice hybrids. Recently, Perumalsamy et al. (2011) utilized functional markers for targeted introgression of *Xa21, xa13* and *xa5* into two elite varieties viz., ADT43 and ASD16. Another noteworth effort is the identification of a new, broad spectrum bacterial blight resistance gene *Xa33* from an accession of the wild rice, *O. nivara*, its molecular mapping on Chr. 7 and marker-assisted introgression of the gene into the elite rice cultivar Samba Mahsuri (Natarajkumar *et al*. 2011, Natarajkumar *et al*. 2012). In addition to bacterial blight resistance, molecular markers have also been used to pyramid three major blast resistance genes, *Pi1, Piz5* and *Pita* into the genetic background of the Indian rice variety Co39 (Hittalmani *et al.* 2000).

The topic of yield improvement through marker-assisted identification and introgression of yield associated QTLs into elite varieties has received considerable attention in recent years. The first such effort was launched at the Directorate of Rice Research, Hyderabad wherein two major QTLs *yld1.1* and *yld2.1* were identified from an accession of *O. rufipogon* (Marri *et al*. 2005). Later these QTLs were introgressed into an elite restorer parent of hybrid rice KMR3R and lines harboring the QTL(s) are under evaluation in All India Coordinated Rice Improvement Project (AICRIP) trials. Efforts are also on at DRR to identify and introgress novel yield related QTLs from other wild species of *Oryza* into elite cultivated varieties. Cheema *et al*. (2008b) from Punjab Agricultural University, Ludhiana used a limited backcross strategy to introgress QTLs associated with yield and yield components from *O. rufipogon* in to the elite cultivated variety IR64.

Molecular markers have also been applied for genetic purity testing of rice hybrids (Yashitola *et al.* 2002; Nandakumar *et al.* 2004; Sundaram *et al*. 2008) and their parental lines (Yashitola *et al*. 2004; Rajendrakumar *et al*. 2007). Nagaraju *et al*. (2002) used SSR markers to develop varietal fingerprinting profile for elite Basmati varieties of India. Singh *et al.* (2004) assessed the suitability of mapped SSR markers for establishing distinctness, uniformity and stability (DUS) in aromatic rice and identified a set of markers which could be utilized. Recently, Jaikishen *et al.* (2009) used EST-SSR markers to study diversity of hybrid rice parental lines and identified a set of 'key' informative markers which could be utilized for heterosis prediction.

Genetic engineering for rice improvement

Genetic engineering or genetically modified (GM) crop technology is another tool that promises to revolutionize Indian rice production scenario. The key advantage of transgenic technology is the capacity to mobilize useful genes from non-rice gene pool into rice with least disruption to rice genome. Ever since the appearance of the first report on successful production of transgenic rice plants of japonica in 1988 (Zhang and Wu, 1988), a large number of rice varieties have been introduced with agronomically and economically important genes. Direct DNA transfer methods such as protoplasts (Datta *et al.* 1990), biolistic method (Christou *et al.* 1991) and *Agrobacterium*-mediated methods (Hiei *et al*. 1994) are being used routinely in rice transformation in the biotechnology laboratories across the world including India. Transgenic indica rice tolerant to biotic stresses such as insect pests and disease causing organisms like viruses, fungi and bacteria have been developed and tested by research group's worldwide (Lin *et al.* 1995; Datta *et al*. 1996; Tu *et al*. 1998).

In India, transformation studies initially involved standardization of various gene transfer techniques. Freely available genes in public domain to most researchers like *gus* and *hygromycin* resistance have been widely used for confirmation of transformation events. Subsequently, genes that confer resistance to pest or disease were targeted and within a few years, Nayak and co-workers reported the development of first transgenic rice with Bt gene in 1996 (Nayak *et al*. 1996). Since then, several groups started working on transfer of different genes into important genotypes of rice, most notably the introduction of *Bt* genes such as *cry1A(b)*, *cry1A(c)* to obtain resistance against yellow stem borer. Research groups in India have recently succeeded in transferring *Bt* genes into indica rice cultivar IR64 using *Agrobacterium* strategy. Similarly, work is progressing in development of transgenic rice resistant to bacterial blight and sheath blight using constructs with *Xa21* and Thaumatin like proteins. The Directorate of Rice Research, Hyderabad, has been working on production of transgenic elite indica rice varieties resistant to diseases and insects. Nagadhara *et al.* (2003) have reported production of transgenic plants of cv. Chaitanya possessing *gna* lectin gene which confers resistance against sucking insect pest of rice. A list of 'key' genes of agronomic importance introduced in rice through transgenic approach is given in Table 3.

Table 3. List of agronomically important genes deployed through transgenesis in rice

SlN	Gene transferred	Trait	Reference
1	*Bar/gus*	Resistance to herbicide	Christou *et al*. (1991)
2	*CP-stripe virus*	Resistance to stripe virus	Hayakawa *et al.* (1992)
3	*Chitinase (Chi11)*	Resistance to sheath blight	Lin *et al*. (1995)
4	*Proteinase Inhibitor (PinII)*	Resistance to Insect	Duan *et al*. (1996)
5	*HVA1*	Osmoprotectant	Xu *et al*. (1996)
6	*Bt*	Stem borer Multiple resistance	Tu *et al*. (1998a)
7	*Bt*	Stem borer resistance, Tissue specific	Datta *et al*. (1998)
8	*Xa21*	Bacterial leaf blight resistance	Tu *et al*. (1998b)

SlN	Gene transferred	Trait	Reference
9	*P5cs* Pyrolline carboxylate synthetase (proline synthesis)	Increased biomass production under drought and salinity stress	Zhu *et al*. (1998)
10	*Adc* Arginine decarboxylase	Reduced cholorophyll loss under drought stress	Capell *et al.* (1998)
11	*CodA* Choline oxidase (glycine betaine synthesis)	Increased salinity and cold tolerance	Sakamoto *et al.* (1998)
12	Ferritin	Iron improvement	Goto *et a*l. (1999)
13	*Psy, crt1, lyc*	β-Carotene	Ye *et al*. (2000)
14	*adh/pdc1*	Submergence tolerance	Quimio *et al*. (2000)
15	*OsCDPK7* Transcription factor	Increased tolerance of cold, salinity, and drought	Saijo *et al*. (2000)
16	*Cry1Ab, Xa21* and *RC7*	Stem borer, bacterial blight and sheath blight tolerance	Datta *et al.* (2002)
17	*TPSP* Trehalose biosynthesis	Increased tolerance of cold, salinity, and drought	Garg *et al.* (2002)
18	*Psy* (Daffodil)*, crt1*	β-Carotene	Datta *et al.* (2003)
19	*DREB1A* Transcription factor	Increased tolerance of cold, salinity, and drought	Shinozaki *et al*. (2003)
20	*Ferritin*	Iron improvement	Vasconcelos *et al*. (2003)
21	*gna* lectin	Tolerance to sucking pests	Nagadhara *et al*. (2003)
22	*Psy* (Maize) and *crt1*	β-Carotene	Paine *et al.* (2005)
23	*asa* lectin	Tolerance to sucking pests	Saha *et al*. (2006)

Current status of transgenic rice development

Despite being the most important cereal crop of the world, field release of GM rice has lagged way behind the other GM crops. Iran, the first country to approve commercial growing of transgenic rice in 2005, has grown Bt rice in less than 0.1 million hectare (http://www.isaaa.org). Though China has completed the field trials of Bt rice, it is yet to start commercial cultivation. The main bottlenecks are (i) several regulatory and ethical issues associated with GM rice, particularly since it is staple food for a majority of the population living in under developed and developing countries, (ii) majority of rice is produced and consumed locally in poor countries. Nevertheless GM rice has great potential in alleviating many problems faced by poor farmers like reducing attack of pests and diseases, reducing losses due to abiotic stresses and poor rice consumers through nutritional enhancement and above all protecting the environment by reducing the consumption of toxic pesticides. Further, a major part of R & D associated with GM rice is still with the public sector, hence a free flow of technology can be expected from lab to land without much interference. At the same time, public-private partnership in developing and deployment of transgenic rice is expected to hasten the productivity gains substantially. Notwithstanding the above problems in India, several public sector institutions and private companies are involved in development of GM rice for various biotic and abiotic stresses and nutritional improvement.

Bt rice – developed by different public and private research groups are ready for field testing. The first field evaluation of Bt rice in the background of IR64 with Cry1Ab was conducted at IARI, New Delhi (Khanna & Raina, 2002). Simultaneously, Bt rice in the genetic background of IR72 imported from IRRI field tested by DRR, Hyd, showed moderate resistance to stem borer. Recently (2007-08), Bt transgenic rice with Cry1Ac has been evaluated by MAHYCO in 11 test locations to assess the performance against yellow stem borer.

Xa21 rice in the genetic background of IR72 imported from IRRI field tested by DRR and shown to be highly resistant to different isolates of bacterial blight (Laha *et al*. 2008).

Golden rice – Main focus is on Golden rice developed by Syngenta and distributed through Golden rice humanitarian board. SGR1 (with Beta carotene levels of 7 µg/gm) developed in the background of from at BC1F1 to BC2F1 generation by DRR, IARI and TNAU. Homozygous lines are expected in another 2-3 seasons. SGR2 (developed by Syngenta and with Beta carotene levels of 30 ug/gm) was received by IARI in March 2006. The lines are being currently used for backcross breeding.

Drought tolerant rice – Material under development stage in the genetic background of IR64 with trehalose biosynthesis (TPSP) gene. Confirmed transgenic lines are expected after 2-3 seasons.

Herbicide tolerant rice (with bar gene) – Being developed mainly by private sector. Few lines ready for field trials

Transgenic rice with gna lectin gene – Osmania University, Hyderabad in the year 2004 developed this transgenic rice. This was field tested at DRR and at APRRI, Maruteru extensively. The results show that these lines possess moderate resistance against sap sucking pest, particularly brown planthopper (BPH).

Besides the above, several 'putative' transgenic rice lines possessing abiotic stress tolerance genes like DREB, P5CS, SOS1 have been developed by ICGEB, University of Hyderabad and Bose Institute, Kolkata which are yet to be tested for their efficacy. Recently, Calcutta University developed transgenic rice that are highly tolerant to drought and salinity using *AtDREB1a* and *OsDREB1b* transcription factors (Datta *et al.* 2012) and DRR, Hyderabad has developed drought tolerant transgenic rice in the background of Samba Mahsuri (BPT 5204), an elite indica variety (DRR Annual Report, 2011-12).

Though limited field tria\ls of GM rice (Table 4) for resistance to yellow stem borer (Bt rice), sucking insects like BPH resistance (with lectin) and bacterial blight resistance (with *Xa21*) were field tested, these are yet to be released for commercial cultivation.

