Increasing Rice Production in Bangladesh

Challenges and Strategies

Edited by
Sadiqul I. Bhuiyan and A. N. M. Rezaul Karim

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Suggested citation:
Bhuiyan SI, Karim ANMR, editors. 1999. Increasing rice production in Bangladesh: Challenges and strategies. Dhaka (Bangladesh): Bangladesh Rice Research Institute and Manila (Philippines): International Rice Research Institute. 167 p.

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ISBN 971-22-0128-7

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Foreword

Rice research in Bangladesh has a long history. The rice improvement program began at Dhaka in 1911 under the British Government. In 1934. the rice experiment station at Habiganj was established as the first outpost involved in the improvement of deepwater and born rice. The Bangladesh Rice Research Institute (BRRI) at Gazipur was established in 1970. Research strategies for advancing knowledge and technologies of rice production have changed over time in response to changing demands, perceived opportunities, and available knowledge and resources.

Rice production technologies developed at BRRI have enabled Bangladesh to meet its population's growing need for rice, which has increased nearly 80% since the country became independent in 1971, without adding new land for rice cultivation. In the next three decades, Bangladesh will have to produce 50-60% more rice to make food available to everybody. The challenge is monumental. Undoubtedly, BRRI's continued success in developing new technologies that will allow the country to produce enough rice without degrading the natural resource base is critical to meeting the challenge. An adequate understanding of production issues and the adoption of appropriate research strategies to minimize constraints to productivity are the *sine qua non* for continued gains in food production. The International Rice Research Institute (IRRI) and BRRI share this concern and this goal-to improve the welt being of present and future generations of-rice- farmers and consumers, particularly those with low incomes.

Bangladesh does not face this challenge alone. Many Asian rice-producing countries have to achieve a similar goal under the sane constraints. Active partnership among the research organizations of these countries can go a long way toward addressing the constraints more effectively, faster, and with less cost. IRRI has therefore actively pursued collaborative research in Asia's rice-producing countries, including Bangladesh, for a long tine.

In February 1997, IRRI and Bangladesh officials and scientists held a strategic dialogue focusing on rice production in the future. As a part of this initiative, the Government of Bangladesh organized a seminar which was attended by the Honorable Prime Minister, the Honorable Minister for Agriculture and Food, and the Secretary of Agriculture. Dr. M.S. Swaminathan, UNESCO professor in ecotechnology, delivered the keynote speech. The director general of IRRI, the executive chairman of the Bangladesh Agricultural Research Council, and three eminent rice scientists from Asia presented papers. The seminar was followed by a symposium on partnership on rice research for sustainable agricultural development in Bangladesh. Following a new model of partnership, these activities resulted in the establishment of a stronger collaborative relationship between BRRI and IRRI. This volume contains the technical papers presented in tat seminar-symposium. Its publication reflects the partnership effort between BRRI and IRRI: staff of both institutes collaborated on the editing, design, and layout and printing was done in Bangladesh.

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Acknowledgments

This book contains papers presented at the February 1997 strategic dialogue on future rice production, which took place at Dhaka between IRRI and Bangladesh officials and scientists, and the papers presented at the symposium on partnership in rice research for sustainable agricultural development in Bangladesh, held in conjunction with the dialogue. We are grateful to the authors for their cooperation during the editing process, especially to those who made substantive revisions to their original papers for this publication.

To highlight the relevance of the papers to the important rice production issues in Bangladesh, we have included an overview of the major issues raised by the authors. In the same chapter, we tried to identify from three case studies presented the common thread underlying the success achieved in accelerating rice production growth in West Bengal (India), Indonesia, and Vietnam.

We thank the staff of the IRRI Communication and Publications Services, specifically Gene Head, Bill Hardy, and Tess Rola, for their editorial and technical assistance. We are grateful to IRRI management for providing the funds for publishing the book.

Increasing rice production in Bangladesh to cope with the rising future demand presents both an opportunity and a major challenge. This book will have served its purpose if it can guide future brainstorming, program planning, and the formulation of implementation schemes to enhance rice research and improve rice production in Bangladesh.

Sadiqul I. Bhuiyan
A.N.M.R. Karim
Editors

Rice production in Bangladesh: an overview

S.I. Bhuiyan and A.N.M.R. Karim

Food security has been and will remain a major concern for Bangladesh. Rice is not only the foremost staple food, it also provides nearly 40% of total national employment (48% of total rural employment), about two-thirds of total calorie supply, and about one-half of the total protein intake of an average person in the country. The rice production system in Bangladesh has undergone immense change during the past three decades. The Green Revolution in rice ushered in a period of substantial growth, which resulted in the near doubling of rice production between 197 1-72 and 1995-96. But per capita rice production has increased only marginally because of continued population growth at a relatively high rate during the period. By 2020, rice production will have to increase by 60% to maintain the current level of per capita rice availability from local production. This is a monumental task because the average land-use intensity in Bangladesh has already reached about 180%, perhaps the highest in the world. Furthermore, agricultural land is increasingly being diverted to other uses such as housing, roads, and industrial development. To be sustainable, future production must be achieved with less land, less labor, and less water, with no harm done to the natural environment. Against this backdrop, the challenge for Bangladesh is indeed enormous and only the application of the most appropriate strategies will lead to success.

The views expressed by the authors in this book are especially important for chaffing the future course of action to increase rice production in Bangladesh. In this chapter, we try to provide an overview of the main issues raised.

Raising the yield potential of rice varieties

Although greatly improved in terms of shorter growth duration, better grain quality, and more tolerance for biotic and abiotic stresses, the yield potential of the recently developed modem rice varieties (MVs) is no higher than the yield of the early “Green Revolution” varieties such as IRS. A major breakthrough is needed to push the yield ceiling of the future MVs to higher levels. Karim emphasized the need for creating a new genetic potential of future varieties through improved plant architecture for higher harvest index. He called for higher efficiency in breeding research using enhanced germplasm, modem breeding tools, and fanner participatory breeding methods.

Nasiruddin suggested that rice breeders should concentrate on redesigning the morphology and physiology of the rice plant into one tat is capable of breaking the yield barrier. He particularly urged rice breeders in Bangladesh to exert concerted efforts in developing high-yielding varieties to suit the specific but diverse ecosystems in which rice is grown. Much work is being done at IRRI to develop a new plant type capable of substantially outyielding the existing MVs. Also in IRRI and in other research centers, the genetic potential of rice is being harnessed by using biotechnological tools. However, practical results are yet to emerge from these activities.

To date, hybrid rice technology is the only proven way of shifting the yield frontier of rice. Hybrid rice has been developed and used with astounding success in China for the past 20 yr. Recently, it has also gained significant ground in India, Vietnam, and the Philippines. For Bangladesh, where internal demand for rice is constantly increasing, hybrid rice technology seems to open a window of opportunity for increasing rice production. Hybrid rice research in the country made a serious start only about 2 yr ago; much work still has to be done before the technology can be effectively exploited in a sustainable manner. Virmani shed some light on this issue. He pointed out 'that, with its better seedling tolerance for low temperature, faster tillering capacity, early vegetative vigor, and a better root system, hybrid rice is ideally suited for the boro season in Bangladesh, He emphasized that successful adopdon of hybrid rice technology in Bangladesh, as in other developing countries, hinges on the degree of commitment of those working on its development and adaptation and on appropriate support for its promotion. Hybrid seed production is a critical component of hybrid rice technology, which must attain a significant level of efficiency for it to be commercially viable. It seems that every country goes through a learning stage to achieve respectable levels of seed yield. It took China nearly 10 yr to develop its present capacity; it now produces, on average, about 2,500 kg of hybrid rice seed ha^{-1}. In Andhra Pradesh, India, the average seed yield increased from 560 kg ha^{-1} in 1992-93 to 1,385 kg ha-' in 1994-95. The latter yield is still below the economically viable yield of 1,500-2,000 kg hr'. These facts show that hybrid rice technology is unlikely to be successful and sustainable with a short-term approach, and that high priority must be given to learning seed production techniques under local environments and to disseminating this know-how to seed producers at large. Further, appropriate incentives must be given to seed producers in the initial years until the technology attains sufficient efficiency.

Should hybrid rice be promoted to all farmers in all areas for all seasons in Bangladesh? Because of the low proportion of its irrigated rice area, Bangladesh has been categorized as generally having "low potential demand" for hybrid rice technology. But researchers have justifiably considered the boro season (in which all rice areas are irrigated and farmers have attained high productivity) as highly suitable for hybrid rice. At least initially, the born season and the highly productive areas, which have successfully exploited the opportunities offered by the MV technology with inbred varieties, should be targeted. Significant economic gains using hybrid rice technology may be achieved in these areas. To raise the productivity of rice in other seasons and areas, it would be a sound decision to promote the use of the best-suited inbred varieties.

Yield stagnation and productivity decline

In Bangladesh, future crop production gains will have to be achieved by increasing yields in intensively cropped areas. Many scientists are concerned about the stagnalion or decline in rice yields in areas subjected to high cropping intensity. But this appears to be more speculative than factual. Although the yield potential of varieties released in the past few years has remained more or less constant (see earlier discussion on raising the yield potential of rice varieties), no hard evidence shows stagnant or declining yields of MVs in farmers' fields. This issue is critical for sustaining production in the future. A systematic field monitoring and assessment scheme is needed to determine actual productivity situations in farmers' fields and to identify factors that affect them. Serious efforts to achieve this objective have been lacking in the past. After analyzing government statistics, Hossain and Shahabuddin concluded that, at the national level, no decline has taken place in rice yields in Bangladesh since the mid-1970s. They also cited a study done by the Bangladesh Institute of Development Studies in 62 villages (at the parcel level) during 1987-94, which showed no difference in yields of MVs grown under single-cropped and double-cropped systems. Similarly, no yield decline occurred during the period. More long-term studies of this nature involving various land types are needed.

Karim identified stagnation or decline in productivity (productivity decline is the reduction in total factor productivity; it is not the same as yield decline) as being caused by soil nutrient mining, organic matter depletion, inefficient irrigation management, poor seed quality and a weak seed replacement program, and increased pest outbreaks. A large body of research literature has been produced over the past several decades on irrigation problems in Bangladesh, but little is known about the other related issues. An in-depth assessment should be made to better understand the nature of these problems and their impact on production, and to identify means to alleviate them.

Accelerated food production

In Bangladesh, the pressure to produce more food will continue until a stable population growth rate stabilizes, a rather formidable task in the next few decades. In spite of recent successes in reducing the growth rate, the population is projected to increase from 120 million in 1995 to 173 million in 2020, when the demand for rice will have increased by more than 60% from the 1995 level.

In the past several decades, the increase in rice production, which was mostly attributed to increased yield, was on a par with population growth. In their assessment of alternative agricultural growth scenarios, Hossain and Shahabuddin concluded that pressure on the agricultural sector would be much higher than today if substantive improvement in the growth of national income were to be achieved. To support the desired 6.5% rate of growth of national income (a 4.6% growth rate was achieved during the 1983-84-1993-94 period), rice production should increase annually at 2.9% until 2010 and at 1.4% during the next decade. The challenge is certainly much tougher in the first decade of the 21st century, considering that actual rice production growth in Bangladesh in the past 10 yr or so was less than 2.0% yr^{1}.

