Revitalizing Rice-Systems for Enhancing Productivity, Profitability and Climate Resilience

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SUMMARY

Rice (*Oryza sativa* L.) is the staple food for about half of the global population, grown in 160 million ha (Mha) with 493 million tons (Mt) milled rice production. Out of about 141 Mha of net cultivated area in India, rice occupies the maximum i.e., about 43 Mha. Over the last four decades, rice production has witnessed impressive growth due to the development of high-yielding varieties, coupled with the adoption of intensive input-based management practices. The task of increasing rice production has become quite challenging, however, in recent years due to degradation in natural resources such as soil, water and air along with shortage of labour and emerging problem of climate change. In future, rice would have to be produced using less land, water and labour through more efficient, environment-friendly production systems that are more resilient to climate change and also contribute less to greenhouse gas emission. Moreover, all of our efforts so far were production-centric. Now we need to shift the focus to make it profit-centric. In the process of pursuing higher yield, we neglected the environment i.e., soil, water and air, considering them to be passive and inactive players of crop production. To increase productivity, profitability, climate resilience and sustainability of rice production, a range of strategies i.e., technological, infrastructural and policy need to be adopted to transform the current production-driven rice-based cropping system to profit-driven rice-based farming system. Agricultural research should be re-oriented with farmers' participatory approach to unshackle the vicious circle of poverty, reduce drudgery and fulfill the aspirations of resource-poor, smallholder rice farmers.

1. INTRODUCTION

Rice is the staple food for about half of the world population (Table 1). Grown for more than 6000 years, it is economically, socially, and culturally important to a large number of people across the globe. More than 100 countries grow rice with the third highest worldwide production of 740 million tons (Mt) of rough rice, after sugarcane and maize. It accounts for 35-75% of the calories for more than 3 billion Asians. Globally, it provides 27% of dietary energy, 20% of dietary protein and 3% of dietary fat. Rice fields cover around 160 million hectares, the third largest cereal, and most important food of majority of global poor. It is grown in a wide range of climatic conditions spanning from 44^{o}N latitude in North Korea to 35^{o}S latitude in Australia. It is cultivated from 6 ft below sea level (such as in Kerala, India) to 2700 ft above sea level. Most of the rice in tropical countries is produced in irrigated and rainfed lowland areas. Irrigated rice systems account for 78% of all rice production and 55% of total

Table 1. Global and national importance of rice.

Parameters	Global scenario Magnitude	Per cent[a]	Indian scenario Magnitude	Per cent[b]
Population dependent (billion)	4	56	0.8	65
Families involved (million)	144	25	67	56
Area cultivated (Mha)	160	10	43	22
Production of milled rice (Mt)	493	20[c]	110	30[c]
Productivity (t ha^{-1})	2.95	80[d]	2.56	82[d]
Providing livelihood (Million)	400	40[e]	150	40[e]
Annual value (billion US$)	206	13	53	17
Fertilizer use (Mt)	25	15	6	25
Irrigation water use (km^3)	880	35	200	30
Methane emission (Mt)	25	12	3.5	18

Note: Data pertain to 2015-16. a, per cent of global total; b, per cent of country total; c, of total food production; d, of agriculture; e, of rural poor

Source: Compiled from various publications from IRRI (2016); NRRI (2016), MoA (2016)

harvested rice area, mostly concentrated in alluvial floodplains, terraces, inland valleys, and deltas in the humid and sub-humid subtropics and humid tropics of Asia. The crop occupies largest area in India followed by China and Indonesia, whereas China has the highest production but, Australia has the highest productivity (Table 2).

Table 2. Area, production and yield-wise top five countries (2012-14).

Country	Area (Mha)	Country	Production (Mt)	Country	Yield (t ha^{-1})
India	43.67	China	137.64	Australia	6.68
China	30.67	India	105.79	Egypt	6.37
Indonesia	13.69	Indonesia	46.93	USA	5.66
Bangladesh	11.67	Bangladesh	34.27	Spain	5.14
Thailand	11.49	Vietnam	29.50	Turkey	5.11

Source: FAOSTAT (2016)

In India, rice plays a major role in diet, economy, employment, culture and history. It is the staple food for more than 65% of Indian population contributing approximately 40% to the total food grain production, thereby, occupying a pivotal role in the food and livelihood security of people. The country has the world's largest area under rice i.e., about 43 million hectare (Mha) and the second highest production i.e., about 110 Mt of milled rice at productivity of 2.56 t ha^{-1} (Table 1) as per 2016-17 statistics. The crop is cultivated round the year in one or the other parts of the country. The leading rice producing states are West Bengal, Uttar Pradesh, Punjab, Odisha, Andhra Pradesh, Bihar and Chhattisgarh (Table 3). About 40% of the rice area in India is rainfed and more than 70% of which is in eastern India. Out of the total rainfed area, 23% are rainfed upland and 77% are rainfed lowland. The entire rainfed upland and 52% rainfed lowlands are drought prone. About 17% of rainfed lowlands are flood prone.

Table 3. Area, production and productivity of rice in different states of India (2015-16).