Table 4. Field trials of transgenic rice

Gene	Trait	Country	Performance	Year
cry1Ab *cry1Ac* *Bt fusion gene* *cry1Ab and cry1Ac*	Insect resistance	China	Field-testing of transgenic hybrid rice showed high protection against YSB and leaf folder without any yield reduction	2000 2001 2002
cry1Ab		Iran	Field testing & commercial release	2005
cry1Ab (from IRRI)		India	Moderate resistance of transgenic rice to stem borer	2002-2005
cry1Ac		India	Moderate resistance of transgenic rice to Stem borer Good level of resistance	
cry1Ac, cry2A	Insect resistance	Pakistan	Fifth generation of indica basmati rice showed resistance to YSB. No effect on non-target pests	2004
cry1Aa, cry1B	Insect resistance	Spain	High protection against SSB	2004
Xa21	Bacterial blight resistance	China & India (DRR, Hyderabad).	Excellent field performance of transgenic IR72 in response to BB	2000 & 2002-2004

Gene	Trait	Country	Performance	Year
Bar	Herbicide resistance Herbicide tolerance	Loui-siana, USA Bayer, India	Good level of tolerance Good level of tolerance	2000 2005-2007
Psy, crt1	Beta caro-tene biosyn-thesis	Loui-siana, USA	Good level of trait expression	2004
NHX	Salinity tolerance	India	Moderate level of tolerance	2005

Genomics for rice improvement

Because of rice's global importance, small genome size (~ 390 Mb size), and genetic relatedness to other major cereals, efforts were undertaken to sequence the entire genomes of the two subspecies of rice—*indica* (by a Chinese research group) and *japonica* (by the International Rice Genome Sequencing Project). Genome sequence drafts were completed for both subspecies in 2002 (Goff *et al.* 2002; Yu *et al*. 2002) and a high-quality and annotated version of the japonica species was completed in 2005 (IRGSP 2005). This represents a landmark achievement in biological research since it has opened enormous possibilities to understand the functional/molecular basis of various agronomically important traits in rice and their manipulation for the benefit of the mankind.

The beginning of the 21st century is considered the dawn of the genomics era due to the enormous amount of genomics research in bacterial, plant, and animal species, as well as the rapid development of high-throughput equipments for whole-genome genotyping, gene expression, and genome characterization, and the establishment of advanced bioinformatics tools and databases. Such rapid developments have greatly influenced and redefined plant breeding in the 21st century as "molecular plant breeding" or "genomics-assisted breeding" (Varshney *et al*. 2006).

Genomics is the study of gene location, function, and expression (Collard *et al*. 2008). Genomics as a discipline includes identifying the location of genes as well as the study of gene function in terms of their expression and regulation. Genomics has two components (i) Structural genomics and (ii) Functional genomics.

Structural genomics refers to a systematic reading of all the sequences of the rice genome. Structural genomic efforts has been completed by 2005 for both *indica* and *japonica* recently and the complete rice genome sequence of a Japonica rice variety- Nipponbare has been shared among rice researchers free of cost. Structural genomics, by itself is not an end. Through structural genomics, a set of ~30,000 genes have been identified in rice. The task now for rice molecular biologists is to decipher the function of each of these genes. The process of understanding the function of each of the sequenced genes is called as Functional genomics. This can lead to more intelligent and predictive plant breeding and provides access to many more beneficial genetic and genomic resources of rice. With the developments in genomics, rice breeding has steadily progressed from an art to a science.

Singh and Mohapatra (2007) have enumerated the possible utilities of the rice genome sequence information in rice genetics and breeding. They are:

i) Easy and quick annotation of function of rice genes: About ~32,000 genes have been identified in the rice genome based on sequence analysis and by using various mutant resources. The predicted gene models would serve as the base for a functional analysis of the rice genome. Each of these genes can be characterized individually through RNAi technology. Gene chips based on these sequences have already been designed for use in whole genome expression profiling to identify and understand the role of genes in complex biological processes such as yield and abiotic stress tolerance.

ii) Increased availability of molecular markers for MAS: A large number of sequence based molecular markers such as SSRs and SNPs have been designed that practically saturate the genome. Another possibility is the development of functional markers based on candidate genes associated with agronomic traits. Many genes have been cloned recently after the availability of rice genome sequence information. These markers can be used to map and tag genes for both qualitative and quantitative traits at very fine scale into short physical intervals, which in turn is helping isolation of genes by positional candidate approach.

iii) Quicker mining of novel alleles of candidate genes: Once genes are identified and functionally validated, it would be possible to identify new alleles in the germplasm by association mapping and thus enable designing allele specific markers. Use of such functional markers in crop breeding will make selection most efficient. Further, the novel alleles can also be deployed in elite rice varieties through transgenic breeding.

iv) Use of rice genome as a reference for targeted improvement in other cereal crops: Rice is a small genome member of the grass family that includes many large genome members such as wheat, barley and maize. Synteny among the genomes of the family members is known. It is therefore possible to extend the rice gene information to other important cereal crops.

Genomics will have a very significant impact on rice breeding and can facilitate enhanced identification of genes for key traits; enhanced scanning for useful genetic variation; more rapid transfer of genes and knowledge between the species of *Oryza*; and enhanced tools for molecular tracking in complex breeding programmes. Genomics-assisted breeding can facilitate the transfer of only the desired genes, rapid recovery of elite lines with inserted traits, better gene combinations and a clear targeted strategy, allowing supplementation of available genetic variation with precisely tailored genes and accelerating gene pyramiding efforts (Varshney *et al*. 2006).

India has contributed significantly to both structural and functional genomic efforts and has successfully sequenced a portion of chromosome 11L of rice (IRGSP, 2005). Similar research initiatives are under progress with respect to functional genomics of rice in India. DRR is coordinating a DBT sponsored collaborative network project on rice functional genomics, which is aimed towards understanding the functionality of genes associated with biotic stress resistance and grain yield. Ingenious utilization of information derived from functional genomic efforts can offer durable solutions to many breeding problems hitherto not available.

The application areas where genomic tools are expected to have significant impact in the near future in rice are:

(i) Yield improvement through quicker and efficient discovery and dissection of yield enhancing QTLs and their utilization in marker-assisted breeding/transgenic breeding

(ii) Possibility of conversion of rice from a C3 to C4 plant

(iii) Understanding the molecular basis of heterosis and cytoplasmic male sterility

(iv) Enhanced availability of agronomically important genes for transgenic breeding

(v) Unraveling the pathways/networks associated with abiotic stress tolerance.

Conclusion

Application of the tools and techniques of genetics and plant breeding has made remarkable progress in rice improvement and it is critical that this should continue for ensuring future food security. Molecular breeding could greatly assist rice breeders in reaching this goal although, to date, the impact on rice varietal development in India has not been very significant. For the potential of molecular breeding to be realized, it is imperative that there should be a greater integration with conventional breeding program and that current barrier be well understood and appropriate solutions developed for this integration. The exploitation of the advantages of molecular breeding relative to conventional breeding could have a great impact on rice improvement. The recent integration of advances in molecular biology, genomic research, transgenic breeding and molecular marker applications with conventional plant breeding practices has created the foundation for molecular rice breeding or 'precision' breeding in rice. The trinity of DNA marker technology, genetic engineering and genomics will certainly accelerate rice improvement programs across the world including India. Through a judicious application of all these three technologies, development of a designer rice plant which is high yielding, using lesser nutrients from soil, with tolerance to biotic and abiotic stress and with enhanced nutritional quality may be possible in the near future.

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Knowledge Management Portal for Enhancing Rice Production and Productivity

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ICTs are not really the use and application computer, the Internet, and telephone lines, they are about information and communication. This makes the issue of content a very important priority as we try to use the new technologies for community development and alleviation of poverty. In the fast changing scenarios, Indian Council of Agricultural Research (ICAR) wishes to promote the use of Information and Communication Technologies (ICTs) in agriculture by developing national level knowledge management portals. As a first step towards achieving this objective, an exclusive portal on rice viz., Rice Knowledge Management Portal (RKMP) is developed by ICAR under the NAIP project. The portal is built by the Directorate of Rice Research, Hyderabad in association with 8 consortium, two convergent and 20 AICRIP partners. This serves as an information highway for rice sector in sharing rice knowledge through latest ICT tools including mobile telephony. It also helps agricultural departments ongoing activities in reaching out to the farmers through extension advisory services, in most effective way.

The RKMP has several global firsts in terms of comprehensiveness and utility. Perhaps, this is the most comprehensive and one stop shop source for credible, validated, relevant and contextual information on rice at higher scale. Built on web 2.0 standards, this portal caters to location specific information needs of many stakeholders (policy makers, farmers, extension professionals, researchers, traders, NGOs etc.,) on 24X7 basis. IP based customization helps individuals to browse through location specific content. Providing content in local language is another striking feature of this portal.

Need and purpose

The new agricultural paradigm will have to be recast to take advantage of the wealth of knowledge available to

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achieve multiple goals of sustaining the food security, income, jobs, etc. The ICTs along with Knowledge Management (KM) strategies have significant role to play in evolving such a vibrant agricultural system.

In India, rice is the major cereal crop grown in about 44.6 million hectares. India represents all kinds of diversity under which rice is grown across the globe. No other crop is as versatile as rice. Rice crop is interwoven in the cultural, social and economic life of millions of indians and it holds the key for food and nutritional security of the country.

Rice production scenario in the country during the past decade presents a gloomy picture of compound growth rate of just 1.7 per cent despite the highest production figures (93.3 MT) posted during 2001-02. In near future, land under rice is likely to be reduced further and could stabilize at about 40 Mha. Relative contribution of irrigated rice to the total production is likely to remain same though, on one hand, area under irrigation is likely to increase through popularization of *boro* rice in the eastern part but, on the other hand, likely to be reduced by urbanization, industrialization and crop diversification due to reduced profitability and threat to sustainability in rice-wheat area. To meet a production target of 125 Mt by 2025, all inclusive of food requirement, seed for cultivation, storage in buffer stock and a share for exports, productivity in irrigated area needs to be enhanced by 1.5 tons/ha and in rainfed lowlands by about 1 ton/ha. A careful SWOT analysis presented in vision 2025 document of DRR revealed that there is an opportunity for bridging the yield gap by improving the access to the rice knowledge

Enormous knowledge has been developed about this crop and there is a need to share this knowledge for the betterment of our society. Indian rice research and rice development programmes have been recognized as successful model endeavors all over the world. However, given the burgeoning task of further enhancing the production and productivity of rice, the existing information sharing mechanisms appear to be insufficient.

Knowledge flows and information needs

- Potential users (farmers, scientists, extension officials, private sector and other key players) within and outside the country are not familiar with many of the rice technologies, data sets and other usable form of rice information. There is a need for a concerted effort to promote awareness about the availability of such information at national, regional and local level.