What steps are needed to accelerate rice production growth in Bangladesh? Many valuable suggestions have been put forward in this volume, but, as expected, most are in the form of general recommendations. Thus, no clear priority action can be d& duced. Among the many technological options cited are wider use of MVs, diversifled cropping, greater input-use efficiency, improved crop management, wider irrigation coverage, unproved water and pest management, biofertilizer use, and reduced postharvest losses.

The wide-scale use of new MVs will have to play a crucial role in future rice production growth in Bangladesh. The first MV released in Bangladesh was in 1970. Since then, BRRI has released 36 more MVs, many of which are widely grown by farmers. But, currently, adoption of MVs has reached the desired level only in the boro season; MVs now cover about 90% of the boro area. Adoption of MVs during the aman and aus seasons is still very low––MVs are grown on only 40% of aman areas and on 24% of aus areas. The low adoption during these two seasons can be because (a) MVs are dwarf and hence not suited to areas where floodwater levels are relatively deep, and (b) MVs are not economically attractive for flood-free areas that have no access to irrigation water. Therefore, to accelerate food production, national programs must give highest priority to developing MVs suitable for areas with low-medium submergence and expanding irrigation facilities to rainfed areas.

Not all fanners will achieve the same level of yield, even if they grow the same variety in the same season. Experiment station yields are always higher than average yields obtained by fanners. Therefore, there will always be gaps between yields of more productive farms, average farms, and experiment stations. The issue is how large these gaps are and how they can be reduced. Karim emphasized that, in Bangladesh, the existing gap between the practically achievable yield of most crops and that actually obtained by farmers is large (about 1.6 t ha^{1} for rice), and it must be narrowed through means which farmers can afford. Hoque has suggested closing of the yield gap as the number one priority for Bangladesh. A clear picture of the yield gap in various parts of the country is currently lacking, and it is essential that this problem be addressed to develop practical strategies to minimize the gaps. Dealing only with technical know-how may not always be possible, even when it is available, because farmers' technology assimilation is strongly influenced by the prevailing economic, socio-institutional, and policy environments. These interactive environments must be analyzed to better understand farmers' constraints to technology adoption and to better identify the adoption domain of currently unused and future technologies.

The expansion of irrigation facilities must be given high priority in the future because the currently available MVs express their potential fully in conditions free from water stress. Bhuiyan perceived water scarcity as a major impediment to accelcrated rice production growth in Bangladesh. Although the country is awash with water during the monsoon season, severe water shortages occur in the dry season. Until recently, the groundwater resource was considered almost unlimited and nearly all recent expansions in irrigation have depended on it. But limits to the use of groundwater, in terms of both quantity and quality, set in. Besides, the economically viable options for using surface water for future irrigation expansion are uncertain. Currently, only about 40% of all irrigable areas have facilities for irrigation service. The lack of adequate amounts of good-quality water is becoming the most limiting factor in increasing food grain production in Bangladesh. The colossal problem of arsenic contamination of groundwater must also be resolved to sustain future crop production growth and maintain environmental health in Bangladesh.

Bhuiyan stressed that a large gap exists between actual water needed for growing rice and tat used by farmers. A major part of this gap is explained by farmers' excessive use of water for preparing land for transplanting and controlling weeds in the field. Water use for both purposes can be substantially reduced, without affecting yield. Chemical weed control, which is becoming increasingly popular because of its cost advantage over conventional control methods, can effectively substitute for weed control by overwatering. For this to happen, water must be treated as an economic good. In Bangladesh, where more than 70% of the irrigated area uses water pumped from underground aquifers (the process involves spending cash), the scope for farmer acceptance of water-saving practices is high. There is concern, however, that indiscriminate chemical use, if allowed, may harm the natural ecosystem. On the other front, the use of direct-seeded (wet-or dry-seeded) rice (DSR) is a proven alternative to the popularly practiced transplanted rice production system that demands more water. The DSR system, found promising in preliminary field investigations in Bangladesh, can be attractive to farmers even in relatively water-abundant situations because it requires less labor to establish the crop. Clearly, this option must be seriously pursued to make rice production less water-demanding and more economically attractive to farmers. In general, water productivity in rice culture is improved when early maturing MVs are used. This has a special significance for Bangladesh, inasmuch as all currently used MVs in the boro season---when irrigation demand is highest and the water supply for both irrigation and drinking purposes is under severe stress---require long periods to mature. Early maturing boro varieties will require a greater degree of cold tolerance in the future than current varieties.

Areas affected by tidal fluctuations, including both coastal saline and nonsaline areas, constitute about 800,000 ha of rice land that is very low in productivity. These areas offer a window of opportunity for increasing rice production. Chowdhury emphasized the need for giving high priority to BRRI research programs that aim to develop technologies to fully exploit the opportunity for sustainable rice production growth in these areas. High-yielding, early maturing, and salt-tolerant rice varieties are needed to increase the cropping intensity and yield in these lands, along with techniques for effective management of water and fertilizer.

Chowdhury maintained that BRRI should put more efforts into variety development research. He also stressed that there is much to be gained in the short to medium time frame from the pursuit of conventional breeding techniques for developing new MVs. While this seems logical, it will be expedient to use the outputs of biotechnology and other modem techniques in rice breeding programs to realize the goals faster, particularly for durable resistance against pests and for greater breeding efficiency using marker-aided selection techniques. The challenge is to identify the optimal combination of conventional and modem breeding techniques to meet the various breeding objectives. A critical requirement for pursuing this option is the scientific capacity for assessing the adaptability in local environments of promising outputs from basic and strategic biotechnology research conducted in advanced laboratories, and using them appropriately. This capacity is presently lacking at BRRI.

While more and newer technologies are always in demand, the slow diffusion of existing technologies has been a limitation to accelerated agricultural production growth in Bangladesh. Although improved seed-based technologies are known to be more readily accepted by tanners than knowledge-intensive technologies (e.g., integrated pest management), long time lags exist between the release of an MV and seed availability for farmers'. Clearly, success in accelerating rice production growth will not be achieved on time without the effective dissemination of new technologies to growers. This issue must be adequately addressed through policy interventions and other appropriate tools. Hoque recommended strengthening agricultural research and extension linkages for more effective technology diffusion to tanners. Karim emphasized the need to look into the future beyond the issue of self-sufficiency in agricultural production and advocated for the private sector's leadership in delivering appropriate new technologies to end users. Chowdhury stressed that BRRI should play a more active role in disseminating its products to farmers. For this purpose, BRRI may find it useful to forge collaboration with nongovernment organizations (NGOs) that have extensive rural networks. In addition to yielding a direct benefit in terms of quicker technology diffusion, such involvement would empower BRRI scientists with more direct knowledge of farmers' bottlenecks to improving productivity and thereby enhance BRRI's research relevance.

Case studies

Here, we take a close look at three cases of recently achieved success in accelerating agricultural production growth at the national/state level from Indonesia, India (West Bengal State), and Vietnam. Although each country/state setting was different, some common threads could be identified in the policies and programs pursued.

West Bengal State in India experienced a commendable growth in agriculture over the past 15 yr. It attained a 60% gain in food grain production and a 64% gain in rice production between 1980-81 and 199495. The production gain in rice was due mostly to the substantial increase in rice area in the boro season and the productivity growth of both aus and aman rice. West Bengal also made impressive growth in other crops such as oilseed, potato, and vegetables. Saha credited this success to several well-planned structural and institutional developments. On the structural side, expansion of irrigation facilities through both surface (public sector) and groundwater (private sector) development was the most important one. Institutionally, a comprehensive agricultural support system was established to address the key areas of weakness. For example, a land reform program was implemented that enabled ceiling-surplus land to be distributed to the poor and landless, and established security of tenure for operators of rented land. Local participation in developing plans was ensured through the elected "panchayats." For the effective dissemination of new technologies, a stronger linkage between research and extension was established through well-supervised location-specific adaptive trials of promising' technologies in farmers fields. In addition, innovative programs such as village-level agricultural clinics supported by retired and experienced agricultural specialists and programs to enhance modem agricultural knowledge through village-level cultural activities and competitions were put in place. A strong literacy program through free education and mass literacy campaigns contributed dynamism and momentum to the accelerated production process.

Indonesia achieved remarkable success in using modem technologies and in steadily increasing rice production during the past three decades. It has maintained an average production growth of 2.4% yr^{1} since 1970 and attained self-sufficiency in rice in 1984. The average yield of irrigated rice increased from 2.5 tha^{-1} in 1970 to 3.6 t ha^{-1} in 1980 and then to 4.5 t ha^{-1} in 1995, which has been attributed to the synergistic efforts of government agencies (planning, research, and extension), the private sector, and farmers. The commendable success achieved, despite the physical and administrative barriers that are inherent in a country of more than 13,700 islands, also speaks well of the high degree of commitment on the part of each of these groups of actors, supported by national policies that provided appropriate motivation and incentives for all.

The centerpiece of Indonesia's rice production modernization program was the steady release of suitable high-yielding varieties (MVs are currently used in more than 90% of the country's lowland rice area) and related input management tecimologies through research, and innovative programs for the sustainable adoption of technologies by farmers all over the country. Infrastructure improvements in the form of expanded irrigation facilities and new land development, especially in the outer islands, created new opportunities for using modem rice technologies. To optimize rice productivity throughout the country, a national rice production program, spearheaded by the president of Indonesia himself, was implemented through the central agricultural ministry and its affiliated directorates in cooperation with the provincial governments. It provided a comprehensive service for gaining access to agricultural inputs, credit, and technical supervision at the village level. The emphasis was on the use of research-recommended, location-specific technologies such as MVs, certified seeds, optimum fertilizer application, improved water management, effective weed control, and better handling of harvest and postharvest operations. The national program leaders demonstrated perceptiveness and determination by implementing a year-round floor price for rice that provided production incentives to farmers and protected them from very low Prices and manipulations by middlemen in the market. The results have been very encouraging.

The Indonesian government perceived a large gap between research and extension services; consequently, research results were not readily disseminated to end users. To remedy this weakness, in 1995, the government established in each of the 27 provinces of the country an Assessment Institute for Agricultural Technology (AIAT) under the umbrella research organization called the Agency for Agricultural Research and Development (AARD). Each AIAT has on its staff professionals with research and extension backgrounds who are mandated to jointly plan and conduct adaptive, on-farm testing in large areas of promising technologies generated by research institutions of AARD and to develop technological packages suitable to prevailing agroecological conditions. Although no conclusion can yet be drawn about the merits of this initiative the establishment of AIAT, to say the least, reflects the seriousness of the Indonesian government in eliminating the perceived gap between agricultural research and technology extension groups in order to accelerate agricultural development.