State	Area (000 ha)	Production (000 ton)	Yield (t ha^{-1})
Uttar Pradesh	5862	12501	2.13
West Bengal	5524	15954	2.89
Odisha	3941	5875	1.50
Chhattisgarh	3816	5789	1.51
Bihar	3232	6802	2.10
Punjab	2975	11823	3.97
Assam	2485	5125	2.06
Andhra Pradesh	2161	7489	3.47
Madhya Pradesh	2024	3547	1.75
Tamil Nadu	2000	7517	3.76
Jharkhand	1589	2882	1.81
Maharashtra	1503	2593	1.72
Haryana	1354	4145	3.06
Karnataka	1110	3021	2.72
Telangana	1046	3047	2.91
Others	2878	6298	2.19
India	43500	104408	2.40

Source: Ministry of Agriculture, Government of India.

Global demand of rice needs to increase from the current 493 Mt to about 550 Mt in 2030 (IRRI, 2016). However, rice farming, particularly in the rainfed regions, faces multiple risks from uncertain climate, degraded soil, water shortage and underdeveloped markets. It has come under increasing pressure from intense competition for land and water, a more difficult growing environment because of climate change, higher price for energy and fertilizers, labour shortage, increasing cost of cultivation, declining profit margin and greater demand for reduced environmental footprint (Samal 2009; Samal 2013). The socio-economic dynamics and food habits are also changing adding another dimension to already complex challenges of rice cultivation. Therefore, the goal of rice research and development should be at improving nutritional and income security of rice farmers while addressing environmental sustainability and coping with climate change.

The chapter deals with the rice ecosystems; trends in area, production and productivity; emerging challenges and the strategies for enhancing productivity and profitability of rice production in India.

2. RICE ECOSYSTEMS IN INDIA

In India, rice is grown under highly diverse conditions with area stretching from 79^0 to 90^0 E longitude and 16^0 to 28^0 N latitude under varying agro-ecological zones. It is cultivated mostly in wet season with unpredictable rainfall distribution. It is also grown in areas, where water depth reaches 2-3 m or more. Rice culture in Kuttanad district of Kerala is grown below the sea level, while in the state of Jammu and Kashmir, it is grown upto an altitude of 2000 m above sea level; with temperature range of 15-40 ^{0}C and average annual rainfall range from 30 mm in Rajasthan to more than 2800 mm in Assam. A wide range of rainfall distribution pattern (drought, submergence, deep water) and distinct differences in soils (coastal and inland salinity, alkalinity, acidity), agro-climatic situations (high humidity) and seasons has resulted in the cultivation of thousands of varieties and therefore, one can see a standing rice crop at some parts of the country or the other in any time of the year. Rice is primarily grown under four major ecosystems broadly classified as (i) irrigated, (ii) rainfed lowland, (iii) rainfed upland and (iv) flood prone.

- Irrigated rice eco-system: Total area under irrigated rice in the country is about 26.0 Mha accounting for about 60% of the total area under the crop. It includes the areas in Punjab, Haryana, Uttar Pradesh, Jammu & Kashmir, Andhra Pradesh, Telangana, Tamil Nadu, Karnataka, Himachal Pradesh and Gujarat.
- Rainfed lowland rice ecosystem: In India, lowland rice covers an area of about 14.0 Mha, which accounts for about 32% of the total area, located mainly in eastern India. The area is characterized by poor soil quality and frequent occurrence of drought/flood due to erratic rains.
- Rainfed upland rice ecosystem: Total area under rainfed upland rice in the country is about 6.0 Mha, which accounts for 13.5% of total area, located mainly in eastern zone i.e., Assam, Bihar, Chhattisgarh, eastern Uttar Pradesh, Jharkhand, Madhya Pradesh, Odisha, West Bengal, and North East Hill Region. The rainfed upland ecosystem is drought prone.
- Flood-prone rice ecosystem: It occupies about 2.5 Mha in eastern states of the country. The crop is 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 Odisha.

Among the above ecosystems, further sub-systems are usually identified for location-specific variations such as 'favourable' or 'unfavourable' moisture, soil type, temperature regime, proneness to drought, submergence, both drought and submergence; growth duration (early, medium, late maturity groups) and low light intensity conditions.

3. ACHIEVEMENTS OF RICE RESEARCH

During the last five decades, a lot of advancements have been made on developing high yielding and disease-resistant varieties and production technologies for different ecosystems. The country has released about 1200 varieties including about 240 varieties released by ICAR so far for different ecologies. Most of the recent releases are resistant to multiple diseases such as blast, sheath blight, sheath rot, false smut, brown spot, stem rot and bacterial blight. These varieties are also tolerant to different pests (gall midge, brown plant hopper, stem borer). Many varieties among them have early maturity duration. Several viable rice production technologies have also been developed for adoption in the farmers' fields. Besides, the duration of maturation of aromatic rice has been reduced from 160 days to 110 days, while the yields have increased from less than 2.5 t ha^{-1} to more than 7.0 t ha^{-1}. Shortening of the crop cycle has not only helped in saving water and labour, but also facilitate new combinations of crops in rotations. The hybrid rice technology contributed towards an additional 4-5 Mt to the total rice production in the country and there is a vast scope for increased adoption of this technology by the farming community in future. Along with increasing the productivity, emphasis has been given on improving the nutritional quality of rice varieties and developed varieties with improved quality attributes such as high protein (CR Dhan 310, CR Dhan 311), high zinc (DRR Dhan 45), low glycemic index (Improved Sambha Mahsuri) in rice to provide nutritional security to the population depending on rice as staple food. High yielding varieties of rice developed and released by ICAR-institutes and SAUs have reached millions of farmers in different states of the country and are cultivated under different agro-ecologies. Currently, about 85% of rice area is covered with high-yielding varieties. Stress tolerant varieties have also helped steady production levels making rice production systems climate-resilient. India's rice export has also steadily increased making it the leading rice exporter followed by Thailand, Vietnam, USA and Pakistan. Currently, the country exports about 10 Mt rice annually.