- There is an inbuilt inability to cross-search rice information available in India in an isolated manner, at once. There is presently no single gateway through which a user can search all the information resources available on rice.
- Even the rice workers themselves do not have a single window of identifying commonalities between their work and that of their colleagues in other rice research stations.
- There is a lack of data refinement, standardization within and between stakeholder communities working towards the rice development.
- There is increased risk of duplication of efforts while collecting, analyzing and processing scientific rice research information, technologies, technological & information needs of farmers, socio-economic and institutional information of different rice regions of the country. Such duplications lead to excessive wastage of time and other monitory resources on the exchequer.
- At various hierarchical levels, the existing information sharing mechanisms do not allow unifying efforts of various stakeholders working in the area of rice cutting across the rural development sectors.
- Existing traditional training programmes and facilities are inadequate to meet the demand of millions of rice stakeholders including farmers.
- At organizational levels, there is no real time Knowledge and technology exchange among the rice based institutes, state departments of agriculture, other stakeholders and the farmers. The virtual triangle of access, quality and costs of knowledge interventions are high.

Linkage matrix

Organizations that jointly and/or individually contribute to the development, distribution and use of rice knowledge in rice sector may broadly be classified as Rice policy makers (P), Rice research & extension organizations (R), Credit Institutes like banks (B), Farmers (F), Input supply firms (I), Rice marketing firms (M), Rice processing firms (Pr), Consumers (C) and External organizations (X). In most of the cases, due to several reasons, there is no knowledge /information and data sharing amongst these organizations (See Fig 1). Moreover, building a strong linkage among these organizations is called for, in the recent past.

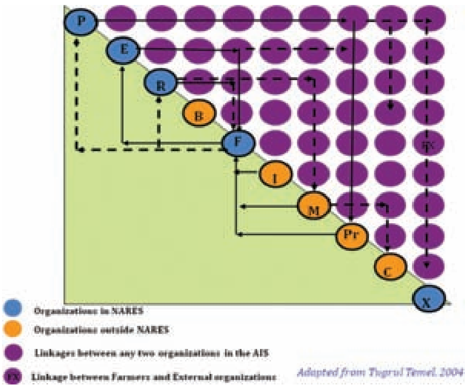


Figure 1. Diagrammatic representation of linkage matrix in rice

(Adapted from Tugrul Temel, 2004)

With the existing knowledge flow mechanisms, a stakeholder (researcher or planner or development professional or extension agent etc.,) needs to follow a tedious process to identify all relevant information and expertise through individual sources, manually retrieve individual pieces of information and consolidate them. For example, a simple search in goolge.com on rice gives a minimum of 6 million hits without much of relevant, validated, contextual and local language content on rice.

In these circumstances, it becomes imperative to strengthen the capacity to enable rice workers to create, manage and share information for the benefit of all stakeholders. This includes scientific, technology-related information (for research and research management and for extension outreach), market information for the agencies and farmers, generic information for the public and comprehensive information for better decision making for the policy makers. There is a need to catalyze the mobilization of a critical mass of researchers, extensionists and farmers into leap-frogging the knowledge barriers to modernization of agriculture in India. It is with this vision, it is proposed to develop and maintain the Rice Knowledge Management Portal (RKMP).

Benchmark analysis

As a subset to the envisaged RKMP project objective, the task of understanding and assessing the existing rice knowledge dissemination portals on the internet, their current status in terms of metrics, average daily views, benefits derived by stake holders by the use of these portals, information requirements of various stakeholders in Rice sector viz., Researchers, Extension workers, NGO's/KVK's, Traders, Farmers, policy makers etc., was done with the following objectives;

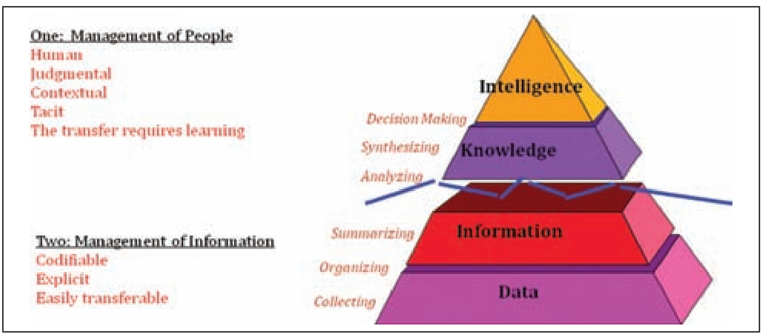
1. To analyze knowledge needs of various stakeholders in rice sector with respect to
   a. Extent of integration of information and Knowledge needs of stakeholders at various hierarchical levels.
   b. Accuracy of knowledge perceived by the rice workers
   c. Existing system analysis on knowledge quality, system quality, service quality, Use, user satisfaction and net benefit derived by various stakeholders
   d. Sustainability options

2. To delineate a roadmap for development of extensive and exhaustive Rice Knowledge Management Portal auguring the information and knowledge needs of various Rice stakeholders

Existing system analysis was carried out by dwelling of secondary information and data sets depicted on various rice portals by deploying system optimizing studies, portal metrics analysis, and portal interface analysis. Assessment of knowledge needs and information requirements of various stakeholders in the rice research and value chain was collected and compiled by carrying out an extensive primary survey by deploying structured questionnaires, duly back tested. In total, 11 states, encompassing 11 AICRIP centers were considered for enumeration of data to understand and assess the knowledge needs and information requirements of various rice stakeholders. The result? A document with comprehensive list of information/ knowledge needs as to what rice stakeholders require and in what format.

Understanding KM in the present context

After having known what are the information needs of rice sector and a complete knowledge flow matrix, next focus was on understanding what KM processes, tools and strategies to be deployed into making of RKMP. As the figure below indicates, data, information and knowledge differ from one region to other. Knowledge varies between contexts and emerges from the flows of information around the system. Knowledge includes data and information within a particular context. When a scientists' knowledge moves into an extensionist's context, it is relegated to information and it is the practitioner that has to do the work of making this information into new knowledge. Agricultural Research knowledge is just another piece of information to be incorporated into the knowledge of an extensionist. Of course this works the other way. When we think of multiple stakeholders in the agricultural value chain, the interaction between the data, information and knowledge gets much complicated. Using the traditional knowledge flow mechanisms, it is not possible to facilitate different processes (from collection to decision making) at various hierarchical levels. The KM practices using ICTs are emerging fast as viable solutions.



Knowledge management generally refers to the sharing of knowledge inside and from an organisation to the outside. This involves generating, capturing and disseminating knowledge. Researchers have pointed out two kinds of knowledge: tacit (context-specific personal knowledge embedded in individual experiences, and, thus, difficult to share) and explicit (that can be easily articulated and transmitted). Knowledge management deals with both the experience and understanding of people in organisations (mostly tacit) as well as information artefacts such as documents and reports (which are explicit) available within organisations and outside them. While explicit knowledge is easy to share or transmit, sharing tacit knowledge is difficult, although not entirely impossible. Tacit knowledge plays an important role in providing meaning to explicit knowledge as well as contributing to the development of new knowledge. ICTs can support the transformation of tacit knowledge to explicit and vice versa (See Table 1).

Table 1. Example of processes identified to support Knowledge transformation

Tacit to Tacit	**Tacit to Explicit**
E-learning, Video conferencing, Blogs, Synchronous collaboration (chat)	Answering questions Annotation , Theme and status Papers
Explicit to Tacit	**Explicit to Explicit**
Visualisation Browsable video/audio of presentations	Text search, RLOs, i3R Document categorisation, CMS

The efficiency of future extension efforts will be determined by how effectively these KM practices are incorporated into the existing extension system. The Rice Knowledge Management Portal (RKMP) tried to translate valuable data and information into useful knowledge for the extension workers working in the rice sector.

Objectives of RKMP project

To develop and maintain Rice Knowledge Management Portal to strengthen research, extension, farmers, and private subsystems, partnerships and networks, through better flow of rice knowledge and information contributing to the overall rice development in the country

Specific objectives:

1. To develop structure and content for RKMP comprising research information systems, extension information system, service information system, farmers information system, general information system and e-learning platform related to rice
2. To pilot these information systems for uploading, sharing and harnessing rice knowledge amongst rice stakeholders
3. To build the capacity of the stakeholders in using the Rice Knowledge Management Portal for effectively transforming rice knowledge and information as a viable factor of production

Defining workflows

Defining the functional requirements for a portal, that addresses information needs of 700 rice scientists, 1,10,000 Public sector extension officers, 225 civil society organizations, 600 Farm Science Centres, 4.26 lakhs stakeholders etc., was going to be a herculean task. Since RKMP was envisaged to be 'content portal' rather than 'collaborating portal', it was decided to involve the partners with a focus on content development.

The project is implemented in a consortium mode. Each consortium partner has specific roles to play based on their core competency. DRR lead the consortium. ICRISAT and CDAC are technical partners focusing KM models and font technologies respectively. Other partners are called 'content collaborators/ partners', whose primary responsibility is to develop local content in collaboration with the AICRIP centres, SAUs and other stakeholders from the states within their jurisdiction. A conceptual model is developed and implemented for content development across the country.

The design, planning, coordination, execution, technical expertise, and hosting and maintenance of the proposed Rice Knowledge Management Portal was taken up by the Directorate of Rice Research, Hyderabad in association with its collaborating institutes. The information support is provided by the selected stakeholder in rice sector of the country.

What is available on RKMP?

Today, a rice farmer from Uttar Pradesh is able to get all the rice related reliable information specific to their region in Hindi language. This dream of any Indian extension professional to provide the right information at the right time and context in the local languages to the ever "Information-Hungry" farmers is realised through Rice Knowledge Management Portal (www.rkmp.co.in)- the one stop shop for rice related information.

The portal is the product developed by Indian Council of Agricultural Research (ICAR) under the National Agricultural Innovation Project (NAIP) project and is built by the Directorate of Rice Research, Hyderabad in association with 8 consortium partners along with two convergent and 20 AICRIP partners.

The all-rice portal serves as an information highway for rice sector in sharing general rice knowledge along with specific content for 15 states in English, Hindi, Telugu, Tamil, Kannada and Marathi. RKMP hopes to serve the wide range of stakeholders like farmers, extension professionals, researchers, traders, NGOs, policy makers, etc. and help in better planning and realizing higher productivity & production of rice by the farmers through improved knowledge and skill.

Through one of its domain exclusive for rice farmers namely "Farmers'Domain", the portal provides range of critical information like package of practices and production know how in English and local languages as well provided with the help of the credible information sources like state agricultural universities and various organisations of that particular state.