Vietnam achieved spectacular success in increasing rice production in recent years––from 19 million t in 1989 to 28 million tin 1996. This transformed Vietnam into a major rice-exporting economy. It exported more than 3 million t of rice in 1996. Vietnam started from a very different background than did Indonesia and West Bengal (India). It took two successive land reforms of the government,, one in 1988 and the other in 199i, to break away from the bondage of a centrally planned economy and give cultivators the right to use the land on a long-term basis and to operate under a free market economy. Concurrently, the state made the agricultural cooperatives responsible for providing agricultural extension, marketing, and credit services, and for mobilizing fanner savings for local investments. The state's investment priorities in agriculture were for infrastructure (irrigation, wads, electricity, marketing, etc.), credit to households, human capital, and research and extension. To build up its national research capacity, Vietnam established and maintained a strong partnership with various international agricultural research centers, especially with IRRI. About 370 Vietnamese scientists, who have been trained at IRRI through its degree and nondegree training programs, are now engaged in new rice technology generation/ dissemination. About 80% of the popular rice varieties in Vietnam are either varieties developed by IRRI or have IRRI parents.

What common threads bind the three country cases? What lessons can Bangladesh learn from them? Each of the three countries gave high priority to developing infrastructure, mainly irrigation facilities, roads, and markets, making this the backbone of agricultural development. Also, each country put in place a strong technology dissemination program for modernizing the production process. Furthermore, all three benefited from a background of high rural literacy-both Indonesia and Vietnam have, for many years, achieved high levels of literacy among their population; West Bengal State recently implemented a mass literacy program and made it freely available to all. In two cases (West Bengal and Vietnam), an effective land reform program was implemented, enabling cultivators to invest in land improvement and to use land optimally. Clearly, without this empowerment, land operators would have little incentive to produce more from land that they did not own or had no right to cultivate for long.

Of the three case studies, Indonesia stands out for achieving the highest average rice yield (4.5 t ha^{-1}). Among several possibilities, the provision of a guaranteed year-round floor price to farmers must have played a major role in attaining this high level of productivity. Farmers are encouraged to give their best efforts to optimizing yields in an economy where the price is attractive and the market is assured.

From these examples, lessons that would have direct relevance to Bangladesh can be drawn. Bangladesh itself has its own success story---the country's rice production increased at a significant rate, which must form the basis for future programs. The task is indeed enormous and success can be achieved only by formulating comprehensive strategies that cover all fronts from planning to implementation.

Scientific research capacity

The best chance for achieving sustainable food production in Bangladesh rests wit the sound application of science and technology. Adequate scientific and professional human capital is a *sine qua non* for this purpose. Several authors have touched on this issue. Both Karim and Chowdhury stressed the need for creating appropriate environments in the research institutions that will promote creativity and excellence, enhance staff morale as well as accountability, and discourage a brain drain to advanced countries. Karim favored a clear policy framework for human resource development, especially in high-technology areas, to accelerate scientific progress in Bangladesh. Adequate attention should be given by policyrnakers and planners at all levels toward building a sound scientific research capacity in agriculture and making the best use of scientific talents.

Chowdhuiy cited the erosion of BRRI's research capacity in recent years as a major limitation faced by the institute. At least 57 highly trained scientists, all in mid-career and having advanced degrees from advanced institutions, had left BRRI to seek jobs abroad in the past 8-9 yr. Apart from the loss of research capacity, this has adversely affected BRRI's staff morale and working environment. There is hardly any argument about the desirability of keeping trained scientific manpower working for the benefit of the country. No cost seems too high for achieving this objective if we look into the urgent and crucial nature of future food production in Bangladesh. Even though the vacancies created by the exodus of trained scientists might eventually be filled by new recruits, and they would, over time, gain the needed training and experience, it would take a long time to regain the capacity that was lost. Besides, if conditions do not change, there will be no guarantee that newly trained scientists will remain in their jobs. No institution, certainly not BRRI, which has the daunting task of creating technologies to meet the rice requirements of Bangladesh, can afford to lose its scientific strength at or near the scale that took place in the recent past. An indept assessment of the situation must be able to identify appropriate policy support and policy implementation schemes to address the problem satisfactorily.

Maintaining adequate scientific research capacity will require appropriate policy interventions and increased government support for agricultural, research in Bangladesh. Only about 0.25% of the agricultural gross domestic product is now spent on supporting agricultural research; this percentage is one of the lowest among the Asian rice-producing countries. Future actions must be made with full recognition of the fact that because of severe land constraints, sustainability of growth in food production in the 21st century will depend on Bangladesh's ability to constantly develop appropriate new technologies and to disseminate them to farmers.

The role of global partnership

Bangladesh has managed to increase rice production without bringing more land into rice cultivation and to keep pace with the growing population, which increased by 80% since the country was created in 1971. This remarkable success could be credited to the strong leadership in research and extension and to the hard work of millions of rice farmers. But there is no scope for complacency; the race to maintain the balance between food production and population growth is not yet over for Bangladesh.

Rothschild believed that the nature of the challenge and the inherent complexities in the task demanded greater collaboration among players in the global research community in which the complementary strengths of member organizations could be harnessed for solving problems. He emphasized that IRRI, with its unique capacity as a premier research institution with commitment and long experience in collaborative research in rice-growing Asia, has emerged as a major facilitator of global research partnerships. IRRI has been a major partner in the development of Bangladesh's rice research capacity and research outputs during the past several decades. Bangladesh research institutions will benefit from establishing closer collaboration with outside institutions that conduct basic and applied research and with development organizations that holistically address future food production problems. The model of partnership advocated by Rothschild is along the line of strategies and actions that the agricultural research institutions such as BRRI have pursued in the past. In-depth deliberations and analyses should be made, however, to determine the specific nature of the partnerships that will effectively and adequately support Bangladesh's needs, and to identify foreign institutions that have the appropriate capacity and resources. The importance of such strategic actions can hardly be overemphasized.

Harnessing science and technology to benefit the masses

Recent progress m science and technology has empowered human beings to triumph over negative forces in delivering adequate food for all. A major concern is how to apply new knowledge to solve the problems of hunger and nutrition, while protecting the physical environment and establishing social equity. Swaminathan dealt with these issues and advocated a solution using a holistic scientific approach. He emphasized the virtues of ecotechnologies-technologies rooted in the principles of ecology, economics, and equity-and advocated their use for solving the dilemma of how to produce more food without associated environmental costs from soil degradation, aquifer depletion, genetic erosion, and pesticide pollution; and how to create more income opportunities for the rural poor. He believed that an "ever-green revolution," oriented toward integrated fanning systems based on the ecotechnology concept, would find common acceptance for sustainable food and nutrition security in the near future.

The ecotechnology concept and methodologies advanced by Swaminathan have high relevance for Bangladesh, where much indigenous agricultural knowledge, many skills, and muck art that developed in farmer communities through hundreds of years of practical experience have yet to be fully assessed. These have not found proper recognition or use in modem times because of the pursuit of short-range goals and because the consequences of exploiting natural resources beyond their rejuvenation capacity have already been harmful in many instances. The advocated methodologies put people at the center of sustainable development, mixing indigenous wisdom with scientific knowledge and using local leadership to implement actions for the collective good. Government planning and rural development agencies, NGOs, and social development organizations stand to benefit from the concepts espoused by Swandnathan.

Research for sustainable agricultural development in South Asia: opportunities and challenges

M.S. Swaminathan

Since the advent of the industrial and technological revolutions, economic indicators have been used as the principal criteria for measuring sustainability. Population expansion, rapid industrialization, commercialization of agriculture, and quantum jumps in economic activity have been some of the results of the development paradigm adopted after the Second World War. Technological progress in areas such as space, information technologies, biotechnology, energy, and new materials has been impressive. At the same time, understanding of the ecological and social costs of such progress is growing. The UN conferences on human environment held at Stockholm in 1972 and on the environment and development held in Rio de Janeiro in 1992 helped to articulate the serious environmental repercussions of contemporary development pathways. The UN conference on social development held in Copenhagen in March 1995 warned that development that is not socially equitable will lead to social disintegration and conflicts. Jobless economic growth and feminization of poverty are the other consequences of the current pattern of development. Thus, the concept of sustainable development now has to be viewed in terms of ecology, social and gender equity, employment, and economics. How to achieve such a synthesis in developmental thinking, planning, and implementation, thereby enabling humankind to take to the pathway of green productivity, is the task facing every society. In its report titled "Changing Course," the International Business Council pointed out that where there is a will, there is a way (Schmidheiny 1992). If technology has so far been a major cause of ecological damage, it can also lead us to find methods to ensure that development is sustainable. In a recent study, Repetto et al (1996) of the World Resources Institute (USA) have shown That environmental protection need not reduce productivity growth but can stimulate growth without accompanying ecological damage.

Ecotechnology and sustainable livelihoods

As we approach a new century, we can look back and prepare a balance sheet of our achievements and failures (Table 1). Spectacular progress in science and technology ranks first among our major accomplishments. Recent advances in biotechnology and genetic engineering, space technology, information technology, and new materials have opened up uncommon opportunities for a world where every individual can lead a healthy and productive life. The spread of democratic systems of governance, the breakdown of apartheid, and the advent of the information age have created the

Table 1. Contemporary development, a 50+yr balance sheet (1945-95).

Achievements	Concerns
Impressive progress in science and technology	Scientific dimensions of sustainable development
Information age: global village	Era of unfulfilled expectations
Unprecendented economic growth	Damage to life support systems and potential adverse changes in climate and sea level
Uncommon opportunities for food, health, literacy, and jobs for all	Populations growth, jobless economic growth, and social disruption; gross economic and gender inequity
Peace dividend: from defense to development	Growing violence in the human heart: from AIDS to ethnic strife
End of apartheid: spread of democratic tradition and renewed faith in UN and other multilateral institutions	Debt burden and emerging technological and economic gaps between rich and poor

sociopolitical substrate essential for integrating the principles of intra- and intergenerational ‘equity in public policy. The power of a right blend of technology and public policy is strikingly evident from the progress made in recent decades to keep the growth rate in food production above the rate of population growth, thereby ensuring that the Malthusian prediction of population overtaking our ability to produce enough food does not come true.

Although the positive achievements are many and make us proud of the power of the human intellect, we will be entering the new millennium with some of the greatest social and scientific challenges humankind has ever faced. Several of these challenges have been articulated clearly in the Human Development Reports of the United Nations Development Programme (UNDP) in recent years.

Environmental degradation and increasing economic and gender inequality are among the most serious problems we face today. The rich-poor divide is increasing at an alarming rate. The development pattern adopted by rich societies is leading to jobless economic growth, pollution, and potential changes in climate. Unsustainable lifestyles on the tart of the rich billion and unacceptable poverty on the part of another billion coexist. The absence of an educational and healthy environment, which helps all children achieve their innate genetic potential for physical and mental development, leads to the spread of poverty in capability. UNDP has proposed indicators for measuring both human development and human capability.