Production of rice has increased more than five times since 1950-51 and made India self-reliant in rice from early 1980s (Fig. 1). The sources of growth in the past were increase in area and yield, which has increased by 1.4 and 3.6 times, respectively since 1950-51. Though during Green Revolution period the production growth has accelerated, during 2000s, the growth has decelerated, threatening the national food security. It is observed that the additional production during 2000s has decreased over the previous decade. More precisely, additional production during 1990s over

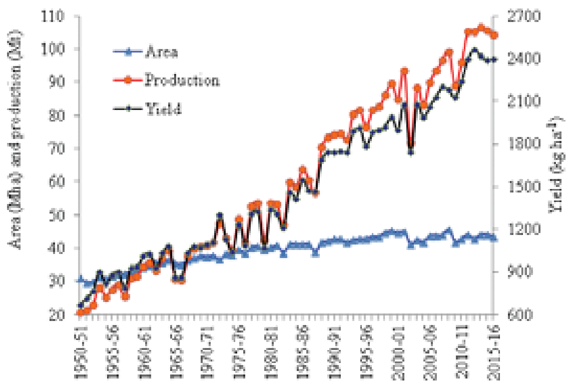

Fig. 1. Trends in area, production and yield of rice in India.

Source: Ministry of Agriculture, Government of India (2017)

1980s was 20.3 million tons, which reduced to 9.2 tons during the 2000s, indicating thereby that the production base is shrinking, which is a cause of concern. The additional yield has also reduced from 387 kg ha^{-1} during 1990s to 200 kg ha^{-1} during 2000s. However, some signs of improvement were noticed during the recent period (2010-11 to 2015-16) and the additional average yield has increased from 200 kg ha^{-1} during 2000s to 332 kg ha^{-1} during 2010-16. A major share of production increase during the recent period is from the eastern states (Assam, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Odisha, Uttar Pradesh and West Bengal). It is also observed that the area growth has almost exhausted in rice. These observation leads to the conclusion that the area growth in India has been exhausted and further increase in production has to come from yield increase only.

4. PROJECTED DEMAND OF RICE

Population growth is the major driving force for increasing rice demand in India. In addition, the low-income segment of the population will also demand more rice with increase in income. It is estimated that about 120 and 140 Mt of rice would be required by 2025 and 2050, respectively in India. In addition, India is exporting about 10 Mt of rice per year, which earns valuable foreign exchange for the country. There is a growing middle-class, rice-consuming population in domestic as well as international markets. This will increase the demand for high-quality rice creating great opportunities for India for exporting basmati and high-quality non-basmati rice. This increased production has to necessarily come from increased productivity rather than increase in area under rice and that too under deteriorating soil, water and other natural resources. Therefore, to sustain present food self-sufficiency and to meet future demand of food and export, the production has to increase by about 1.5 Mt yr^{-1} and the productivity to 3.25 t ha^{-1} by 2050 from the current level of 2.56 t ha^{-1} (2016-17) i.e., an increase of about 30%.

5. EMERGING CHALLENGES OF RICE FARMING

Rice production is intricately linked with land and water, and this has unique and profound implications for the environment. Hence, careful management of the natural functioning of rice ecosystems is critically important for protecting the environment while raising rice productivity to meet growing demand. The Green Revolution in south Asia in the 1960s helped doubling food production with a mere expansion in area of 10–20% and introducing seeds of high-yielding varieties, fertilizers, irrigation, and pesticides. However, this intensification of agriculture had adverse environmental consequences such as the deterioration of natural resources. As a result, the increase in productivity is showing signs of slowing down/stagnating. Yield trends from long-term continuous rice-rice experiments conducted in Bangladesh, China, India, Indonesia, Nepal, the Philippines, and Thailand indicated that, even with the best available cultivars and scientific management, rice yields (holding input levels constant) have either stagnated or declined over time since the early 1980s. The rice-wheat cropping system of the Indo-Gangetic Plains (IGP) also showed yield stagnation/decline in the last two decades. Earlier gains in rice output were driven by the increase in area under modern varieties, irrigated area, fertilizer use, increased cropping intensity, and supportive input and output price policies in irrigated areas. However, in the last decades, there is sign of yield plateauing in major irrigated states. There is now growing concern that other non-price factors, such as the declining scope for further gains from existing modern varieties, deteriorating soils and ground water supplies, and reduced public investment in research have contributed to poor performance in recent years in irrigated areas. The challenge is to integrate productivity and profitability improvement while conserving and enhancing the quality of the environment on which production depends. The major environmental concerns of modern rice farming and suggested potential remedial measures are presented below (Pathak and Ladha 2006).