If the farmers have more queries, the portal provides the answer through its online/SMS based question answer platform "Expert Answers on Rice" with 152 Rice Experts by using the three tier structure namely Web-based Question and Answer Forum, SMS based alerts and Web based Questions answered through SMS

Completely Image Driven Diagnostic tool is developed exclusively for the extension professionals and farmers to diagnose the field problems based on the stage of the crop. The largest rice database of location specific content also helps the farmers to know about the soil health and fertilizer recommendation system through online Fertimeter application. Also, the exclusive and exhaustive information on weeds aims to make wise decisions in weed management

As Indian Agriculture is highly dependent on vagaries of weather and the portal provides the short term weather forecast to render timely information to the farmers and extension agents for real time decision making. The day to day mandi price of rice prevailing in the various national markets are channelled into this portal for better decisions for better remuneration of the rice farmers.

For having the first hand information, any farmer is given assistance in spotting the nearest research station, extension office, KVK, dealer. The information on various government schemes at both the national and state level will take the outreach of the government activities to various unreached farmers.

A gallery of 52 Video clips and 4000 minutes of audio clips and the details of various front line demonstrations are sure to benefit the rice farmers in need of reliable and convincing information.

Portal aims to kindle the innovativeness in the farmers through its well documented database of various rice innovations and at the same time has put enormous efforts in preserving the indigenous rice knowledge to the future generations.

To enhance the export opportunities for rice from India, Trade Information System delivers the trade information at different markets all over the World and Exports & Imports information of Rice.

Other than farmers' domain, the portal caters the needs of the other stakeholders through research domain, extension domain, service domain, general domain and E-learning. The portal developed through the latest ICT tools envisions supporting mobile telephony and will also help agricultural departments' ongoing activities in reaching out to the farmers through extension advisory services, in most effective way.

Uniqueness of this portal

Harnessing existing AICRIP (All India Coordinated Rice Improvement Project of ICAR) set up through Knowledge Management Tools is one of the finest innovations of this project with in-built sustainability. RKMP is being included in 12th FYP of DRR for its sustainability.

- Operational expenses are met from the private sector involvement and online advertisements.
- Harnessing existing AICRIP set up through Knowledge Management Tools – enhancing the efficiency
- Building the virtual Communities of Practice (CoP) for rice sector
- Developing huge location specific content in usable format
- 24X7 learning opportunities in local languages, in modular format
- Transmitting online content through offline delivery mechanism
- Transmitting offline content through non-digital means
- Roping in all stakeholders for a common cause of knowledge creation, capture and sharing
- Harnessing the best expertise of Information technology and Rice sector
- Creating a prototype for other crops

How can users contribute to RKMP?

As registered user, one can upload the content into RKMP, irrespective of his/ her institutional affiliation. RKMP Nodal officers (AICRIP Centre Scientists from State Agricultural University) will validate and approve the content before it is displayed online. At RKMP, source of each content is acknowledged. It is suggested that before uploading better to go through RKMP Content Upload Policy available online.

Institutionalization - sustainability

It is proposed to continue the activities of RKMP during XII Five Year Plan, as part of DRR mandate. Continuation of RKMP activities will serve two important purposes.

1. Knowledge from the AICRIP system will directly flow into extension system that will help ushering knowledge intensive rice production across the country. As many KM theories suggest, a system in place will enable enhanced efficiency in transfer of technology.
2. Showcasing the visible impacts of AICRIP system by creating and sharing research products through this platform. This will enhance the visibility of ICAR system online.

Conclusion

RKMP is the first step in terms of the application of ICTs and KM strategies in agriculture to build portal with enormous content. The portal which serves as an information highway in rice sector for farmers, researchers, extension professionals, policy makers, home makers, students etc. The vision is to realise higher productivity and production of rice through improved knowledge and skill sets. The efforts will pave the way to reduce the gaps of the growing "digital information divide" specifically in the important cereal crop of the country namely Rice. The success of these strategies can be up scaled to reach the rice stakeholders with more features and can be emulated in other important crops. The efforts are coinciding with the increasing technological advances, technological reach and ICT readiness at the grassroots level which is a positive signal for the more investments.

The technology mediated knowledge management in agriculture is relatively new concept. While efforts are going on to address the digital divide in terms of connectivity what appears to be limiting factor is the availability of relevant contextualized, validated content in usable format. In the developing world, R and D organizations need to take up content development on large scale so that the knowledge flows amongst agricultural stakeholders are strengthened.

Achievements, Challenges, Technology Dissemination of Rice in India

R.S. Kulkarni, K.P. Raghuprasad and Mallika Meti

Rice is India's prominent crop, and staple food for the native population of eastern and southern part of the country. The country has the highest area of fertile land under rice cultivation. Though rice was cultivated traditionally, a lot of technologies have been developed in this field and diffused to farmers. It is evident that though more technologies are available, farmers fail to adopt in large scale. Chandrakandan *et al.* (1995) reported that in the present days the most important factor affecting the process of technology transfer and adoption is lack of availability of location specific and need based appropriate technology. Objectively about 70 per cent of the recommended technologies are not being adopted by the farmers. Some of the reasons for non-adoption may be their inconsistency with the particular farm setting or their inappropriateness to the local resource endowment. Moreover, many technologies evolved by the researchers are more appropriate to resource rich farmers (Chambers and Jiggins, 1986) whereas most of the farmers in India are small and marginal.

Changing extension scenario

During 1960s i.e., in the green revolution era extension efforts were concentrated on one or two prominent rice varieties. As a result, extension workers easily reached farmers and convinced them for adoption. Over the years, more number of varieties/hybrids in rice cultivation and plateauing of yields made extension workers difficult in reaching the farmers. At present, the whole concept of "Production-led-Extension" has been shifted towards "Market-led-Extension".

A large number of recommended rice production technologies are either being adopted in piece-meal or not at all. The analyses of several studies conducted on the causes of non adoption have revealed very interesting trends. While during the period of 1950-60s, the reasons for non adoption of technologies

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by the farmers were explained in terms of "farmer's ignorance" in 1970-80s they were explained in terms of various "farm level constraints". However, during 1990s the explanation was shifted and it is now explained in terms of "lack of appropriateness of technology". Rain fed upland rice constitute about 6.1 million hectare area in India of which about 4.3 million hectare falls under eastern region comprising the states of Assam, Orissa, Bihar, West Bengal, eastern U.P. and Madhya Pradesh with very low productivity of less than 1.0 ton/hectare (Lipi das *et al*, 2010)

ICAR initiated rice research programmes in various states and facilitated to generate more varieties in rice possessing characters like high yield, pest resistance, drought tolerance etc. Even then many released varieties are not adopted fully by farmers. Non-adoption may be because the variety does not meet farmers need or because farmers lack access to seed or information on new varieties. Often varieties that spread rapidly from farmer to farmer are those with highly preferred quality traits.

It was found that the adoption of new rain fed varieties was very less. The reasons behind less adoption rate of rain fed varieties were: they were not suitable to the field conditions but proved to be superior under research area, characteristic of the new rain fed varieties was inferior about which breeders were not aware and other important reason was that farmers may not have access to seed availability or information about the new varieties.

A unique dissemination trend was observed in case of hybrid rice i.e., KR-series developed by UAS, Bangalore. Though the hybrid took considerable time for spreading within the state, it has reached other states like Tamil Nadu, Jharkhand, Orissa, West Bengal and readily accepted due to its inherent quality like higher production and uniformity of the produce. This clearly shows the quality and likeness of the produce plays a major role even with limited extension efforts.

The role of farmer to farmer in varietal dissemination

Farmer to farmer spread in varietal dissemination is the most important mechanism by which rain fed varieties spread. Some farmers are very active in varietal introduction and seed exchange (sometimes also called nodal farmers). Such farmers play active role in dissemination of the technologies among the fellow farmers. Variety dissemination programs that target farmers with a strong interest in evaluating new material results in higher success. Further, informal seed programs providing nodal farmers with small amounts of seed can be highly cost-effective.

Hence, major constraints identified in rice cultivation can be listed below.

Major constraints identified in rice cultivation

- About 78% of the farmers are small and marginal in the country and they are poor in resource.
- The problems of flash floods, water logging/ submergence due to poor drainage are very common in East India.
- Continuous use of traditional varieties due to the non-availability of seeds and farmers lack of awareness about high yielding varieties.
- Low soil fertility due to soil erosion resulting in loss of plant nutrients and moisture.
- Low and imbalanced use of fertilizers,
- Heavy infestation of weeds and insects/pests.
- Delay in monsoon onset often results in delayed and prolonged transplanting and sub-optimum plant population (Mostly in rain fed lowlands).
- In the years of scanty or adverse distribution of rainfall, the crop fails owing to drought etc

Based on the constraints mentioned above, extension methodologies need to be developed to effectively address the current issues of rice growers.

Recent extension methodologies

1. **Use of farmers' organizations like Farmers Interest Groups, Commodity Groups and Self Help Groups:** These organizations are village-level cooperative or association dealing with inputs needed by the members, the resource owners, to enhance the productivity of their businesses based on land, water, or animals. These organizations are generally small, have well-defined geographical areas, and are predominantly concerned about inputs, which will be more useful to rice growers.
2. **Use of participatory mode of outreach activities which includes**

- **Farmers Participatory Research (FPR):** Farmer participatory research (FPR) is an approach, which involves encouraging farmers to engage in experiments in their own fields so that they can learn, adopt new technologies and spread them to other farmers. With the scientist acting as facilitator, farmers and scientists closely work together from initial design of the research project to data gathering, analysis, final conclusions, and follow-up actions.
- **Participatory Technology Development (PTD):** Participatory technology development is an approach that promotes farmer driven technology innovation through participatory processes and skills building involving experimentation to allow small scale farmers to make better choices about available technologies. These innovations could be in improving local technologies or through introducing new technologies from elsewhere.
- **Farmer Field Schools (FFS):** Farmer Field Schools (FFS) consist of groups of farmers who get together to study a particular topic. The topics covered vary from conservation agriculture, organic agriculture, animal husbandry, and soil husbandry etc. FFS provide opportunities for learning by doing. It teaches basic agricultural and management skills that make farmers experts in their own farms.
- **Rapid Rural Appraisal (RRA):** Rapid Rural Appraisal consists of a series of techniques for "quick and dirty" research that are claimed to generate results of less apparent precision, but greater evidential value, than classic quantitative survey techniques. The method does not need to be exclusively rural nor rapid, but it is economical of the researcher's time.
- **Participatory Rural Appraisal (PRA):** PRA entails groups of local people analysing their own conditions and choosing their own means of improving them. They may use a variety of tools, such as maps and diagrams, and the support of a trained facilitator.