The U.S. National Academy of Sciences, the Royal Society of London, the Indian National Science Academy, and 55 other scientific bodies in a statement made in 1993 painted out that “stress on the environment is the product of four interacting factors: population growth, consumption habits, technology, and social organization.” Concurrent attention is needed on all four of these factors to promote sustainable development and sustainable societies. The report “Sustainable America” indicates what an affluent society should do. In poor nations, the social sustainability of the development process is as important as ecological and economic sustainability. Also, if the current pace of damage to the ecological foundations essential for sustainable advances in biological productivity––namely, land, water, flora, fauna, forests, oceans, and the atmosphere––continues, sustainable food and nutrition security cannot be achieved. Therefore, as we approach the new millennium, we need a broader concept of sustainability that encompasses environmental, economic, and social parameters. Among social factors, gross economic and gender inequity need priority attention. If such a shift in developmental thinking and pathways does not occur, 20th century successes in abolishing apartheid, conquering space. and splicing genes will be overshadowed by the spread of technological and economic separateness. If this occurs, social disintegration and ecological destruction will be the result.

Ecotechnology: the emerging solution

Technologies rooted in the principles of ecology, economics, and equity are now referred to as ecotechnologies. UNESCO and the Cousteau Foundation established by oceanographer Jacques Cousteau are promoting ecotechnology networks in different parts of the world. The M.S. Swaminathan Research Foundation (MSSRF) at Madras is the coordinating center for the Asian ecotechnology network. A major purpose of this network is the creation of *ecojobs*, which are economically viable, environmentally benign, and socially equitable. A multimedia database on opportunities for ecojobs is being developed because the dissemination of information on ecojobs is essential for creating opportunities for sustainable livelihoods in rural and urban areas.

The most serious manifestation of poverty is hunger. It is now recognized that endemic hunger is largely the result of inadequate livelihood opportunities, which in turn leads to inadequate purchasing power. Hidden hunger results from both micronutrient deficiencies and poor environmental hygiene, which impair the biological absorption and retention of food.

A Science Academies Summit on uncommon opportunities for a food-secure world held at MSSRIF in July 1996 stressed that national policies for sustainable food and nutrition security should ensure

- that every individual has *physical, economic, social, and environmental access* to a balanced diet that includes the necessary macro- and micronutrients, safe drinking water, sanitation, environmental hygiene. primary health care, and education so as to lead a healthy and productive life.
- that food originates from efficient and *environmentally benign production technologies* that conserve and enhance the natural resource base of crops, animal husbandry, forestry, and inland and marine fisheries.

During the next three decades, the world population is expected to increase by another 2.5 billion people. Food requirements will grow because of increases in both population and per capita purchasing power. World grain production has grown from 631 million tin 1950 to nearly 1900 million tin 1995. The environmental cost of such a phenomenal growth includes soil degradation, aquifer depletion, genetic erosion, and pesticide pollution. This is why we have to produce more in the coming decades, and produce it differently. To achieve such a shift, the following ground rules must be followed in technology development and dissemination as well as in public policy.

First, production advances must be based on linking the ecological security of an area with the livelihood security of the people in a symbiotic manner.

Second, steps must be taken to create widespread awareness of the human and animal population-supporting capacity of different ecosystems. Sustainable management systems of soil, water, biodiversity, and forests should be internalized in rural societies.

Third, since the poor remain poor because they have no productive assets and there is no value for their time, creating assets and adding value to time should receive high priority in poverty alleviation programs. Women belonging to the economically underprivileged sections of society, in particular, are often overworked and underpaid. They need a reduction in the number of work hours and an increase in the economic value of each hour of work. This calls for massive efforts in information and skill empowerment of the poor, particularly women. Emerging technologies are largely know1edge-intensive and *hence the transfer of knowledge and market-driven skills can become the most powerful instrument for fighting poverty and deprivation.* Modem information technology affords opportunities for reaching the unreached and thereby achieving a learning revolution within a short span of time.

Fourth, equal attention needs to be focused on the problems of' the rural and urban poor. The lack of livelihood opportunities in rural areas leads to the proliferation of urban slums. Damage to common property resources in villages results in the growth of environmental refugees. Because in many developing countries, agriculture, including crop and animal husbandry, forestry, fisheries, and agroprocessing, provides most of the jobs and income in rural areas, the triple challenge of producing more food, income, and jobs from diminishing per capita land, water, and nonrenewable energy sources can be met only through agricultural intensification, diversification, and value addition. Integrated intensive fanning systems, which are ecologically sustainable, are needed for this purpose.

Fifth, microcredit and microenterprises should be linked in a symbiotic manner, as is successfully done in Bangladesh through the Grameen Bank and other innovative initiatives.

Finally, an evergreen revolution of the kind described above can be imparted with a self-propelling and self-replicating momentum only if it is based on the self-mobilization of the people. *In all externally funded and introduced development projects, there should be a built-in withdrawal strategy, so that the pm gram does not collapse when the external inputs are withdrawn.*

The responses being developed and field-tested by MSSRF to identify implementable approaches at the micro and policy levels to meet the challenges outlined earlier are briefly described below.

Linking the ecological security of an area with the livelihood security of the local community

The community biodiversity program of MS SRI illustrates how such mutually beneficial linkages can be fostered in biodiversity-rich areas. It is a sad fact that the tribal and rural families who have conserved and enhanced biodiversity remain poor, while those who are using the products of their efforts become rich. When the conservers have no social or economic stake in conservation, denudation of natural ecosystems becomes more rapid. MSSRF has adopted a three-pronged strategy for creating an economic stake in biodiversity conservation.

First, a transparent and implementable methodology has been developed for incorporating in *sui generis* systems of plant variety protection procedures for recognizing and rewarding informal innovations in genetic resources conservation and enhancement.

Second, a symbiotic social contract between commercial companies and tribal and rural families is being fostered to promote the cultivation by local communities of genetic material of interest to the companies on the basis of buyback arrangements. Such a linkage will prevent the primary material from being exploited unsustainably.

Third, local women and men are trained in compiling biodiversity inventories and in biomonitoring, so that they themselves become custodians of their intellectual property. Such trained women and men constitute an agrobiodiversity conservation corps and they will be able to help their respective communities to deal with issues such as "prior informed consent" in the use of genetic resources.

For assisting the community biodiversity movement, MSSRF has established a Technical Resource Centre for the implementation of the equity provisions of the Convention on Biological Diversity. This is the first Technical Resource Centre of its kind in the world. Its six major components are:

- *Documenting local people 's contribution to agmbiodiversiry.* Chronicling the contributions of tribal and rural families to the conservation and enhancement of agrobiodiversity through primary data collection in the states of Tamil Nadu, Kerala, Andhra Pradesh, and Orissa as well as in the Lakshadweep and Great Nicobar group of islands.
- *Organizing agrobiodiversity conservation.* Corps of young tribal and rural women and men, who have a social stake in living in their respective villages and who, with appropriate training, can undertake tasks such as compiling local biodiversity inventories, revitalizing the in situ genetic conservation traditions of their respective communities, monitoring ecosystem health with the help of appropriate big-indicators, and restoring degraded sacred groves. The members of the corps will be able to assist their respective communities in dealing with the "prior informed consent" provision of the Convention on Biological Diversity in the use of genetic resources.
- *Developing multimedia databases.* Documenting the contributions of tribal and rural families in the conservation and improvement of agrobiodiversity to enable them to secure their entitlements from national and global community gene funds.

- *Maintaining a community gene bank and herbarium.* A community gene bank with facilities for medium-tam storage has been established to conserve fanner-preserved and -developed seeds from the tribal areas of south India. The material will be catalogued and linked to the Technical Resource Centre database. The herbarium serves as a reference center for the identification of landraces, traditional cultivars, and medicinal plants conserved by tribal and rural families.
- *Revitalizing genetic conservation.* Social recognition of the contributions and traditions of tribal and rural families and the creation of an economic stake for them in conservation are needed. For this purpose, replicable models of private-sector engagement in contract cultivation by tribal and rural families of plants of commercial value are being developed.
- *Forming a legal advice cell.* This cell, will make available to tribal and rural families appropriate legal advice in matters relating to intellectual property rights and plant variety protection.

The population-supporting capacity of ecosystems: local-level sociodemographic charter

To help internalize and understand the vital need to restrict population growth within the supporting' capacity of land, water, forests, and other components of the ecosystem, training modules have been developed to enable the women and men members of village-level democratic institutions to prepare sociodemographic charters for their respective villages. A gender code is an important component of the charter Such sociodemographic charters will help local communities to view population issues in the context of social development and to ensure that children are born for happiness and not just for existence.

Information and skill empowerment

For this purpose, the concept of "information villages" has been developed. Trained rural women and men will operate "information shops" where generic information on the meteorological, management, and marketing factors relevant to rural livelihoods will be converted into location-specific information. Trained farm women and men themselves become trainers. The computerized extension system adopted in the information shops also helps to sensitize local families on their entitlements from the government and other programs. Information technologies provide considerable opportunities for value-added jobs in rural areas. While new technologies are important, folk media are often even more effective in reaching the unreached. Hence, folk plays and folk arts and theater are fully mobilized for achieving information empowerment. To ensure the success of information empowerment programs, the information disseminated should be demand-driven and should be locally targeted.

Agricultural Intensification, diversification, and value added

This is achieved through participatory research with farm families. Ecotechnologies such as integtated pest management (IPM) and integrated nutrient supply (INS) are used. Ecotechnology development involves blending the best in frontier technologies with traditional wisdom and practices. Modem science and the ecological prudence of the past can thus be combined.

Ecotechnologies are also practiced in aquaculture. Integrated agriculture and aquaculture techniques enhance both farm income and the nutrition security of the household. Whole villages are enabled to adopt such integrated intensive fanning systems (IIFS). Because this approach is essential for meeting the triple goals of more food, income, and jobs from available resources, the seven basic principles guiding the IIFS movement are described below.

- *Soil health care.* This is fundamental to sustainable intensification. IIFS fosters the inclusion of stem-nodulating legumes such as Sesbania rostrata, incorporation ofAzolla, blue-green algae, and other sources of symbiotic and nonsymbiotic nitrogen fixation, and promotion of cereal-legume rotation in the farming system. In addition, vermiculture composting and organic recycling constitute an essential component of IIFS. IIFS farmers are trained to maintain a soil health card to monitor the impact of farming systems on the physical, chemical, and microbiological components of soil fertility.
- *Water harvesting and management.* IIFS farm families include in their agronomic practices measures to harvest and conserve rainwater so that it can be used in conjunction with other sources of water. Where water is the major constraint, technologies that can help to optimize income and jobs from every liter of water are chosen and adopted. Maximum emphasis is placed on on-farm water use efficiency and on the use of techniques such as drip irrigation, which help to optimize the benefits from the available water.
- *Crop and pest management.* The INS and IPM systems form important components of IIFS. The precise composition of these systems will depend on the components of a farming system as well as on the agroecological and soil conditions of the area. Computer-aided extension systems will provide farm families wit timely and precise information on all aspects of land, water, pest, and postharvest management.
- *Energy management.* Energy is an important and essential input. Besides the energy-efficient systems of land, water, and pest management described earlier, every effort will be made to harness biogas, biomass, solar, and wind energies to the maximum. Solar and wind energy will be used in hybrid combinations with biogas for farm activities such as pumping water and drying grains and other agricultural produce.
- *Postharvest management.* IIFS farms will not only adopt the best available threshing, storage, and processing measures but will also try to produce value-added products from every part of the plant or animal. Postharvest technology becomes even more important in the case of perishable commodities such as fruits, vegetables, milk, meat, eggs, fish, and other animal products and processed food. A mismatch between production and postharvest technologies adversely affects both producers and consumers. Growing urbanization leads to a diversification of food

habits. Therefore, demand will increase for animal products such as milk, cheese, eggs, and processed food. Agroprocessing industries can be promoted based on an assessment of consumer demand. Such food processing industries should be promoted in villages to increase employment opportunities for rural youth. In addition, they can help to mitigate micronutrient deficiencies in the diet.