5.1. Degrading the water resource base

The productivity of water for rice is very low. Rice requires about two times as much water as wheat or maize. In some regions, such as northwest India, water application in rice is about 5-6 times more than that of wheat. Large water demand of rice is expected to outstrip the available supply in the near future. The declining availability and quality of water, increased competition from domestic and industrial sectors, and increasing costs are already affecting the sustainability of irrigated rice production systems in many parts of south Asia. For example, in the upper transect of the IGP, rice cultivation resulted in a decline in water tables and water quality. A rapidly depleting water table in many northern and southern states is also a matter of concern for future productivity growth. Five major rice surplus states, Punjab, Haryana, western Uttar Pradesh, Tamil Nadu, and erstwhile Andhra Pradesh, where groundwater depletion is a major issue, account for around 42% of India’s rice production (in 2015-16). These states contribute a significant amount to the country’s central pool, which is critical for India’s food security and also to the functioning of India’s food distribution program, through which poor people are provided with highly subsidized grains. Many districts in the rice-wheat growing area of Haryana, and Punjab, show a water table decline in the range of 3-10 m over the last two decades. The groundwater table has fallen at about 23 cm yr^{-1} in the central Punjab, India. The other side of the water problem is waterlogging in some areas. In some districts of Haryana, the water table is rising at 0.14 to 1.0 m yr^{-1} and more than 0.4 Mha of land has a water table within 3 m of the soil surface. Apart from water scarcity, the growing demand for land from urbanization, industrialization, and for growing cash crops is likely to cause a decline in rice area. According to the NRRI 2050 vision document, rice area may decline by 6-7 Mha by 2050, a decline of around 15% in the next 35 years. In other words, India will need to produce 137 million tons of rice on 37 Mha of land in 2050 compared with the current production of 105 Mt of rice on 43 Mha. Therefore, yield will have to increase by 50% in the next three decades to keep India food secure.

The demand for fresh water is growing from other sectors of the economy like industry, domestic and environmental use besides water for irrigation purpose to raise crops. Among cereals, rice consumes much more water than others and it is estimated that 2500-5000 liters of water is required to produce one kg of rice. As the demand for water by all the sectors of the economy grows, ground water is being depleted, water reservoirs and canals is being silted, other water ecosystems are becoming polluted and degraded, and developing new sources of water is getting more costly, policy makers and researchers are concerned that water will be the main obstacle for growing enough food in the coming years.

Water application in rice production needs to be decreased by increased water-use efficiency through reduced losses caused by seepage, percolation, and evaporation; laser land leveling; crack plowing to reduce bypass flow; and bund maintenance. Management options to increase the efficient use of rainwater include crop scheduling, diversified cropping, and the construction of small ponds serving as on-farm reservoirs for water harvesting. Various crop and water management systems such as water-saving irrigation techniques, intermittent drying of the soil, growing rice with reduced or no tillage either on flat land or raised beds, and shifting away from continuously flooded (anaerobic) to partly or even completely aerobic rice can drastically improve the efficiency of water use.

5.2. Degrading soil resource base

Concerns about sustainability are arising throughout tropical rice ecosystems because of decreasing soil fertility as most countries move into the post-Green Revolution era. Recent trends of yield decline/stagnation observed in long-term experiments in south Asia were mostly due to soil-related causes such as the decline in soil C and macro- and micro-nutrients in rice-rice and rice-wheat systems; accumulation of phenolic compounds, Fe^{2+}, and sulfides in the rice-rice system; and the increase in soil salinity. Intensive use of irrigation water in rice led to a salinity buildup. In Pakistan's Sindh Province, large areas became saline after the introduction of extensive irrigation. In the short term, salinity buildup leads to reduced yields, whereas, in the long term, it can lead to abandoning of crop lands. Farmers are also using poor-quality water for irrigation in several areas of the Indo Gangetic Plains for rice and run the risk of further aggravating soil degradation. The soil quality of rice systems therefore, needs to be continuously monitored.

Though farmers apply some of the macro-nutrients like N, P and K, they usually neglect application of micronutrients. Even the N, P, K fertilizers are not applied proportionately. In the long run, this causes an imbalance in soil and plant nutrition resulting in yield decline. It has been reported that during 1950s, there was only one nutrient deficiency (Nitrogen), which has increased to eight (N, Fe, P, Zn, K, S, Mn, B, Mo) during 1990s. Moreover, the soil quality is deteriorating from the loss of organic carbon, erosion, soil compaction, salinization, heavy metal introgression into soil from industries and pesticides, and other anthropogenic activities.