3. **Establishment of satellite farms for large scale demonstrations to showcase the utility of the technologies:** Resource centers are established with the objective to disseminate the technologies at farmers place as per the requirement.

4. **Use of ICT tools which includes:**
    - **Mobile message service:** Short message service is a mechanism to deliver short, concise, text messages over the mobile networks. SMS is a store and forward way of transmitting messages from one mobile to another mobile. The message (text only) from the sending mobile is first sent to what is called short message center (SMSC), which stores the message and then forwards to the destination mobile. This means that in the case that the recipient is not available or out of range or switched off, the short message is stored and can be sent later.
    - **Interactive video conferencing:** Allows users at two or more locations to have 2-way video, audio and data communications for meetings, classes, discussion groups, interviews, trainings and other events. Video conferencing uses compressed audio/video that is sent and received over the Internet.
    - **Document development:** Developing video-documentaries on rice production technologies, mechanization, post harvest technologies with digitalized audio-visual impacts which will help farmers to accept the technologies at faster rate.
    - **Rice Portals:** Extensive use of the web is done to disseminate information and provide services to farmers on production technologies of rice. Portal is convenient, effective and unified system through which farmers can have easy and intuitive access to their needed information and services regarding rice cultivation.

Other innovative extension approaches to disseminate new rice varieties/technologies

1. **Recognitions to the successful farmers:** Awards and recognition encourage the farmers to take up innovative methods of cultivation
2. **Celebrations:** Helps the rice farmers to understand the National and Global prospectives of important technologies
3. **On-farm testing/Frontline demonstrations:** Testing the new technologies at farmers' field to revalidate the results in real situation and popularization.
4. **Exhibitions:** Showcasing the innovative method of rice cultivation with necessary audio visuals, literatures etc.

5. **Krishimela:** Sharing platform for dissemination of technologies and interactions with scientist and successful farmers along with advisory services by the experts.
6. **Organizing Workshops/ Seminars/ Summer School:** Keep pace with the developments of new methods of cultivations for arriving common consensus
7. **Exposure visits:** To make them aware about the innovative practices successfully adopted else were which can be replicated at farmer's level.
8. **Field days:** showing the worth of technologies in the principle of "Seeing is Believing".
9. **Agri. Clinics:** Using the services of qualified graduates at field level to supplement the public extension system

Conclusion

Technologies play an important role for enhancing production and productivity. Different Organizations (ICAR/ Universities/ State dept./ NGOs/ Private organizations) are involved in development and dissemination of rice technologies over the years. Although different technologies are disseminating through different extension methods, adoption rate of rice technologies seems to be low. Hence, Extension strategies are to be re-oriented to popularize rice technologies among different sectors of farming community. Further, Extension services needs to increase its capacity for two-way information sharing – between experts in research and farmers themselves for easy access to information. As a result we could be able to reap benefits of technologies in real field situations.

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Nature and Dimensions of Farmers Indebtedness in India

Meenakshi Rajeev, B.P. Vani and Manojit Bhattacharjee

This paper examines nature and extent of farmers' indebtedness in India using unit record data from NSSO 59th round, and provided a comparative picture of major Indian states. Using data from rice cultivating farmers it reveals that productivity of small farmers is not only higher than the medium farmers, it increases with access to credit. In terms of access to credit, seen through extent of indebtedness, Karnataka is better placed than many Indian states. But Andhra Pradesh, Tamil Nadu, Punjab and Kerala lie ahead of Karnataka. Ironically however, almost half of the credit is still provided by the informal sector in the state of Karnataka. Region wise picture shows that Southern region is more dependent on informal sources of credit. Poor farmers with lower land holdings are much more deprived of the formal sources of credit than the comparatively richer ones. Thus they also pay a much higher rate of interest with modal value of 36%. But it is heartening to note that loans are taken mostly for income generating purposes. It also indirectly implies that even for the income generating purposes poor are not getting access to formal sources of credit.

In the discussion of the issue of rural indebtedness, no doubt the farmers assume considerable importance. This is mainly because amongst the 60% of population who depend on cultivation in India, a large percentage belongs to the marginal and small farmer category. These cultivator households need credit on a continuous basis for meeting their working capital needs. Food security of the country to a large extent also depends on the output generated by these farmers. Therefore it is necessary to ensure timely and affordable credit to the cultivator households.

In reality however, we observe that most of the poor and marginal farmers do not get access to the formal credit network. In this context it is important to note that the farmer class is

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not a homogeneous group. They belong to different economic and social groups and for policy purposes it is essential to understand access to credit by these different groups of farmers' households in India. Regional variations in this context also assume importance as in certain states of India we observe burden of indebtedness. This calls for identifying specific state level measures necessary to combat credit related problems.

When we consider farmer households, land holding size provide a better indicator of their economic status than the household income or expenditure. Keeping this aspect in mind we examine indebtedness scenario with respect to certain indicators by classifying farmer households according to their landholding size. Analysis is also carried out by considering the social class to which the household belongs, such as schedule caste or schedule tribes (SC or ST) or, weaker section such as households headed by woman.

A number of studies examine trends in formal sector lending for different economic activities or different sectors in India economy using the bank level data from the Reserve Bank of India (see Shetty, 2005; Patnaik, 2005; Chavan, 2005, Basu, 2006). Studies on the rural credit market observe that there was an increase in supply of credit to rural areas during the period after nationalization of commercial banks (in 1969). However, after liberalization (1991) there has been a decrease in rural banking net work as reflected through indicators such as number of rural branch offices of commercial banks (Rajeev, 2011).

The problem of non accessibility of formal sector credit to the poor and needy has been often highlighted in the literature. Even though the state made endeavors to address this problem by stipulating norms for compulsory lending to the agriculture sector, the formal lending agencies have not been successful in reaching out to the poor. National Sample Survey Organization (NSSO, 2002-03) data reveals that while about 30% of the poor borrowers get credit from the formal sector banks, this percentage increases to 60 for the richer farmers (see also Siamwalla *et al*., 1990, Bell, 1990). The problem of access may be due to the lack of collateral, inability to comply with bureaucratic procedures; illiteracy, etc. (see also Gupta and Choudhuri, 1997, Lele, 1981, Benjamin, 1981).

Most studies that deal with NSSO data however, do not provide analysis of unit record household level data; authors generally argue on the basis of the consolidated statistics provided in the NSSO report. This paper is intended to fill this gap.

Data source

Union ministry of Agriculture desired a comprehensive assessment of the situation of farmers in the country in the beginning of the millennium with the interest to understand various aspects concerning farmers, which include farmers' levels of living, income and income generating assets they possess, farming practices and preferences, availability of resources, their awareness on technical developments and access to modern technology in the field of agriculture etc. To provide information on these to the ministry of agriculture, National Sample Survey Organisation (NSSO), as a part of 59th round, conducted Situation Analysis Survey of farmers (SAS). The period of survey was January to December 2003. We may note in this context that *presently this is the most recent data on farmers' indebtedness available at the macro economy level.*

The survey was conducted only in the rural areas of the country and the respondents were from farmer households where a farmer household is defined as one, which has farm land and at least one member is engaged in farm activities on any part of the land during the last 365 days. In all 51,770 households were surveyed in the central sample conducted directly by NSSO. States are also supposed to carry our similar surveys in their respective states in order to increase the sample size. This is called the state sample. Pooling of state and central sample then enables one to arrive at estimates at a regional level. In this survey however, only seven states participated in the state sample and Karnataka is *not* one of them. Hence, strictly speaking, not too reliable estimates could be expected at the district level and consequently, most of our analysis is concentrated at the state level. However, we do present estimates of a few district level indicators generally to throw light on district level variations.

It is worth mentioning that while the survey provides rich micro-level information based on large samples, very few studies carry out unit level analysis (see Bhatacharjee *et al*, 2009, 2010) and the existing studies are usually based on the published data in the NSSO reports.

NSSO data provide information regarding households that have outstanding loan on a pre-specified date (in this case as on 30th June, 2002), based on which one can arrive at the percentage of households within a category of households (such as within an income category and so on) that have outstanding credit. This indicator termed as the *incidence of indebtedness* (IOI) essentially represents the percentage of households having outstanding loan amongst the households of that category. A careful examination of the above data reveals that IOI is higher for the higher income groups and secondly, more economically advanced states have higher level of IOI. Further, schedule tribe households in general have lower IOI than the General or OBC category households. Observing these characteristics one is tempted to interpret incidence of indebtedness more as a pointer of access to credit rather than an indicator of distress, though the latter possibility also cannot be ruled out especially for the relatively poorer households.

Productivity analysis of rice farmers

A careful analysis of NSSO data shows that yield rate of the marginal and small farmers are higher and more importantly access to credit enhances productivity (Table 1). This clearly shows how critical is the credit for improvement of productivity.

Table 1: Yield per hectare of rice crop

Land in Hectares	Borrowers	Non Borrowers	Total
0 - 0.4	3366.7	2841.9	3169.0
0.41 - 1.00	2682.0	2504.6	2626.4
1.01 - 2.00	2563.2	2022.9	2411.9
2.01 - 4.00	2110.7	2858.0	2371.4
4.01 & Above	3374.2	4359.4	2577.0
Total	2832.2	2617.1	2762.1

Source: Authors' analysis of NSSO data

Thus making credit available to the small and marginal farmers assumes considerable importance as these cultivators are economically vulnerable. Unfavourable terms and conditions of a loan can indeed make serious impact on their sustainable livelihood. The important question that arises is what is the scenario at the ground level? The next section examines this issue using NSSO data in some detail.

Accessible to finance: all india and inter-state analysis

At all India level the incidence of indebtedness was 48.6 percent with an average outstanding debt per farmer household of Rs. 12,585. This figure rises to Rs. 25,891 if we consider only the indebted households. As discussed earlier, if indebtedness can be taken as a proxy for access to credit then it implies that only 49% of the farmer households have an access to credit either from formal or informal source. Is it that the rest of the household do not require credit or they do not have an access to credit? IOI across different landholdings (see Fig 1) shows that access to credit increases with the landholdings. One can broadly say that the household with landholdings more that 4 hectares may or may not require credit, but majority of the households with less than 4 hectares of land possibly need credit for farm activities ; the fact that IOI for these households are much lower than 50%, is an indirect indication of presence of constraint in accessibility to credit for the small and marginal farmers (both from formal and informal sources).