Investment in sanitary and phytosanitary measures is important for providing good-quality food for both domestic consumers and export. To help spread IIFS, the government should make a major investment in storage, roads, transportation, and sanitary and phytosanitary measures.

- *Choice of the crop and animal components in fanning systems.* In IIFS, it is important to carefully consider the composition of the fanning system. Soil conditions, water availability, agroclimatic features, home needs, and, above all, marketing opportunities will determine the choice of crops, farm animals, and aquaculture' systems. Small and large ruminants have an advantage among farm animals because they can live largely on crop biomass. Backyard poultry farming can help provide supplementary income and nutrition.
- *Information, skill, organization, management, and marketing empowerment.* IIFS is based on the principle of precision farming. Hence, to succeed, IIFS needs a meaningful) and effective information and skill empowerment system. Decentralized production systems have to be supported by a few key centralized services, such as the supply of credit, seeds, biopesticides, and animal disease diagnostics. An information shop can be set up by trained local youth to give farm families timely information on their entitlements as well as on meteorological, management, and marketing factors. Organization and management are key elements and, depending on the area and farming system, steps have to be taken to provide small producers advantages of scale in processing and marketing.

IIFS is best developed through participatory research between scientists and farm families. This will help ensure economic viability, environmental sustainability, and social and gender equity in IIFS villages. The starting point is to learn from families who have already developed successful IIFS procedures.

It should be emphasized that IIFS will succeed only if it is a human-centered rather than a mere technology-driven program. The essence of IIFS is the symbiotic partnership between fanning families and their natural resource endowments of land, water, forests, flora, fauna, and sunlight. Without appropriate public policy support in areas such as land reform, security of tenure, credit supply, rural infrastructure, input and output pricing, and marketing, small farm families will find it difficult to adopt IIFS.

- *Increasing farm and nonfarm employment.* The biovillage program addresses three key areas-preventing resource degradation, improving crop and animal productivity, and alleviating poverty. The existing biovillage program in the Pondicheny area of India places equal emphasis on off-farm livelihood opportunities and on-farm jobs.

The program regards the poor as producers and innovators and helps build on their assets by adding value to time and labor. The basic approach is on asset building and sustainable human development leading to the growth of entrepreneurship.

The program is designed to be pro-nature, pro-poor, and pro-women. The biovillage model of sustainable development revolves around the welfare of the economically and socially underprivileged and emphasizes the livelihood security of the poor.

It is thus a human-centered pattern of development. Because of the market-driven nature of the enterprises, the economic viability of the biovillage approach is assured. Production and postharvest technologies and farm and nonfarm occupations are brought together so that both producers and consumers benefit.

Biovillages around biosphere reserves would help provide alternative sources of daily needs for food, fuel, fodder, and other commodities of families living near such biodiversity-rich areas. Also, biovillages near urban areas help to develop a mutually beneficial partnership between rural producers and urban consumers. Producing processed and semiprocessed food products needed in urban areas in villages near towns and cities minimizes the need for the rural poor to migrate to urban centers for livelihood opportunities. Also, food processing can be used to provide the needed micronutrients by including mullets and grain legumes in food.

Toward an evergreen revolution in agriculture

The term Green Revolution coined by Dr. William Gaud of the USA in 1968 has come to be associated not only with higher production through enhanced productivity but also with several negative ecological and social consequences. There is also frequent reference to fatigue of the Green Revolution because of stagnation in yield levels and a larger requirement of nutrients to produce the same yield as in the early 1970s. Experts such as Lester Brown of the Worldwatch Institute have been warning about an impending global food crisis because of

- increasing population,
- increasing purchasing power leading to the consumption of more animal products,
- increasing damage to the ecological foundations of agriculture,
- declining per capita availability of land and water, and
- the absence of technologies that can further enhance the yield potential of major food crops.

I believe we are now in a position to launch an evergreen revolution that can help to increase yield income, and livelihood per unit of land and water; if we bring about a shift in our agricultural research and development strategies. The Green Revolution was triggered by the genetic manipulation of yield in crops such as rice, wheat, and maize. *The evergreen revolution will be triggered by farming systems that can* *help produce more from available land, water; and labor resources without either ecological or social harm.* Thus, progress can be achieved if we shift from a commodity-centered approach to an entire cropping or fanning systems approach to technology development and dissemination. This does not mean that we should decelerate our efforts in crop improvement research. But such research should be tailored to enhance the performance and productivity of the entire production system.

Let us take, for example, the prospects for "super rice," which is capable of yielding more than 10 t ha^{-1}. Such a rice plant will need a minimum of 200 kg nitrogen ha^{-1}, together with other major nutrients and micronutrients. The addition of such nutrients solely through mineral fertilizers will lead to serious environmental problems; hence, the introduction of legumes in the rotation becomes important.

Scientists now have unique opportunities for designing fanning systems for achieving the triple goals of more food, more income, and more livelihood per hectare of land if ecotechnologies resulting from a blend of traditional knowledge with frontier technologies such as biotechnology, informatics (including geographic information systems mapping), space technology, renewable energy technologies (solar, wind, biomass, and biogas), and management and marketing technologies are harnessed.

Industrial countries are responsible for global environmental problems such as potential changes in temperature, precipitation, and sea level, and the incidence of ultraviolet-B radiation. Although further agricultural intensification in industrialized countries will be ecologically disastrous, the failure to achieve agricultural intensification and diversification in developing countries where farming provides most jobs will be socially disastrous. This is because agriculture, including crop and animal husbandry, forestry and agroforestry, fisheries, and agroindustries, provides livelihood to more than 70% of our population. The smaller the farm, the greater the need for a higher marketable surplus for increasing income. Eleven million new livelihoods will have to be created every year in India and these have to come largely from the farm and rural industry sectors. Importing food and other agricultural commodities will thus have the same impact as importing unemployment. What we need now is an environmentally sustainable and socially equitable green revolution or an evergreen revolution.

Those who advocate going back to the old methods of farming ignore the fact that just a century ago, when the population of undivided India was 281 million, famines claimed 30 million lives between 1870 and 1900. The famine eradication strategy comprising the following is perhaps the most important achievement of independent India:

- enhanced production and productivity,
- better distribution through the public distribution system,
- adequate grain reserves,
- purchasing power enhancement through various employment generation and guarantee schemes, and
- special intervention programs for children, pregnant and nursing mothers, and old and infirm persons.

While famines have been prevented, widespread undernutrition prevails among the economically underprivileged. Because nonfood factors such as health care, environmental hygiene, and literacy play an important role in promoting sustainable food security at the level of the individual, we should redefine security as follows.

Steps for achieving sustainable food security

First, sustained physical access to food will involve a transition from chemical- and machinery-intensive technologies to ecological fanning technologies.

Second, the emphasis on economic access underlines the need for promoting sustainable livelihoods through multiple income-earning opportunities.

Third, environmental access involves, on the one hand, attention to soil health care, water-harvesting management, and conservation of forests and biodiversity and, on the other, attention to sanitation, environmental hygiene, primary health care, and primary education.

If the political vision to implement this mission exists, population stabilization can be more readily achieved. The prediction of Marquis de Condorcet (1743-94) that population will stabilize itself if children are born for happiness and not just for existence will then come true.

The emphasis on the individual is important because the household is not often a homogeneous unit. Women and girls tend to suffer wore from undernutrition than men and boys. The UNDP's 1995 human development report contains distressing data on the growing feminization of poverty. To put food security into operation, we should initiate a hunger-free area program (HFAP) consisting of the following components.

1. Ensure the sustainable availability of food by maintaining growth in food production over population growth through the development and dissemination of ecotechnologies, supported by appropriate packages of services and public policies. Ecotechnology involves the blending of the ecological prudence and technologies of the past with the best in frontier technologies, particularly biotechnology, information technology, space technology, renewable energy technology, and management technology. Without ecotechnological empowerment, farm men and women will not be able to produce more food and other agricultural commodities on an environmentally sustainable basis from less land, water, and energy resources.
2. Sustain the productivity of the natural resource base by conserving and improving the ecological foundations essential for continuous advances in crop and animal productivity.
3. Ensure adequate household income through promotional social security. Access to assets, employment, and organizational and marketing empowerment/agricultural programs should concurrently aim at more food, more jobs, and more income. Integrated attention to farm and nonfarm employment and adding value to primary agricultural commodities will be necessary to enhance income and rural livelihood security.

4. Provide vulnerable groups entitlement to food via employment guarantee and food-for-nutriton programs.
5. Introduce a national food and livelihood security act with the concurrence of the national development council for integrated attention to
   - conserving land, water, forests, and biodiversity, and protecting the atmosphere;
   - enhancing productivity through ecotechnologies;
   - improving distribution to eliminate endemic hunger;
   - maintaining adequate food security reserves;
   - strengthening the techno-infrastructure for better postharvest technology and expanding the coverage of sanitary and phytosanitary measures; and
   - using efficient research, education, extension, and marketing systems to take full advantage of emerging opportunities in international trade and to ensure that research and extension designed to promote public welfare receive adequate support.

Potential future challenges: climate change

The second assessment of climate change and its impact made by the Intergovernmental Panel on Climate Change (IPCC) in 1995 confirmed the potential for climate change because of the injection of various greenhouse gases such as carbon dioxide ($C0_2$), methane, nitrous oxide, and others. IPCC projects an increase in global mean surface temperature of 2 °C, which is Lower than that projected in 1990, or a change of 1 °C by the year 2100. Changes at the regional level, however, continue to remain difficult and uncertain for projection. A mean change of 2 °C, the "best estimate," could mean <0 to >4 °C in different regions.

Studies in India showed that a change of 1.7 °C in temperature in a large grid caused a change from -0.4 to 4.5 °C from coastal to interior areas. Recent studies in the United States also showed that an increase of 0.4 °C resulted from changes ranging from 0 to 2 °C or more.

These changes would affect major crops, particularly grain crops. An increase of 1-2 °C combined with reduced radiation causes enhanced sterility of spikelets in rice. Fortunately, there is already evidence of genetic variability in rice tolerance for both higher temperature and reduced radiation. Crops such as pigeonpea promote vegetative growth with enhanced humidity and reduced radiation. We do not know the response of most vegetable and fruit crops.

It is believed that enhanced CO_2 concentration benefits crops through improved photosynthesis rate. At double the CO_2 equilibrium, the actual concentration of CO_2 could be around only 450 ppm in the atmosphere. Therefore, we should be cautious in extrapolating data from a CO_2 concentration of 600 ppm or more. We need more studies on the interaction of CO_2. temperature, and radiation to project the impact of climate change on any individual crop or agricultural system.