5.3. Burning of rice residues

Rice straws and husks are often not disposed of in an environment-friendly manner. In a recent survey, it was noted that 60% and 82% of rice straw produced in the northwestern states of Haryana and Punjab, respectively, is burned in the field (Pathak et al. 2012). About 20 Mt of rice residues are burned annually in Punjab, India, alone. The burning of rice straw is environmentally unacceptable as it leads to (1) the release of soot particles and smoke, causing human health problems such as asthma or other respiratory problems; (2) emission of greenhouse gases such as carbon dioxide, methane, and nitrous oxide, causing global warming; and (3) loss of plant nutrients such as N, P, K, and S. Almost the entire amounts of C and N, 25% of P, 50% of S, and 20% of K present in straw are lost due to burning.

One potential solution to the problem of rice straw burning would be its retention on the soil surface. This straw mulch reduces moisture loss from soil, controls weeds, manipulates soil temperature for better crop growth, and improves soil organic matter content. With the development of new machines (such as the Happy Seeder), it is now possible to sow seeds in residue-retained fields.

5.4. Climate change

Climate change effects include increase in temperature in the long-run, changes in rainfall regimes with increasing year-to-year variability and a greater prevalence of extreme events. Climate has changed worldwide over the last century. It is predicted that a warming of 5°C can eliminate 20% of the coastal wetlands by the year 2080. Apart from rice area reduction, rice yield under simulated global climatic change scenarios have shown a decline, when temperature increase is more than 0.8°C per decade. It is feared that a 20% decline in rice yields can occur in north-west India due to elevated CO_2 and temperature. At present, we do not have thermo-insensitive rice varieties with comparable yield levels within the present high yielding varieties to cope up with the situation. Besides the above, emergence of new pests with higher degree of virulence will be there due to changing climate.

Rice production contributes to global climate change (through emissions of methane and nitrous oxide) and in turn suffers from the consequences. An increase in temperature has two effects on rice: decreasing spikelet fertility due to higher maximum temperature and increasing respiration due to higher minimum temperature. The increase in temperature, especially that of mean minimum night-time temperature, has adverse effects on rice productivity as it reduces crop duration, increases respiration rates, alters photosynthate partitioning to grain, affects the survival and distribution of pest populations, hastens nutrient mineralization in soils, decreases fertilizer-use efficiencies, and increases evapo-transpiration (Wassmann et al. 2009a; 2009b). An increase in atmospheric carbon dioxide, on the other hand, has a fertilization effect on rice, promoting its growth and productivity. Recent studies, however, suggested that the effect of global warming would be largely negative for rice production because of increased respiration and a shortened vegetative and grain-filling period. It is believed that climate change would affect the quality of crops, particularly important aromatic crop such as basmati rice. In addition to direct effects on rice plants, climate change and global warming might affect other organisms associated with rice and thus, alter the occurrence and severity of rice pests. There is also a need to meet the challenge of the increase in extreme climatic events associated with climate change, such as the increasing severity and frequency of floods and droughts, as well as more frequent hurricanes, and their effects on rice production.

Field measurements in several Asian countries have identified possible technical options to mitigate methane emissions through modified water regime (mid-season drainage, alternate flooding), modified residue management (sequestration of straw), use of additives (phosphogypsum, nitrification inhibitors), and modified land management (direct seeding, reduced tillage and site-specific nutrient management) (Pathak 2015). Similarly, novel approaches of demand-driven N supply using leaf color charts and site-specific N management minimize the pool of excessive nitrogen in the soil and thus reduce nitrous oxide emissions. At the same time, adaptation strategies such as (1) resilient varieties for moisture-stress environments, (2) management systems that reduce water use, and (3) insect-pest and disease resistant varieties should be developed to overcome the ill effects of climate change and climatic variability.

5.5. Loss of biodiversity

The introduction of modern rice varieties and practice of monoculture have caused a reduction in and loss of biodiversity as many traditional varieties have been abandoned when farmers found modern varieties to be more productive and profitable. Genetic diversity is required for the continual improvement of the rice crop, as cultivars need to be invigorated every 5 to 15 years to better protect them against diseases and insect pests. With the advances in biotechnology, there is a need for a diversity of genetic material for the potential of these technologies to be fully achieved.

5.6. Increasing cost of cultivation and decreasing farmers income

The cost of cultivation has increased and profits decreased over years in majority of the states. The cost of cultivation per ha across states varied from Rs. 37,071 to Rs. 78,968 and profits were either low or negative in many rice-growing states (Table 4). Policy makers are now concerned, how to make rice cultivation remunerative and at the same time supply consumers rice at affordable prices.

5.7. Increasing labour shortage

With the process of development, the non-farm sector is growing and young people are attracted to non-farm jobs due to higher wage rates in that sector and higher drudgery involved in agricultural operations. Therefore, growing labour shortage is observed throughout the country during peak period of different agricultural operations and thus, escalating agricultural wages year after year. We do not have cost effective small size machines for different operations in rice farming.

Table 4. State wise costs and returns of rice cultivation (2014-15).