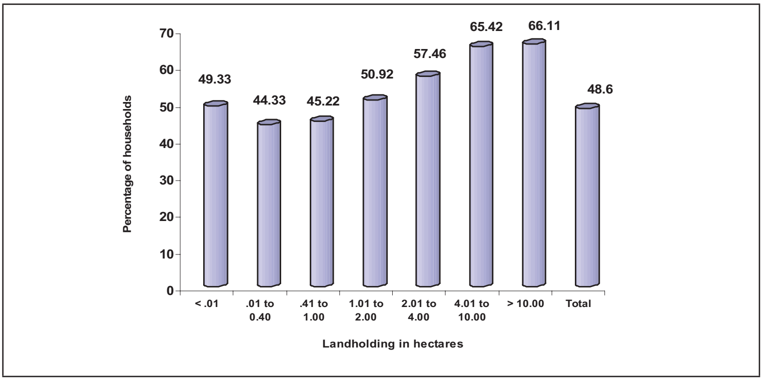

Figure 1. Incidence of Indebtedness across landholdings: All India (formal and informal sources)

Note: Interpretation: 49.33 % of the households with landholding less than 0.01 hectare have outstanding loan and the rest 50.67% households belonging to the same landholding category have no outstanding loan.

Source: Authors' analysis of NSSO data

Regional variations

Interstate analysis indicates a wide variation across States with Andhra Pradesh having the highest IOI at 83.1% and Uttaranchal the lowest at 7.2%. All the four southern States and

Punjab possess IOI greater than 60%. These are also the States with good banking network, and a good network of informal lenders which possibly result such high percentages (see Table 1 in the Appendix).

At All India level 58% of this credit supplied to the indebted households is financed from formal source and the rest i.e., 42% is from the informal source. Banks play a major role in the formal sector (35% in total credit and 60% of the formal sector credit) and money lenders are the largest suppliers of credit among the non-formal sources (26% of total credit and 62% of informal credit) (see Fig 2).

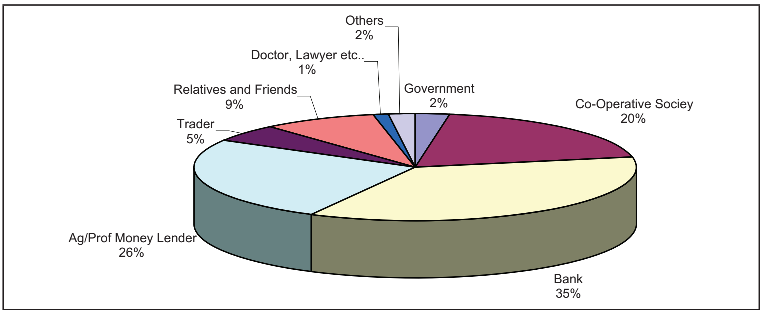

Figure 2. Source wise access to credit (percentage of amount of total loan): All India

Source: Authors' analysis of NSSO data

Interstate variation in access to formal credit is also quite noticeable. Andhra Pradesh had the lowest share from formal sector at 31% and Kerala and Maharashtra had the highest i.e., around 83% (see Fig 3). This reveals an interesting fact that even though access to credit is quite high in Andhra Pradesh, most of it is from non-formal source. In the States of Maharashtra, Gujarat, Kerala, Haryana and Tamil Nadu co-operative societies have played a major role in providing credit to the farmers. This is an additional insight received from the analysis of data on farmer households. Concentrating on Andhra Pradesh we see that 53% of the credit is financed from agriculture or professional moneylenders. The other States where the dependence on the moneylenders is more are Tamil Nadu, Rajasthan, Punjab and Bihar. The modal (mode) interest rate charged by these moneylenders is 36% which is more than three times the interest rate charged by the formal source. If the fund borrowed is at least used for the income generating purpose then the farmer households would be in a position to repay the amount borrowed; otherwise repayment can be a serious problem. We therefore examine next the purpose of usage of loan.

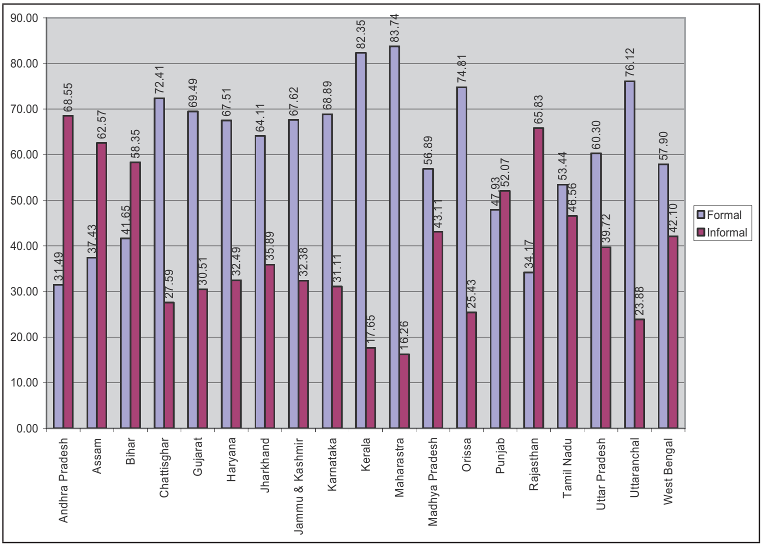

Figure 3. State wise access to formal credit (shares of formal and informal sector loan amount in total amount of loan outstanding as of June 2002)

Source: Authors' analysis of NSSO data

The purpose wise usage of the credit at the all India level reveals that 65% is used for the income generating purpose and only 35% for the non-income generating purposes (see Fig 4). Among the non-income generating category, expenditures on marriage and ceremonies play a dominant role. From our field experience we have also found that festivals and ceremonies play a major role in rural areas and the farmers end up spending substantial amount by borrowing from the informal source at a high interest rate. Variations across states are seen in this respect; for example, Assam uses only 39% of loan for income generating purposes whereas, Maharashtra, Karnataka and Chattisgarh are the States, which use nearly 80% of the credit for the income generating purpose. Both Capital expenditure and current expenditure in farm are the main categories under the usage of credit (see Fig.4).

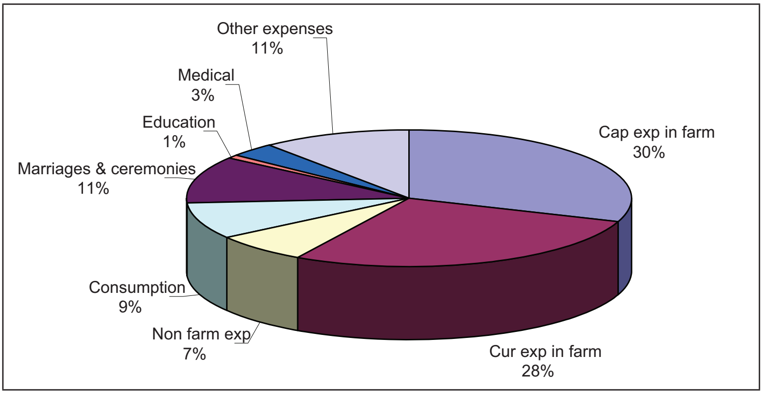

Figure 4. Usage of the credit (percentage of total amount of loan outstanding): All India

Source: Authors' analysis of NSSO data

a) Access to and usage of credit across landholdings

Table 2 (column 1) indicates that 61% of the farmer households belong to 0.01 to 0.40 and 0.41 to 1.00 hectares of land holding categories taken together. Another 18% of the households belong to 1.01 to 2.00 hectares of land holding category. i.e., nearly 80% of the farmer households belong to marginal and small farmer category. These categories have 45%, 53% and 58% respectively of their credit through formal agencies. i.e., on an average only 50% of their credit is through formal agencies. In other words, these small and marginal farmers constitute 80% in number while their share in the total formal credit is only 52%. They in turn use 36%, 57% and 69% of total borrowings respectively towards income generating purposes. The farm households with less than 0.4 hectares of land (i.e., between 0.01 hectare to 0.40 hectare), use less than 36% of loan towards income generating purpose; with 55% of the total borrowing coming from informal sources for such farmers, and 64% of total loan amount used for non income generating purposes, may lead to the problem of repayment. Thus formal sector needs to reach out to the comparatively poorer farmers not only for production related credit but also for consumption credit. Presently there is a provision for debt swap whereby a formal bank can take over informal loan of a farmers and help him to repay loan under better terms. But the farmers often lack information about such useful schemes and the need of the hour is to make such provisions more popular especially among poor farmers.

Table 2. Access to credit and usage of credit (amount of loan): All India

Land holding in hectares	Share of household (%)	Source of credit		Purpose of usage	
		Formal* (%)	Informal (%)	Income generat-ing** (%)	Non income generating (%)
< 0.01	3.62	24.19	75.81	24.93	75.07
0.01 to 0.40	29.39	44.79	55.21	35.76	64.24
0.41 to 1.00	32.49	52.64	47.36	56.90	43.10
1.01 to 2.00	18.10	57.66	42.34	68.92	31.08
2.01 to 4.00	10.64	65.02	34.98	78.28	21.72
4.01 to 10.00	4.82	68.99	31.01	83.25	16.75
> 10.00	0.90	67.01	32.99	81.59	18.41
Total	100.00	57.68	42.32	65.15	34.85

*: Percentage of amount of formal loan outstanding of total amount of loan outstanding.

**: Percentage of total amount of loan used for income generating purposes out of total loan amount outstanding.

Source: Authors' analysis of NSSO data

Across states access to credit through formal sources displays wide variations. In most of the states marginal and small farmers rely heavily (to the tune of 70% of total loan amount) on the informal source. In addition the share of usage of credit for income generating purposes in most of the states by the marginal and small farmers is quite low and this trend is especially prominent in the backward states. Thus more dependence on informal credit accessed at a high interest rate, coupled with usage of it primarily for non-income generating activities are definitely not promising signs. Thus as mentioned above the formal credit institutions have a challenging task to reach out to the economically backward classes. But what about the socially backward classes? Are they comparatively better off?

b. Access and usage of credit across social groups

Across social groups we find that at all India level only 36% of the households belonging to schedule tribe (ST) category are indebted. Both with respect to schedule caste (SC) category and the general category the incidence of indebtedness is 50%. Other backward class (OBC) category has the highest incidence of indebtedness at 52%. Thus access to credit is substantially lower for tribal farm households revealing that the formal credit institutions not only have an important role to play to reach out to the economically backward classes but also to the socially backward classes.

The incidences of indebtedness for the women headed households is 42% vis-à-vis their male counter part which equals 50%. Thus we observe that not only the socially backward classes like STs but also the weaker sections such as women headed farmer households have lower access to credit (considering both formal and informal sources) compared to other categories. In particular, access to formal credit was quite high for general category (66%) and lowest for the SC category 46%. Both the SC category and the women headed farmer households category used relatively lesser share towards the income generating purpose.

Even though at all India (average) level the share from the formal source of credit is low for the SC category farmer households, a wide variation is seen across States. In States like Maharashtra, Kerala, Orissa and West Bengal, these SC households had more than 70% of their credit from formal source. These households also used substantial portion of their credit for income generating purposes. States like Kerala, Maharashtra and Gujarat are more gender sensitive and more than 70% of their credit for the women headed farmer households have come from formal sector.