Projected changes in climate, particularly temperature, humidity, and radiation, could have a profound effect on diseases, pests, and microorganisms. Incorporating disease and pest resistance at higher levels of temperature should be an important objective in crop improvement programs. A change of 1 °C affects the virulence of some races of rust that infect wheat. A small change in temperature can affect the entire life cycle of insects.

The impact of change in precipitation and temperature on crops has received much less attention than it deserves. Records show that the rainfall pattern has changed during the past 75-80 yr Some areas have either an overall decrease in rainfall or. in the total number of rainy days while maintaining the same total rainfall. This causes increased intensity of rain, resulting in greater soil erosion and runoff. Thus, new crops and varieties will have to adapt to greater soil and water stress. It is here where traditional agricultural systems such as mixed cropping may prove advantageous. Consequently, crop improvement for intercropping/mixed cropping should receive a greater emphasis.

The final milestone: a hunger-free world

Dr. M. Karunanidhi, the chief minister of Tamil Nadu, India, in his budget speech of July 1996, made the following announcement:

> "Feed the people
> Who are hungry,
> Educate the people
> To uplift the world."

To fulfill this dream of Mahakavi Bharatiyar, the Tamil Nadu government will launch a new HFAP to eradicate poverty-induced hunger. Several schemes are already under implementation to alleviate poverty and to cater to the nutrition requirements of different groups of the population. Gaps will be identified, which can then be specifically targeted under the HFAP. A detailed strategy to implement this program will be made in association with the author

Studies at MSSRF have shown that by adding a horizontal dimension to numerous vertically structured programs and by promoting a coalition of all concerned wit ending hunger and deprivation, it is now possible to provide opportunities for a healthy and productive life for all.

Designing a hunger-free area program

The problem of food and nutrition security at the individual level has to be viewed in three dimensions. First, inadequate purchasing power leads to calorie-protein undernutrition. Second, the lack of the needed quantity and variety of micronutrients and vitamins in the diet leads to several nutritional disorders, including blindness caused by vitamin A deficiency. This problem is referred to as "hidden hunger," and it affects more than 2 billion people in the world today. Third, the lack of environmental hygene and sanitation leads to a low biological absorption and retention of food because of intestinal injections and diarrhea. Thus, both food and nonfood factors are important in determining a person's nutrition security. Concurrent action at all these levels is necessary in a HEAP. The various steps involved in this process are described below:

1. Identify the basic reasons underlying chronic undernutrition and malnutrition.
2. Collate information on available programs and opportunities for the sustainable end of hunger.
3. Articulate' the steps needed to provide the "missing elements" in achieving the end of hunger.
4. Mobilize local-level community action and commitment to achieve the end of endemic hunger by the end of the Ninth Five-Year Plan and enlist mass media support for this purpose.
5. Assess the extent of financial resources required, technical resources for. technological empowerment necessary, and managerial and organizational resources needed.
6. Foster the' organization of a grass-roots-level coalition for ending hunger in each HEAP area with representatives from
   - those elected by the people,
   - government agencies,
   - civil society—nongovernment organizations. voluntary agencies, service organizations like Rotary clubs, Lions clubs, etc.,
   - academia—–research and training institutions and universities,
   - the corporate sector,
   - financial institutions, and
   - mass media.

Global action for sustainable food security

The commitment of the international community to ensuring food and nutrition security for everyone has been reiterated at several international conferences held during this decade:

1990 World Summit for Children, New York;
1992 International Conference on Nutrition, Rome;
1992 United Nations Conference on Environment and Development, Rio de Janeiro;
1993 World Conference on Human Rights, Vienna;
1994 International Conference on Population and Development, Cairo;
1995 United Nations Conference on Social Development, Copenhagen;
1996 World Food Summit, Rome.

Despite such high-level political reaffirmation of the need to speedily. achieve the goal of "food for all," more than 800 million people now suffer from hunger and malnutrition. Hidden hunger is widespread. Endemic hunger is now due more to the lack of adequate purchasing power at the household level than to the lack of food availability in the market. Both poverty and nonfood factors such as environmental hygiene, sanitation, and the lack of safe drinking water are becoming major contributors to food insecurity at the individual and community levels. Most of the food-insecure live in South and Southeast Asia.

Concern is also increasing about the earth's capacity to produce enough food for the growing population. The increase in population, now mostly confined to developing countries, coupled with enhanced purchasing power leading to greater capability to buy food and increasing urbanization, will lead to greater demand for food as well as more diversified food products in the coming millennium. Thus, on the one hand, there will be a need for intensification and diversification of agriculture, particularly in developing countries. On the other hand, the ecological foundations essential for sustainable advances in crop and animal productivity are becoming eroded. This situation has led to warnings by experts on the earth's capacity to produce enough food to meet growing needs. Lester Brown concluded: "Constraints imposed by the earth's natural systems, the environmental degradation of land and water resources, and the diminishing backlog of yield-raising agricultural technologies are slowing the growth in world food production, raising questions about the earth's population carrying capacity. The earth's capacity to produce enough food to satisfy expanding demand is now emerging as the overriding environmental issue as the world approaches the 21st century."

The year 1998 will mark the bicentenary of Malthus' essay on population. The onward march of scientific technology, supported by appropriate public policies, has so far helped humankind to keep Malthusian forebodings on the population-food supply equation at bay. It is, however, becoming increasingly clear that without concerted national and global action to arrest environmental degradation, promote economic and gender equity, and check population growth, the Malthusian scenario may still come true in the .21st century. The Food and Agriculture Organization of the United Nations therefore organized a World Food Summit in Rome on 13-17 Nov 1996, at which a Rome Declaration on World Food Security and a World Food Summit Plan of Action were adopted. The following are some of the highlights of these resolutions.

Rome Declaration on World Food Security

The Declaration makes a commitment to reduce the number of undernourished people to half their present level no later than 2015. It also states that "We will pursue participatory and sustainable food, agriculture, fisheries, forestry, and rural development policies and practices in high and low potential areas which are essential to adequate and reliable food supplies.... We will strive to ensure that food, agricultural wade, and overall trade policies are conducive to fostering food security for all through a fair and market-oriented world trade system."

World Food Summit Plan of Action

The plan of action contains the following seven commitments:

1. Create an enabling political, social, and economic environment designed to eradicate poverty and achieve durable peace.
2. Implement policies aimed at eradicating poverty and inequality and improving physical and economic access to sufficient, nutritionally adequate, and safe food and its effective use.
3. Pursue participatory and sustainable food, agriculture, fisheries, forestry, and rural development policies and practices in high- and low-potential areas.
4. Ensure that food, agricultural trade, and overall trade policies are conducive to fostering food security for all.
5. Prevent and be prepared for national disasters and man-made emergencies.
6. Promote an optimal allocation and use of public and private investments to foster human resources, sustainable food, agriculture, fisheries, and forestry systems, and rural development in high and low potential areas.
7. Implement, monitor, and follow up the Rome Plan of Action at all levels in cooperation with the international community.

The above plan of action integrates the principles of (a) *conservation* of the ecological foundations essential for sustainable advances in agricultural productivity and production, (b) *sustainable production* through ecotechnologies, and (c) *equity in access* to food through an appropriate blend of national and international action in the area of entitlements and employment. Food and livelihood security must be viewed in an interlinked manner.

Conclusions

We are facing a race against tine in safeguarding our natural resources. In his book *The Diversity of Life,* E.O. Wilson has warned that *Homo sapiens* is in imminent danger of precipitating a biological disaster of a greater magnitude than anything we have witnessed so far in our evolutionary history. There is hence no tine to relax, if we are to ensure that the Maithusian prophecy of famine and pestilence does not come true in the coming millennium. Legal, educational, and participatory measures of program implementation and benefit sharing will all be needed to promote a people's movement for conservation.

From the foregoing, it is clear that the concept of sustainable development should be broad-based to incorporate considerations in ecology, equity, employment, and energy, in addition to those of economics. This calls for a systems approach in project design and implementation. Both unsustainable lifestyles and, unacceptable poverty have to be eliminated. Factors influencing climate changes and sea level have to be addressed seriously. Sustainable development can become a reality if we keep in mind that the greatest responsibility of our generations is, to quote Dr. Jonas Salk, "to be good ancestors."

It is appropriate to conclude with a statement from the U.S. Presidents' Council on Sustainable Development document on "Sustainable America": "Prosperity, fairness, and a healthy environment are interrelated elements of the human dream of a better future. Sustainable development is a way to pursue that dream through choice and policy."

I an confident that the enlightened and human-centered political leadership of Bangladesh will help to promote the growth of a sustainable Bangladesh.

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Citation: Bhuiyan SI, Karim ANMR, editors. 1998. Increasing rice production in Bangladesh: challenges and strategies. Manila (Philippines): International Rice Research Institute, and Dhaka (Bangladesh): Bangladesh Rice Research Institute.

Research partnership for sustaining food security beyond 2000: IRRI's vision and strategic roles

G. Rothschild

The spectacular growth achieved by many Asian developing countries in rice production in the 1970s and 1980s has not been sustained in the 1990s. the near stagnation of production in the 1990s has resulted in grain stocks falling to low levels in some countries. Continuing poverty and malnutrition, unabated environmental degradation, and high population growth in most of these countries are puffing pressure on the delicate balance between supply and demand for rice, the staple food for nearly half of the world's population. Bangladesh has, since independence in 1971, succeeded in providing rice at affordable prices to a population that has grown by 80%, without bringing more land into rice cultivation. But future rice production increases will have to be achieved in the face of growing shortages of land, water, and labor, using technologies that will adequately protect the quality of the resource base. The challenge is enormous. It will demand much greater collaboration and partnerships among the members of the global rice research community than in the past for planning and implementing strategic research, and for technology transfer across national boundaries. The International Rice Research Institute (IRRI) has been increasingly committed to playing a major part in this bridge-building and facilitating role. The Institute has helped mobilize international support for developing rice research capacity in Bangladesh and provided training to a large number of the nation's scientists. IRRI scientists and their Bangladeshi counterparts have collaborated in addressing critical issues that hinder productivity gains. IRRI shares with Bangladeshi research institutions a common goal-to improve the well-being of present and future generations of rice farmers and consumers, particularly those with low incomes. The major avenue for achieving this goal is through strengthening research partnerships to harness the modern methods of biological, physical, and social sciences.

Rice remains the staple food for nearly half of the world's population, most of them living in Asia, many of them among the poorest of the poor in the world. The rice research community, including the International Rice Research Institute (IRRI), has been successful so far in helping provide this staple food to expanding populations. But alarming indications of continuing poverty and malnutrition, unabated environmental degradation, and high population growth are again placing pressure on the fine balance between supply and demand for this important staple grain.

Only a few years ago, governments of less developed countries were somewhat complacent about their ability to provide adequate food for their people. Spectacular growth in grain production throughout the 1970s and 1980s that contributed to a respectable increase in per capita availability of the staple food and a continued long-term decline in the prices of all staple grains encouraged this view. But the near stagnation of production growth in the 1990s has depleted grain stocks to alarmingly low levels. Frequent large fluctuations in grain prices in the world market and the substantial increase in rice prices in the domestic markets of major Asian countries challenge agricultural research yet again to abate the risk of food insecurity, even at high income levels, and to support economic growth.