State	Cost of cultivation (C_2)* (Rs. ha^{-1})	Gross return (Rs. ha^{-1})	Profit over C_2 cost (Rs. ha^{-1})	Cost of cultivation (A_2+FL)** (Rs. ha^{-1})	Profit over A_2+FL cost (Rs. ha^{-1})
Andhra Pradesh	78968	83972	5004	51821	32151
Assam	49887	36819	-13068	36000	819
Bihar	40097	43483	3386	26308	17175
Chhattisgarh	45775	45303	-472	30848	14455
Jharkhand	38848	43429	4582	23875	19554
Gujarat	55798	73484	17686	41447	32036
Haryana	78948	119977	41030	45717	74261
Punjab	73254	106826	33572	34041	72785
Himachal Pradesh	37071	46368	9298	26323	20045
Karnataka	68315	81571	13255	48419	33151
Kerala	71972	89927	17955	52905	37022
Madhya Pradesh	41381	37492	-3889	28415	9077
Maharashtra	68262	48758	-19505	54417	-5659
Odisha	56914	47153	-9761	42302	4851
Tamil Nadu	74077	76294	2217	55252	21042
Uttar Pradesh	58982	50417	-8565	39481	10936
Uttarakhand	45634	62115	16481	30396	31719
West Bengal	71840	58956	-12885	54259	4696

*C_2, operational and fixed costs; **A_2+FL, operational costs including family labour; FL, Family labour.

Source: Ministry of Agriculture, Government of India.

6. STRATEGIES FOR ENHANCING PRODUCTIVITY AND PROFITABILITY OF RICE PRODUCTION

Rice research should aim at tapping genetic resources and utilizing them for breeding rice varieties with higher yield potential, better grain and nutritional quality, enhanced input use efficiency and increased tolerance to major biotic and abiotic stresses through conventional and innovative techniques such as marker assisted breeding, development of transgenics, functional genomics, improvement of degree of heterosis, and improvement of photosynthetic efficiency through C_4 mechanism. Identification of potential new donors for abiotic and biotic stresses and unravelling the underlying tolerance mechanisms will also receive due attention. Genomics, proteomics, metabolomics and phenomics tools will be employed for understanding multiple abiotic/biotic stress tolerance mechanism. Redesigning rice plants for improving photosynthesis and plant productivity under multiple abiotic stress environments through transgenics would also be one of the approaches. Research emphasis will be on improving water and nutrient use efficiencies with special emphasis on conservation agriculture, climate-resilient rice and rice-based cropping and farming systems. Rice physiology and biochemistry under high CO_2, ozone and temperature would be unravelled for defining climate resilient rice cultivars. Innovative approaches involving nano-technologies will be taken up for efficient use of fertilizers and pesticides. Use of newer molecules for control of diseases and insect pests, including bio-pesticides, and integrated pest management (IPM) are other areas of focus. Host-parasite/pathogen interaction at molecular level including QTL identification to design suitable control strategy will be the approach for resistance breeding.

Management of rice related knowledge, with due attention on extension services and fostering linkage and collaboration with public, private, national and international organizations are other important areas on which the institute will focus. Strategic planning, priority setting and impact assessment of rice research in India with a global perspective will be taken up to consolidate the gain. Capacity building of scientists, farmers and other stakeholders will be given due importance, so as to be globally competitive and ensure food and nutritional security of the country.

The following options are available for increasing farmers' productivity and income in rice-based systems.

6.1. Improving productivity and quality

6.1.1. Providing quality seed and enhancing seed replacement ratio: Seed is the critical determinant of agricultural production on which depends the performance and efficacy of other inputs. Quality seeds appropriate to different agro-climatic conditions and in sufficient quantity at affordable prices are required to raise productivity. Availability and use of quality seeds is not a onetime affair. Sustained increase in agriculture production and productivity necessarily requires continuous development of new and improved varieties of crops and efficient system of production and supply of seeds to farmers. Despite a huge institutional framework for seed production both in the public and private sector, availability of good quality seeds continues to be a problem for the farmers. As a result, they prefer to rely on farm saved seeds; seed replacement rate continues to remain low for most crops. As is well known, seed replacement rate has a strong positive correlation with the productivity and production of crops.

6.1.2. Promoting high-yielding varieties and hybrids: Due to unavailability of the quality seeds of high yielding varieties and high seed cost of the hybrids, farmers are unable to get those seeds and they prefer to grow their local seed materials. The yield potential of local seeds is low and they are susceptible to many pests and diseases. Although many government programmes are in operation for making HYV and hybrids seeds available to the farmers, yet there is ample scope of promoting high-yielding varieties and hybrid. Further, improved market support will encourage the farmers for adopting high yielding varieties and hybrids.

6.1.3. Growing nutrient rich and aromatic rice: At present no support price for farmers for high nutrient rich rice such as high protein rice CR Dhan 310 and CR Dhan 311 or any other specialty rice (aromatic non-basmati) is available. Therefore, for popularization of the variety in suitable lands and for increasing the higher commercial value of these rice, initiatives from institutional and extension machinery as well as modification in policy decision are collectively required. Higher support price for growers and subsidy for mid-day meal rice are required to give benefits both the poor rice-farmers and our underprivileged children in villages of India.