Conclusion

In this paper we examined the yield rate of rice crop for different types of farmers. It is observed that yield rates are higher for the small and marginal farmers and access to credit enhances productivity. Thus this study has revealed the nature and extent of farmers' indebtedness (which represent access to credit) in India and provided a comparative picture of major Indian states. In terms of access to credit, seen through extent of indebtedness, Karnataka is better placed than many Indian states. But Andhra Pradesh, Tamil Nadu, Punjab and Kerala lie ahead of Karnataka.

At all India level the share from the formal source is quite low for the SC category farmer households and a wide variation is seen across States. In States like Maharashtra, Kerala, Orissa and West Bengal, SC households had more than 70% of their credit is from formal source. These households also used a large proportion of their credit for income generating purposes. States like Kerala, Maharashtra and Gujarat were more gender sensitive and more than 70% of their credit for the women headed farmer households came from formal sector. Other states can learn lessons from these states.

Thus to conclude, for many states in India dependence on informal loan by deprived class such as SC/ST is much higher than the 'others' category. Weaker sections such as women headed household also depend to a large extent on informal sources of credit. Thus there is an urgent need to improve access to formal credit for the backward class, poorer and weaker sections of farmer community.

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Appendix

Table 1. Incidence of Indebtedness

States	Incidence of Indebted-ness	Average outstanding loan (in Rs)		Median outstand-ing loan (in Rs) within indebted household
		All house-holds	Within indebted households	
Andhra Pradesh	82.13	23965	29178	13910
Assam	18.12	813	4484	1400
Bihar	33.02	4476	13552	5166
Chattisgarh	40.19	4122	10256	4125
Gujarat	51.91	15526	29912	15000
Haryana	53.13	26007	48952	24357
Jharkhand	20.87	2205	10564	4000
Jammu & Kashmir	31.84	1903	5977	576
Karnataka	61.61	18135	29437	10300
Kerala	64.37	33907	52676	22150
Maharashtra	54.85	16973	30948	12000
Madhya Pradesh	50.80	14218	27987	11200
Orissa	47.83	5871	12275	5700
Punjab	65.44	41576	63529	20000
Rajasthan	52.43	18372	35044	15500

States	Incidence of Indebtedness	Average outstanding loan (in Rs)		Median outstanding loan (in Rs) within indebted household
		All households	Within indebted households	
Tamil Nadu	74.47	23963	32178	12360
Uttar Pradesh	40.33	7425	18409	8250
Uttaranchal	7.18	1108	15429	6840
West Bengal	50.12	5237	10449	4650
All India	48.61	12585	25891	10000

Source: Author’s analysis of NSSO data

Recent Developments in Water Management and Conservation in Rice

P.V. Veerraju, K.P. Aruna and Putra

The real challenge to the agricultural development in rain-fed area can be expressed in single line, as "To provide reasonably assured good quality irrigation water during dry season/ scanty rainfall and remove excess rainwater during monsoon season". Distribution of rain, the only source of water for substance of agriculture, is unpredictable in timing and amount. In cereals like rice moisture stress during critical stages reduces both grain and stalk yields. Aberrant behavior of monsoon is a serious constraint, affecting productivity, profitability and sustainability. Prospects for application of modern technologies including adoption of HYV is either minimal or nil without improvement in the hydrological conditions in coastal agro eco system and rain fed agro ecosystems. Coastal areas suffer from inundation with sea water, since major portion of the area may be below the sea level.

The technology for the improvement of agriculture productivity in these areas appear to be through judicious water harvesting and water banking through structures like Vented Dam(VD), Farm ponds, Shallow open wells, Check dam etc. Water banking: the rainfall – run off – stream water received and stored in water harvesting Structures like VD in rainy season could effectively meet the water requirement of rice and that of subsequent crops like Pulses & Groundnut- giving substantial economic gain to the farmer through increased productivity, production and also through fixing Nitrogen in the soil. In coastal belts, VDs help to avoid intrusion of sea water during high tide in to the paddy field through streams (Fig 1).

Vented dam

The cost of VD (fig.1) varies from Rs.1.20 Lakhs to 5.00 Lakhs depending on the length and height of the Dam - minimum catchment area 25 Ha. - stream size and material used and so, with the capacity of the VDs to store water.

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$$\text{VD (Storage Capacity in m}^{3)} = \frac{\text{Height (m) X Width (m) X Length (m)}}{2}$$

$$\text{Example:} \quad = \frac{1.6 \text{ X } 10 \text{ X } 100}{2} = 800 \text{ m}^3$$

Figure 1. Watershed development activities at Uttarakannada Taluk: Ankola

This quantity of water (with continuous seepage water), is sufficient to irrigate 2-5 ha depending on the soil texture, variety, critical stages, climate etc. Fig 1 also depicts the Vented Dam used to avoid intrusion of sea water into the paddy field during high tides and also Fig 1 and 2 depict the Water harvested and stored to provide irrigation to the paddy fields.

Figure 2: Vented dam- Watershed development Department Uttarakannada Taluk: Siddapur

Shalow seepage wells & farm ponds

The cost of Shallow Well (Fig 3) varies from Rs. 60,000 to 1, 00,000 and could irrigate 0.2 to 0.4 ha and also provide timely nursery operational backup if rainfall is delayed.

Figure 3. Watershed development activities at Uttarakannada Taluk Bhatkal village: Mutnalli WGDP

Vented dam cum foot bridge

Fig 4 shows how a foot bridge over the vented dam could help the farmers in paddy cultivation for carrying the inputs across the nala in addition to provide timely irrigation.

Figure 4. Foot bridge over the vented dam

The rising cost of cultivation of rice involving the rain-fed farming threatens the economic viability of the rice as moisture stress, scanty rainfall during the crop cycle reduce the grain yield.

Water banking coupled with water harvesting help to meet water requirement of rice crop at every stage – Nursery (3%), Field preparation (16%), transplanting to panicle initiation (37%- critical stage), PI to Flowering (34%- critical stage), Flowering to maturity (10%). Through this water requirement could be met if there is delay in on set of monsoon, scanty rainfall, variation in intensity and duration. So that, continuous supply of water in the form of supplementary irrigation either for crop establishment or at critical growth stages, continuous submergence with stagnant irrigation is possible. Timely application of fertilizer, timely sowing and transplanting would help to prevent the yield reduction of up to 20-40% or even crop failure with appropriate varieties, there by farmers will not abandon the growing of Paddy.

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Summary

Key Research Inputs and Technologies in Rice Production in Pre and Post Green Revolution Era

B.C. Viraktamath

In this article, the author highlights many factors that contributed in rice production in pre and post green revolution era in India. It was observed that the growth trend in rice production has kept in pace with population growth rate during the last five decades. However in the recent past there is downward trend in the growth rate of rice production. This has been case of concern as rice is the primary food material required by the major population of our country. It is estimated that by 2030, at least 150 million tonnes of milled rice is required to meet the food requirement of the growing population as against 95 million tonnes produced presently in the country. That means in another 17 years the production has to be raised by 55 million tonnes. This needs for a paradigm shift in the rice research programmes to meet the challenges in the coming years. In the article the author clearly brings out the research achievements in rice during last five decades. During this period 944 varieties have been released to grow in 13 different agro climatic zones. Various strategies to be followed in breeding for development of hybrids, development of aerobic rice, application of biotechnological tools including genetic engineering, natural resource management and crop protection have been detailed.

Strategies for Enhancing Production and Productivity of Rice in India

K. Srinivasa Rao

The author in this paper highlights about the strategies to be followed to bridge the yield gap in rice and explore the possibilities of enhancing the productivity levels in various rice growing eco-systems. The authors briefs about the potential of using hybrid technologies, expansion of rice cultivation in potential areas, use of location specific varieties and technologies, developing contingency crop planning to address the vagaries of nature, integrated nutrient management, weed management, scientific water management, integrated pest management including multi enterprise farming system. Author argues about the need to give stress on mechanization in rice cultivation, proper post harvest technologies and strengthening the transfer of technology programmes.

Growth in Production, Productivity, Costs and Profitability of Rice in India During 1980-2010

Parshuram Samal

Sustainable rice production in India is not only important from the point of view of food security but also its poverty alleviating effect. This calls for enhancing the rice production to meet the ever increasing demand by the growing population. The author clearly depicts about the growth in area, production and productivity of rice in India and various states during the period of 1980 -2010. The article highlights about the trend in cost of cultivation of rice and price realized per quintal during the last three decades. State wise analysis of cost of cultivation revealed that cost of production per hectare has increased in all the states and profit decreased. And also the support price announced by the government is not in tune with the production cost. Hence, he emphasizes for reviewing the support price and also procurement procedures in various states of the country to make rice farming remunerative.

Hybrid Rice Programmes and its Experience in India

Aldas Janaiah and Fengming Xie

Rice is the key source of livelihood for majority population of the country. The average productivity in rice is 3 t/ha as against its potential of 6 t/ha. Author emphatically stresses that in the coming years the enhanced production of rice is possible only from increasing its productivity. This is mainly possible through development and popularization of hybrid rice in various agro-climatic zones. Presently although about 35 hybrids have been released in India, it covers only 3.2 per cent of the total area under the crop. Due to considerable improvement in grain quality in recent hybrids it had caught the attention of the farmers and consumers. The hybrid rice has got great potential in eastern India where rice is the staple food. The author argues that the large scale adoption of hybrid rice in the country is possible only by further improvement in grain quality and making it comparable with that of popular in-bred varieties.

Hybrid Rice and Water Saving Technologies – A Possible Solution for Inter State Water Dispute

M. Mahadevappa

In this article author emphasizes on ways and means to reduce the use of water in rice but maintaining its production. He emphasizes that China has been successful in reducing the area under paddy to the tune of 20 million acres without sacrificing its production. This has helped in not only saving the land but also to conserve and save precious water. China was able to do this by introducing hybrids coupled with improved management practices. China is now further reducing the paddy area with the introduction of super rice. In India also, if exploitation of hybrid vigour is carried out along with adoption of SRI cultivation method, it will help to improve the production levels in all the states and also to reduce the pressure on water. Author strongly pleads that, adoption of these technologies if implemented earnestly by all the states it will help to overcome the water dispute between various states.

Constraints of Rainfed Rice Production in India : An Overview

Krishna M. Singh, A.K. Jha, M.S. Meena and R.K.P. Singh

Rice is the important staple food of eastern India and also the major cereal crop. The eastern India has high potential to enhance the productivity by providing high priority to overcome the constraints of rice production. Authors clearly bring out major constraints responsible for fluctuating production and other major problems of rice cultivation in eastern region like use of inappropriate cultivars, drought and submergence, bacterial blight, leaf blast, brown plant hopper and poor soil fertility. Another important strategic point the authors emphasize on the strengthening of extension activities to take relevant technologies to farming community.