The world's population continues to increase by 85 million people a year. Although the population growth rate has been declining in most developing countries, the absolute yearly increase in the number of people during this decade will be the highest in modern history because the population base has been expanding. The developing world will be adding another 2.31 billion people over the next three decades compared with an increase of 2.12 billion over the previous three decades. Population growth will be higher in regions characterized by pervasive poverty and malnutrition such as South Asia and sub-Saharan Africa, where per capita grain consumption is expected to increase further because of the large unmet demand for food. The global food projections recently made by the International Food Policy Research Institute showed that demand for cereal grains will increase by 72% and that of rice by nearly 60% over the 1990-2020 period, most of it due to feeding a larger population. For Bangladesh, the demand for rice is expected to increase by 63% over this period. Increasing production of this magnitude with limited natural resources, which are already under stress, places a daunting challenge before the global rice research community.

The primary objectives of rice research in the past were to increase land productivity and stabilize yield and to preserve the scarce land resources of Asia. Emerging trends suggest that tomorrow's rice land will be even more precious. Water for agriculture is becoming scarcer as population, cities, and industries grow. Biodiversity has been eroding. There is also a growing concern regarding the perceived deterioration in soil fertility and water quality from the heavy use of agrochemicals. The future increase in land productivity must therefore be achieved in a manner that protects the soil, water, and biotic resource base from which, all food must come.

Research must also respond to the need for many rice farmers to change from subsistence to market-oriented production systems to feed the rapidly growing urban population. Tomorrow's technology and management practices must also help farmers cope with the growing shortages and increasing wages of labor and the changing tastes of consumers as their incomes grow; and empower them to compete with the higher productive nonfarm activities in domestic markets and with low-cost rice producers in the world market, as they must face the globalization of agriculture resulting from the Uruguay Round of the GATT.

As fertilizer and labor are already used intensively, further increases in rice yield will most likely be based on new biological technologies; greater understanding of the interrelationships among soil, water, and biotic resources; and improved farm-level management of natural resources and material inputs. The scientific breakthroughs of advanced research laboratories, international research centers, and national research systems, as well as the management techniques that will be needed to make use of these breakthroughs, will have to be tine-tuned to suit local conditions. The need to adapt new technology to the specific requirements of variable environments also places substantial demand on national research programs that, in the final analysis, must develop locally appropriate varieties and cultivation practices. All this demands much greater collaboration among players in the global rice research community to develop partnerships for jointly implementing strategic research, to establish stronger links through communication and information technology, and to optimize the spillover effects that can be generated through knowledge and technology transfer across national boundaries.

IRRI has emerged as a major facilitator .of this global rice research system. Its capacity within the research spectrum allows it to link researchers with different expertise and perspectives to form a coherent research continuum. Its record of scientific achievements gives it high credibility with advanced research institutions in both developed and developing countries, while its long-term relationships with rice-growing countries provide a foundation for future linkages with more institutions in national systems and nongovernment organizations. Also, its apolitical status helps build bridges among research institutions across national boundaries and enables IRRI to play a catalytic role in exchanging information, knowledge, and methodologies among countries with different cultures and ideologies.

Since independence in 1971, Bangladesh has achieved a feat in providing rice at affordable prices to 80% more people without bringing more land into rice cultivadon. That remarkable achievement has been possible due to continued government support to rice research and extension, the foresight and dedication of research managers and scientists, and the receptivity and hard work of 12 million rice farmers who, despite a lack of formal education and financial resources, continuously experiment with new ideas and technologies introduced from outside. IRRI has played a small role in that effort by mobilizing international support for developing rice research capacity in Bangladesh and by training a large number of scientists. More than 120 Bangladeshi scientists have received Phil) and MS degrees under the supervision of IRRI scientists for thesis research. The investment that the government of Bangladesh and its development partners has made in rice research has given a high payoff. It is estimated that investment in research has contributed to a cost savings in rice producdon of US$300 million and saved foreign exchange of $350 million per year. The benefits have been a hefty 19 times the cost of investment.

But the race to maintain the balance between food production and population growth is not yet over for Bangladesh. In fact, the challenge may become mare dauntbig for the next few decades. United Nations population projections show that Bangladesh will have to feed an additional 60 million people over the 1995-2025 period. The production of nonrice food items such as pulses and oilseeds, which are important sources of nutrition for the poor, has grown more slowly than the population, and the foreign exchange requirement for in porting these food items has been escalating. In the future, demand for flounce food items will be increasing much faster than rice, with rapid urbanization and acceleration of economic growth. To increase the domestic production of flounce crops, some land and other resources must be released from rice cultivation, which now occupies three-fourths of the cropped land. This means that the increase in productivity in rice cultivation must be faster than the growth in demand. The exploitation, of groundwater for irrigation that has been the main source of increasing rice production in the past will soon reach its limit. Already there are signs that the overexploitation of groundwater has reduced the supply of dunking water and deteriorated water quality. Rice research must show fanners how to save water m rice cultivation so that additional rice land can be served with the existing irrigation infrastructure. There are also opportunities for increasing production in rainfed ecosystems. Suitable technologies have yet to be developed for the 30% of rice & land that is flooded regularly at a depth of more than 90 cm. Scientists need to develop technologies to reduce the cost of fertilizer, water, and pesticides for the bottom 50% of the rural population who find it difficult to mobilize these resources for obtaining full benefits from modem rice varieties. These and many other pressing issues demand the continued attention of rice scientists.

IRRI shares with Bangladeshi agricultural research institutions a common goal: to improve the well-being of present and future generations of rice farmers and consumers, particularly those with low incomes. The additional population can continue to be fed only if food production reaches higher plateaus. Such an increase in production will be attained only through special efforts, in close collaboration with relevant basic and applied research institutions and development organizations throughout the world. By strengthening research partnerships for harnessing the modem methods of biological, physical, and social sciences, I am confident that we can find ways to grow enough rice for the expanding population for the coming decades and to sustain higher rice productivity while maintaining the natural resource base and protecting the environment.

Notes

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Citation: Bhuiyan SI, Karim ANMR, editors. 1998. Increasing rice production in Bangladesh: challenges and strategies. Manila (Philippines): International Rice Research Institute, and Dhaka (Bangladesh): Bangladesh Rice Research Institute.

Shifting the yield frontier with hybrid rice

S.S. Virmani

Shifting the yield frontier in rice is an important research goal for rice scientists to meet the continuously increasing demand for rice produced from less land, less water, less labor, and fewer chemical inputs. China has achieved this goal through hybrid rice technology and several other countries are exploring its prospects. During the past 17 yr, IRRI has helped to develop hybrid rice technology for the tropics. Currently, hybrid rice research is in progress in 17 countries and 13 of them have formal or informal collaboration with IRRI. India, Vietnam, and the Philippines have started commercializing hybrid rice and targeted it to cover more than 2.5 million ha by year 2000. Certain characteristic features of rice hybrids, such as better seedling tolerance for low temperature, faster tillering, early vegetative vigor, and better root system, make them more adaptable to the boro season. In Bangladesh, several IRRI-based rice hybrids have given a 1 t ha^{-1} yield advantage over inbred rice in boro-season trials, indicating the opportunity to increase rice production using hybrids in boro. In addition to increasing average yield, hybrid rice can provide more skilled jobs in seed production in rural areas and improve crop management practices at the farm level. In the future, interest in hybrid rice technology is likely to increase. But plant breeders will face the challenge of developing a large number of stable cytoplasmic male sterile lines and improved restorers to sustain the flow of commercial heterotic hybrids. If successful, research on apomixis, which has begun at IRRI, in China, in the USA, and elsewhere, will create a major breakthrough in rice hybrids and enable farmers to use seeds from hybrid rice crops grown on their own farms. The International Task Force on Hybrid Rice, which is operated under the coordination of IRRI, will expedite the development and use of hybrid rice technology in several countries including Bangladesh.

Major increases in rice production have occurred during the past 30 yr because of the large-scale adoption of high-yielding semidwarf varieties, cropping intensification, expansion of irrigated area, increased nutrient inputs, and improved crop management practices. The rate of increase of rice production is slowing down, however, and if the trend is not reversed, severe food shortages will occur in the 21st century. According to an estimate, 880 million t of rice will be required to feed the world populadon in 2025 compared with the 554 million t needed in 1995. The increased demand for rice will have to be met with less land, less water, less labor, and less pesticide. Achieving self-sufficiency in rice production and maintaining price stability are important political objectives in low-income countries where rice is an important crop in providing food security and generating employment and income for the rural poor

(Hossain 1995). Thus, shifting the yield frontier in rice is an important research goal for rice scientist around the world. Two advances are hybrid breeding and development made in varietal improvement research to increase the yield potential of the new plant type (Khush 1995, Khush and Virmani 1996, Virmani 1996a,b).

Hybrid rice in China

Breeding rice hybrids

China first developed and demonstrated the use of hybrid rice technology to increase rice production (Yuan 1977, Lin and Yuan 1980). Research on hybrid rice began in China in 1964. The first set of commercial rice hybrids was released in 1976. Hybrid rice now occupies about 16 million ha or 50% of the total rice area and contributes about 18 million t of extra paddy annually to China's grain production (Yuan et al 1989, 1994). The average yield of hybrid rice grown in China is 6.7 t ha^{-1} compared with 4.8 t ha^{-1} of inbred rice grown in similar areas. Hybrid rice in China currently contributes about 20% to global rice production.

Yuan et al (1994) recognized the following four phases of hybrid rice development in China:

- 1975-79 Experimentation, demonstration, and extension phase. The first set of rice hybrids (such as Er-Jui-Nan IA/IR24, Zhen Shan 97A/IR24, and V41A/IR24) was developed and released to cover about 5 million ha, with an average yield of 4.7 t ha^{-1} and 20% higher yields than inbred varieties.
- 1980-81 Adjustment phase. The area remained stagnant but yield increased to 5.3 t ha^{-1} with the release of some hybrids possessing resistance to diseases and insects.
- 1982-85 Continuous development phase. Hybrid rice area increased to nearly 10 million ha and the yield increased to between 5.9 and 6.5 t ha^{-1} Short-duration hybrids, such as V2OA/Ce 64, developed collaboratively with IRRI (Yuan 1985) and Zhen Shan 97A/Min Hui 63, played a significant role in this phase.
- 1986-91 Rapid and steady development phase. The area under hybrid rice increased to 17.6 million ha, yielding on the average 6.6 t ha^{-1}, with the development of a series of new hybrids, which showed advantages not only in maturity but also in yield and pest resistance. During the past 5 yr. the grain quality of hybrids has been improved (Zhang et al 1995, Zhou and Liao 1995) and some two-line rice hybrids (indica and indica/japonica) have been developed (Lu et al 1994).

Hybrid rice seed production

Although rice is a self-pollinated crop, significant outcrossing (14.6-53.1% on male-sterile lines) was observed in China (Xu and Li 1988). Guidelines and practices for hybrid seed production in China were developed (Lin and Yuan 1980, Yuan 1985) and modified from time to tine (Mao 1988, Mao et al 1996). Average seed yields in

Table 1. Super high yield records of hybrid rice seed production In China.