6.1.4. Increasing cropping intensity in rice-fallow areas: About 30% (11.7 Mha) of the area under rice production during kharif season in India remains fallow in the subsequent rabi due to number of biotic, abiotic and socioeconomic constraints. Despite of ample opportunities rice fallow systems have been bypassed in the research and developments for a numbers of constraints. Major rice fallow area (82%) is concentrated on eastern parts of the country. States with larger area of rice-fallows are Chhattisgarh, Madhya Pradesh, Jharkhand, Bihar, West Bengal and Orissa the remaining 18% area lies in the states like Tamil Nadu, Karnataka and Andhra Pradesh and there exists a large scope for expansion of area under pulse crops. Short duration pulses are ideal candidates for their cultivation in such areas. To exploit these rice fallow areas with pulses, location specific and economically viable technology for better performances of pulses are required to be standardize through proper understanding of the system ecology and constraints study.

6.2. Increasing input use efficiency

6.2.1. Crop planning: Current land use pattern for agriculture in many states are not based on principles of comparative advantage. Crops pattern in various region are inefficient in terms of resource use and unsustainable from natural resource use point of view. This is resulting into serious misallocation of resources, efficiency loss, indiscriminate use of land and water resources, and adversely affecting long term production prospects. Due to lack of proper crop planning, problems of soil and water degradation are aggravating. So, the need is there for proper crop planning in the country so that it is consistent with natural endowment and resources use efficiency.

6.2.2. Promoting water harvesting and micro-irrigation: In many farming areas, readily available water is in short supply. Although the total annual rainfall in an area may be enough to sustain farm needs, it is often distributed very unevenly so that long dry periods are interspersed with periods of intense rainfall. In many cases, a crop is unable to use a high proportion of this water, as much of it is lost through run off or leaching. This may also cause soil erosion and loss of soil nutrients. Hence, there is need to promoting water harvesting and micro-irrigation to achieve per drop more crop. Further adoption of water saving technologies such as direct seeding of rice and system of rice cultivation can save water. For surface-irrigated areas, a properly leveled surface with the required inclination according to the irrigation method is absolutely essential. Traditional farmers' methods for leveling by eyesight, particularly on larger plots, are not accurate enough and lead to extended irrigation times, unnecessary water consumption, and inefficient water use. With laser leveling, the unevenness of the field is reduced resulting in better water application and distribution efficiency, and improved water productivity.

6.2.3. Using soil health card and site-specific nutrient management: The soil health card carries crop wise recommendations of nutrients/fertilizers required for farms, making it possible for farmers to improve productivity by using appropriate inputs. Under current management practices, nutrient use efficiency are low and farmers often fail to apply nitrogen (N), phosphorous (P) and potash (K) in the optimal ratio to meet the need of crops. Site Specific Nutrient Management (SSNM) provides an approach for feeding crops with nutrients as and when needed. The SSNM eliminates wastage of fertilizer by preventing excessive rates of fertilizer and by avoiding fertilizer application when the crop does not require nutrient inputs.

6.2.4. Promoting farm mechanization and solar energy: Intensification of mechanization is one of the most important factor for increasing agricultural activities and production as well. Productivity of farms depends greatly on the availability and judicious use of farm power. Agricultural implements and machines enable farmers to employ the power judiciously for production purposes. Agricultural machines increase productivity of land and labour by meeting timeliness in farm operations. Mechanization has the advantages of proper utilization of resources, reducing drudgery in farm operations, timely execution of various agricultural operations and best use of the available soil moisture. Switching over from animal power to mechanical and electrical power for enhanced power availability for various farm operations, reduce cost of operation, and crop diversification. Promoting use of renewable energy in farm equipment segment such as solar-powered pumps may have the immense potential in farm operations and can create alternate source of revenue for the farmer by selling the additional power.

6.3. Reducing crop loss

6.3.1. Adopting plant protection measures: Plant protection continues to play a significant role in achieving targets of crop production. The major thrust areas of plant protection are promotion of integrated pest management (IPM), ensuring availability of safe and quality pesticides for sustaining crop production from the ravages of pests and diseases, streamlining the quarantine measures for accelerating the introduction of new high yielding crop varities, besides eliminating the chances of entry of exotic pests.

6.3.2. Promoting resistant varieties and e-surveillance: The crop losses due to pests and diseases occur despite increased pesticide use, which highlight the need to develop sustainable approaches for pest control with less reliance on chemical inputs. To address concerns regarding human health, environmental safety and pesticide resistance, plant defensive traits could be exploited more widely in crop protection strategies. Further, it is essential to have a pest monitoring system, which will check the spread of disease pest and the crop loss.

6.3.3. Crop insurance to mitigate risks at affordable cost: Crop insurance provides required coverage to farmers against production loss for crops. It also offers preventive planting and repellant security. A crop insurance plan could prove a life-saver by providing compensation. Therefore, farmers should be advised to take up insurance plans to compensate their income during adverse years.

6.3.4. Weather services and forecasting system: Every year crops are damaged by pest and diseases. Due to lack of proper operational forecasting system for the incidences of pests and diseases, it becomes difficult to adopt plant protection measures at right time. It has been established with fair degree of accuracy that climate/weather play major role in the incidences of pests and diseases. Thus, there is great scope of utilizing meteorological parameters for the advance information of the occurrences of pests and diseases and ultimately scheduling of prophylactic measures can be taken scientifically and judiciously.