Present Situation and Prospects of Rice Production in India With Special Reference to Karnataka

K. Narayana Gowda and M.P. Rajanna

In Karnataka, rice being important cereal it is grown in 13.3 lakh ha with production of 38.6 lakh tonnes. In Karnataka rice is grown in almost all the agro climatic regions covering various soils & rainfall situations. Authors point out in the article how due to the announcement of MSP for sugarcane well in advance has helped to shift to sugarcane from rice and there by argues for announcement of MSP for rice well before season. The author argues that if at all rice productivity has to be improved important pests like yellow stem borer, gall midge, brown plant hopper, white backed plant hopper & leaf folder and emerging diseases namely sheath blight, sheath rot and rice tungro to be addressed on war footing. Authors emphasize on various strategies to enhance the production and productivity of rice. They are, widening genetic base, exploitation of hybrid vigour, addressing biotic & abiotic stress, adoption of INM & IPM, adoption of SRI, aerobic & AWD method of cultivation to save water, mechanization and effective dissemination of technologies.

Emerging Insect Pests and Diseases of Rice Under Various Rice Ecosystems

K.S. Behera, M. Jena, U. Dhua and A. Prakash

Rice is prone to various insects & diseases and which is major constraint in realizing desired yield. Authors clearly brings out the insect and disease scenario in various ecosystems and also in different states during last decade. The article highlights about the severity levels of pests and diseases in various states, serious pest out break during various years, change in pest scenario and also the reasons for minor pests becoming major. The main reasons being emphasized are, introduction of new varieties, breakdown in resistance, large scale monoculture, unwise farming practice and excessive use of nitrogen etc.

Important Socio-economic and Ecological Factors Affecting Rice Production in India

K.V. Rao, B. Shailaja, B. Nirmala and B.C. Viraktamath

Rice is the number one crop utilizing land & water (> 50% of irrigation water) and inputs (38 – 40% fertilizers and 17 – 18% pesticides) in India. Authors emphasizes in this paper about poor national level productivity as rice is grown in all soils and climatic zones whether they are favourable or non favourable. Due to this, crop is exposed to various biotic & abiotic stress and poor availability of nutrients. Author indicates in the paper that by 2030 about 300 million tonnes of food production is required along with 45 million tonnes of nutrients. The cost of cultivation varies from Rs.16,700 to Rs.55,300 per ha and net returns over paid out costs have shown a declining trend.

Rice Factor Productivity in India: Economic Implications

M.G. Chandrakanth, L. Ranganath and T.N. Prakash

In this article authors emphasize on the annual growth consumption of Rice as influenced by various factors, per capita availability of rice over the years and compares it with fruits, vegetables, meat etc. It is pointed out that low rice production in India is due to lack of input use, low market price and lack of demand due to poor policy support. The authors argue that, in India there is no measurement of factors of production especially of water. There is virtually no volumetric measurement of canal irrigated water provided to farmers. Hence they reinforce the need to educate about judicious use of water. Another area highlighted is needs for increased investment in agricultural research and education.

Agriculture R&D Investment by India and China: A Comparative Analysis with Specific Emphasis on Rice Production

K.R. Karunakaran

It is increasingly felt that higher level of investments in agricultural research is the key factor in increasing agricultural production. Considering its importance, the paper has attempted to provide comparison of public & private investment in agriculture R & D in India & China. China has gone ahead in adoption of hybrid rice & mechanization which have helped to raise productivity & make it remunerative. The author argues that if China could trigger the higher agriculture GDP growth rate due to higher R & D investments, for enhancing production in coming years India also needs to give attention.

Biotechnological Options for Rice Improvement

R.M. Sundaram, S.M. Balachandran, M.S. Madhav and B.C. Viraktamath

Development of improved varieties through genetics and breeding has made remarkable impact on rice cultivation in India. It is emphasized in the article that to keep in pace with the population growth at 1.5% the rice production should be 140 million tonnes by 2030. Authors plead that to overcome plateauing of yields there is necessity to give emphasis on biotechnological approaches like genomic research, transgenic breeding and molecular markers application in rice breeding. These approaches can certainly accelerate rice improvement work in India and can help to trigger the productivity & make rice cultivation remunerative. Authors in this paper have detailed about the list of agronomically important genes having unique traits and also clearly details about transgenic work which is in progress in various countries. A foresight research programme on development of designer rice plant is advocated by the authors.

Knowledge Management Portal for Enhancing Rice Production and Productivity

Shaikh. N. Meera, G.A.K. Kumar, M.P. Rajanna, R.L. Kunkerkar, P.S. Pandey and B.C. Viraktamath

Enormous knowledge has been developed about rice in the National Agricultural Research System. There is urgent need to share this knowledge for the betterment of the society & to overcome present declining yield trends. The article details about the uniqueness of rice knowledge management portal which can help in better flow of rice knowledge & information. This can serve as information highway in rice sector benefitting farmers, researchers, extension professionals, policy makers, students, etc. Authors clearly bring out, how the knowledge portal can be useful for reducing the gaps of growing digital information divide.

Achievements, Challenges, Technology Dissemination of Rice in India

R.S. Kulkarni, K.P. Raghuprasad and Mallika Meti

The authors in this article emphasize on major constraints of rice cultivation in India, need for dissemination of technologies and various methodologies which could be employed. They argue that only technologies which are viable, sustainable, technologically feasible and fit for particular agro climatic situation are adopted instantly. Some of the effective extension approaches advocated for faster adoption are, formation of commodity groups, participatory mode of research, use of ICT tools and other innovative approaches. Authors stress the need for two way information sharing between experts and farmers.

Nature and Dimension of Farmer Indebtedness in India

Meenakshi Rajeev, B.P. Vani and Manojit Bhattacharjee

In this paper, author highlights about the nature and extent of farmers indebtedness in India and emphasize it by using unit record data from NSSO 59th round. Authors clearly bring out how critical is the credit for improvement of rice productivity. In terms of access to credit seen through extent of indebtedness, Karnataka is better placed than many Indian states but below Andhra Pradesh, Tamil Nadu, Punjab and Kerala. Authors plead for improving credit access for the backward class, poorer and weaker sections of the farming community.

Recent Developments in Water Management and Conservation in Rice

P.V. Veeraraju, K.P. Aruna and Putra

The authors draw attention that if at all rice farming to be sustainable there is need to provide reasonably good irrigation water during dry season & remove excess rainwater during monsoon. There is urgent need to emphasize on judicious use of water in rice cultivation through water harvesting and water banking through adoption of various structures like vented dam, farm pond, shallow open wells and check dams. It is emphasized by the authors that all the structures mentioned are cost effective sustainable and help to conserve water effectively.

Dr. P.K. SHETTY

Dr. P.K. Shetty is a Professor and Former Dean of the National Institute of Advanced Studies, Indian Institute of Science Campus, Bangalore. Earlier, he was Head of the Environmental Studies Unit, the Dean (Administration) and the Dean (School of Natural Sciences & Engineering) at the National Institute of Advanced Studies, Bangalore and also Independent Director, Power Grid Corporation of India Limited, Government of India.

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He has been on the editorial boards of many important journals including the Scientific Advisory Board of a Journal of Springer on "Philosophy and Technology. He has conducted several India-centric multidisciplinary discussion meetings, seminars/conferences on advances in Agriculture, Science & Technology. He is associated with various science education, afforestation, energy conservation and environmental awareness programmes in the country. He has received several awards in recognition of his work including the prestigious Karnataka State Rajyostava Award (2007), Government of Karnataka and the Kempe Gowda Award (2011), The Bruhat Bangalore Mahanagara Palike, Government of Karnataka.

Dr. M.R. HEGDE

Dr. M.R. Hegde who after completing Doctorate in Agronomy joined Indian Council of Agriculture Research (ICAR) in the year 1977. During the period of his service he has worked at ICAR Research Council (Shillong), Directorate of Oil Seed Research (Hyderabad), Central Plantation Crop Research Institute (Kasargod), Zonal Coordinating Unit (ICAR) at (Bangalore & Hyderabad) also at Indian Institute of Horticulture Research (Bangalore). He served as Zonal Coordinator, Zonal Coordinating Unit Zone VI (Hyderabad). His area of specialization being crop intensification, low external input agriculture, organic farming and transfer of technology. He has guided four Ph.D. and five M.Sc. scholars. He has to his credit about 100 research publications in national and international journals and about 150 popular articles/technical bulletins including ten books. He is recipient of ten awards from various institutes and organizations. He has served in various national level committees. Presently he is working as Principal Scientist and Chairman, Research Management and Coordination Unit, Indian Institute of Horticulture Research (Bangalore).

Dr. M. MAHADEVAPPA

After obtaining his Bachelor's degree from Hebbal Agriculture College, and his Doctoral degree from Agriculture College, Coimbatore, he served as Post doctoral fellow at CFTRI, Mysore continued his research pursuits at the International Rice Research Institute, Manila and devoted his entire career to the cause of rice research. His contribution sustained breeding efforts at the Vishveshwaraiah Canal Farm, Mandya, which lead to release of rice varieties Madhu, Mangala, Pushpa, Pragathi, Intan, Vikram, Mukthi and hybrids and they are widely recognized and used by the farming community in the country. In addition, Dr.Mahadevappa developed a biological eco-friendly Integrated Parthenium Weed Management (IPWM) Technology, a boon for curtailing Parthenium menace.

Dr.Mahadevappa contributed immensely for the overall development of the University of Agricultural Sciences, Dharwad as its Vice Chancellor for two terms. With his broad vision, he strived hard selflessly resulting in confer of the ICAR's "Sardar Patel Outstanding Institution Award For 2000" for UAS Dharwad. He served as the Chairman of the Agricultural Scientists Recruitment Board (ASRB), New Delhi. Dr.Mahadevappa has published 200 research articles in addition to 31 papers presented in International conferences. He has written 12 books, translated three and contributed to 3 chapters in the field of Rice, Seed Science & Technology and Parthenium in both English and Kannada.

Several reputed organizations have recognized Dr.Mahadevappa's rich contributions for the cause of agriculture and the farming community. He was conferred the coveted (International) Watumull Foundation Award (1987), Hooker Award (1981) and Sir Chotturam National Award. The Karnataka State conferred the Rajyotsava Award in 1984. In addition he was conferred the Nagamma Dattathreya Award by UAS, Bangalore, and Parisara Ratna Award and Bharatha Ratna Sir M. Visvesvaraya Memorial Award (1999). Dr.Mahadevappa was recognized by President of India by awarding "Padmashri".