6.4. Diversification of rice areas with low productivity

6.4.1. Dairy husbandry for small farmers: Dairying is an important source of subsidiary income to small/marginal farmers and agricultural labourers. The manure from animals provides a good source of organic matter for improving soil fertility and crop yields. The cow dung gas from the dung is used as fuel for domestic purposes as also for running engines for drawing water from well. The surplus fodder and agricultural by-products are gainfully utilized for feeding the animals. A large portion of draught power for farm operations and transportation is supplied by bullocks. Since agriculture is mostly seasonal, there is a possibility of finding employment throughout the year for many persons through dairy farming. Thus, dairy also provides employment throughout the year. The main beneficiaries of dairy programmes are small/marginal farmers and landless labourers.

6.4.2. Promotion of intensive vegetable and fruit production: By following intensive vegetable production, and planting fruit trees, farmers can get maximum profit from the farm. Good planning and attention to the production and marketing practices can help the farmers to attain high level of profit.

6.4.3. Promotion of ancillary activities like poultry, beekeeping and fisheries: Small and marginal holdings account for about three-fourth of the total operational holdings in the country, operating over one-fourth of the total area. Majority of small and marginal farmers cultivate mainly low value, subsistence crops. In the absence of adequate farm and non-farm employment opportunities, they are also forced to live below poverty line. The situation is likely to worsen because of the growing pressure of population on land and the limited scope of increasing additional production through subsistence farming. Hence arises the need for commercialization and diversification of small farms within and outside agriculture and their proper integration with local and global markets. This is intended not only to liberate the small and marginal farmers from the poverty trap, but also to meet the country's growing demands for meat, fish and eggs.

6.4.4. Strengthening organic food program: Organic food is preferred as it battles pests and weeds in a non-toxic manner, involves less input costs for cultivation and preserves the ecological balance while promoting biological diversity and protection of the environment. Generally, organically grown food fetches better price in the market.

6.5. Creation of Infrastructure, market price realization and value addition

6.5.1. Infrastructure: The availability of storage facilities is not sufficient for storage during peak harvesting period. Similarly, the availability of number of regulated markets is not sufficient to cater to the needs of farmers. As a result, the MSP is not effective in eastern states. Government should review the state of procurement operations in the six eastern states, *viz.* Assam, Bihar, Jharkhand, Odisha, Uttar Pradesh and West Bengal, where the support price mechanism is not effective, on priority for taking improvement measures.

6.5.2. Community/co-operative farming with crop-value chain: Institutional reforms are necessary to generate collective actions through co-operative avenues to overcome the development deadlock created due to small and uneconomical holding sizes. This is essential not only to enhance collective bargaining power of the farmers but also to inculcate the spirit of submerging the personal interests in collective welfare. Earlier system of co-operative farming, emerging group approaches such as the self help groups (SHGs) and prospects of creating farmers' corporations need to be explored thoroughly.

6.5.3. Using crop biomass to make products through small industry: Biomass pellets can be sold commercially as the main fuel for industrial boilers and replace coal. Micro-pelletization should be incentivized and its local usage promoted. There are other small-scale industries such as cardboard manufacturing and mattress production that can utilize crop residues. Straw can also be used for substrata for mushroom cultivation (Pathak et al. 2012).

6.5.4. Creation of a national e-market: National farm market allows farmers and traders to sell their produce to buyers anywhere in the country. National farm market addresses the modern day market challenges by creating a unified market through online trading platform, both, at state and national level and promotes uniformity, streamlining of procedures across the integrated markets, removes information asymmetry between buyers and sellers and promotes real time price discovery, based on actual demand and supply, promotes transparency in auction process, and access to a nationwide market for the farmer, with prices commensurate with quality of his produce and online payment and availability of better quality produce and at more reasonable prices to the consumer.

6.5.5. Agribusiness Incubation Centres to promote agri-preneurship: The Agri-Business Incubation (ABI) program aim to promote entrepreneurs in public-private partnership mode that maximizes the success quotient of start-up entrepreneurs by offering them best opportunities with minimum risk. Effective communication, coordination and cooperation among the various nodal centres, umbrella consortium and the industry are inevitable for the successful implementation of the schemes.

7. CONCLUSIONS

In order to meet future rice demand, increasing production and productivity of rice is essential. This has to be done in the face of growing shortage of land, labour and water for rice farming. As the profit margin in rice cultivation has decreased, there is need to not only increase in yield per se but also bring efficiency in input use in rice production. The goal of rice research should be in developing profitable and resilient rainfed rice farming system with a vision of enhancing productivity, profitability and resilience for ever-green rice farming with high-quality research, partnership and leadership in rice science. The thrust areas research should include (1) genetic enhancement for improving productivity, quality and climate resilience of rice; (2) ecosystem management for higher input-efficiency and lower environmental footprints; (3) value-addition with improved quality, co-farming, processing and marketing and (4) accelerating technology delivery, capacity building and policy formulation. The rice-research in the past has made immense contributions in developing and demonstrating technologies for improved rice farming. It, however, needs to be strengthened to address the emerging challenges of low productivity and low income of rice farmers in the face of environmental changes. A multi-disciplinary and participatory research should be adopted to address the emerging challenges and make rice farming more productive, profitable and climate resilient.

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