Location	Year	Area (ha)	Yield (t ha^{-1})
Xuning, Hunan	1989	0.22	6.3
Taojiang, Hunan	1990	0.11	6.5
Youxi, Fujian	1990	0.10	6.4
Wugang, Hunan	1990	0.20	6.1
Longhui, Hunan	1990	0.07	6.3
Zhixing, Hunan	1990	0.09	6.3
Youxi, Fujian	1991	010	6.8
Zhixing, Hunan	1992	0.11	6.1
Zhixing, Hunan	1993	0.11	7.4
Zhixing, Hunan	1994	0.11	6.8

Source: Mao et al (1996).

hybrid rice seed production plots in China improved from 0.7 t ha' during the late 1970s to 2.6 t ha^{-1} during recent years. The development process of hybrid rice seed production technology in China could be divided into three major stages (Mao et al 1996).

The first phase (1973 to 1980) was the probational stage when preliminary guidelines and practices on the techniques for parental line multiplication, purification, and F_1, seed production were developed and applied in all hybrid rice-growing areas m China. The nationwide average seed yield ranged from 0.1 to 0.7 t ha^{-1} in this period, which was not profitable for seed growers if no subsidies were provided by the government (Lou and Mao 1994).

The second phase (1981 to 1985) was the consolidation stage when the seed production system was applied to more suitable areas and seasons. These efforts increased the nationwide average seed yield to 1.5 t ha^{-1} by 1985. The increased yield and decreased cost enabled attainment of a profitable threshold for seed growers without subsidies.

The third phase (1986 to 1995) was the super high seed yield stage reached through further technological improvement. The targeted seed yield in this phase was 3 t ha^{-1}. During this period, super high seed yield records of more than 6 t ha' were reached by several seed growers in Hunan and Fujian provinces (Table 1). The nationwide seed yields reached 2.0 to 2.2 t ha^{-1} by the mid-1990s.

In addition to technological innovations, several changes in seed production systems and in government policies were also introduced to increase seed yields. These included shifting the responsibility of purification and multiplication of parental lines from the county level to the prefectural level. The county-level seed company produces F_1, hybrid seeds only. Usually, a few suitable locations are selected in a county because its seed production bases and farmers' groups living around these bases are subcontracted to produce hybrid seed. Over the years, the seed production cost has been reduced from \$6 kg^{-1} in 1976 (av seed yield 0.3 t ha^{-1}) to \$0.79 kg^{-1} in 1995 (av seed yield 2.2 t ha^{-1}) (Mao et al 1996).

High seed yields in China have been associated with skillful spraying and increased dosage of GA_3, discontinuation of flagleaf clipping, increased seed parent:pollen parent ratio, closer transplanting with multiple seedlings, and supplementary pollination at peak anther dehiscence (Huang et al 1994).

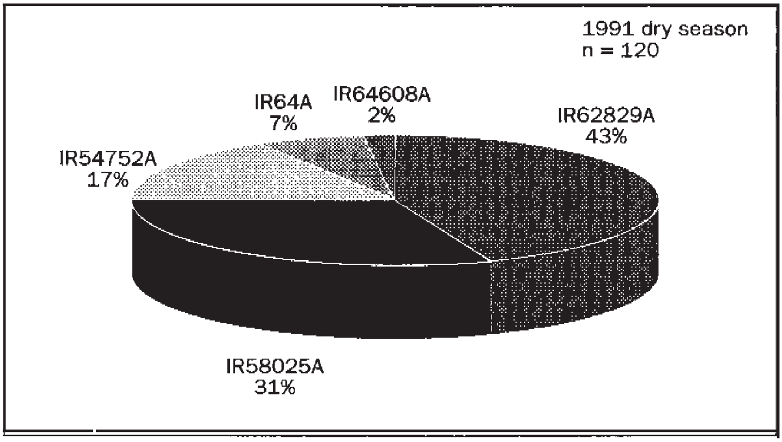
Hybrid rice outside China

Breeding of rice hybrids

The successful development and use of hybrid rice in, China during the 1970s ercouraged IRRI to explore prospects and problems of hybrid rice in in,, creasing rice varietal yields in the tropics (IRRI 1980). Chinese rice hybrids were unadapted to tropical conditions because of their susceptibility to major diseases and insects. As wink pro-. gressed at IRRI and positive results were reported (Virmani et al 1982, Virmani 1987, Yuan and Virmani 1988), several countries collaborated with IRRI in carrying out hybrid rice research. Currently, hybrid rice research is in progress in 17 countries: Bangladesh, Brazil, Colombia, Egypt, India, Indonesia, Japan, DPR Korea, Republic of Korea, Malaysia, Myanmar, Pakistan, Philippines, Sri Lanka, Thailand, the United States, and Vietnam. Thirteen have formal or informal collaboration with IRRI. In Brazil, Colombia, India, Japan, Philippines, and the United States, private companies are also involved in conducting hybrid rice research and/or seed production.

Research in India, Philippines, and Vietnam has already resulted in the development of commercial rice hybrids with yields of 1 t ha^{-1} more than the semidwarf varieties on farms (Virmani 1994b; Virmani et al 1994; Luat et al 1995; Anonymous 1995, 1996; Virmani 1996b). In 1996, Indian rice fanners planted about 60,000 ha with rice hybrids (Siddiq et al 1996) whereas Vietnamese rice fanners covered 100,000 ha with rice hybrids. By 2000, the two countries will extend hybrid rice to 2 million ha and 0.5 million ha, respectively. I~ India and the Philippines, almost all rice hybrids released for commercial cultivation are derived from IRRI-bred parental lines (e.g., IR58025A , IR62829A, IR29723- 1433-2-IR, IR10198-66-IR, IR9761- 19-IR, etc.), whereas most of the hybrids released in Vietnam for commercial cultivation were introduced from China. IRRI-bred hybrids are still under various stages of yield testing in Vietnam.

IRRI has developed many cytoplasmic male-sterile (CMS) and maintainer and restorer lines adapted to the tropics that are shared freely with national agricultural research systems and private companies to help them develop and use this technology. During the past 5 yr, iRRI's capability to breed CMS and restorer lines has increased several-fold because of the initiation of specific maintainer and restorer breeding programs (Virmani 1996b). The latest strategy is to provide national programs with male sterility-facilitated composite populations to extract restorers and maintainers adapted to local conditions (IRRI 1.996, Bharaj ard Virmani 1997). With the availability of many CMS lines, the profile of hybrid combinations derived from CMS lines has broadened significantly between 1991 and 1996 (Fig. 1). New CMS lines have more stable pollen. sterility and better phenotypic acceptability (Table 2). With the availability of better CMS lines, the quality of hybrids has improved over the



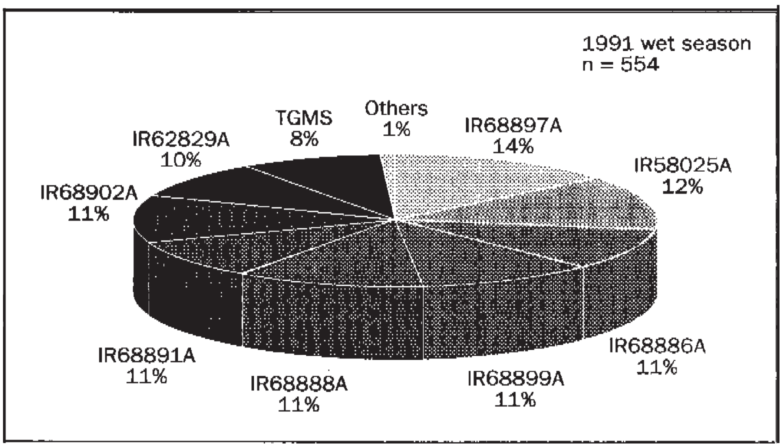


Fig. 1. Comparative profile of hybrid combinations derived from CMS lines In observational yield trials conducted during 1991 and 1996 at IRRI. TGMS = thermosensitive genic male sterility.

years (Fig. 2). The yield advantage of hybrids over inbred checks was higher in high-yielding than in low-yielding viromnents (Virmani et al 1994). Several IRRI-bred rice hybrids tested in the International Network for Genetic Evaluation of Rice have shown at least a 1 t ha^{-1} yield advantage over local checks (Chaudhary and Virmani 1996).

Physiology of rice hybrids

The higher yield of tropical rice hybrids over inbred rice is due to increased dry matter resulting from higher leaf area index (LAI) and faster crop growth rate, and in-

Table 2. New CMS lines developed at IRRI, with good combining ability and desirable floral and agronomic traits.

CMS line	Pollen steriiity		Outerossing rate		Phenotypic acceptability	
	100%	99-99.9%	>30%	25-30%	>5	= 5
IR68886A		X	X			X
IR68888A	X			X	X	
IR68890A	X		X			X
IR68897A	X		X			X
IR68899A		X		X		X
IR68902A	X			X	X	
IR69620A		X	X			X
IR69622A	X		X		X	
IR69624A	X		X		X	
IR69627A	X		X		X	
IR69628A	X		X		X	
IR58025A (check),		X	X		X	
IR62829A (check)		X		X	X	

creased harvest index resulting from increased spikelet number and, to some extent, increased grain weight (Ponnuthurai et al 1984, Akita et al 1986, Agata 1990, Song et al 1990, Patnaik et al 1991, Peng et al 1996). Heterosis in panicles per plant, spikelets per panicle, and spikelet fertility varied greatly among crosses and cultivation condidons because of yield component compensation (Akita 1988). Kabaki (1993) analyzed growth and yield of japonica/indica hybrid rice in Japan and concluded that the expansion of leaf area due to an increased number of fillers was the main factor for achieving heterosis in the crop growth rate of hybrid rice during the 30-d period after transplanting. Although the degree of heterosis decreased thereafter, it rose again after heading, contributing to 'higher grain yield. Vigorous growth in the early and middle part of the growing season led to the development of larger panicles (Cao et al 1980). Hybrid rice displayed an efficient sink formation per unit dry matter production (Cao et al 1980, Kabaki 1993) as well as high ripening potential due to vigorous dry mailer production after heading (Kabaki 1993). Thus, high hybrid yield was attained by the summation of the increase in each of the yield components. Hybrid rice ripens with a higher biomass and larger sink size than inbred rice. Grain-filling percentage of the hybrid. was comparatively high in spite of its large number of spikelets (Yan 1988, Song et a] 1990) because of the high ratio of storage translocated from the culm and sheath to the spikelets, and the high LAT during ripening (Yan 1988, Song et al 1990). Song et al (1990) also reported that nonstructural carbohydrate content in the culm and sheath was higher for hybrid rice than for inbred red rice. Such differences did not exist in the leaf blade.

Peng et al (1996) compared the yield potential of elite tropical rice hybrid IR68284H with high-yielding commercial rice variety IR72 for three consecutive seasons in the Philippines. The hybrid outyjelded IR72 significantly in grain and total dry mailer at harvest (Fig. 3). The hybrid produced 23.5 t dry matter ha^{-1}, which was the highest biomass production reported for tropical rice.

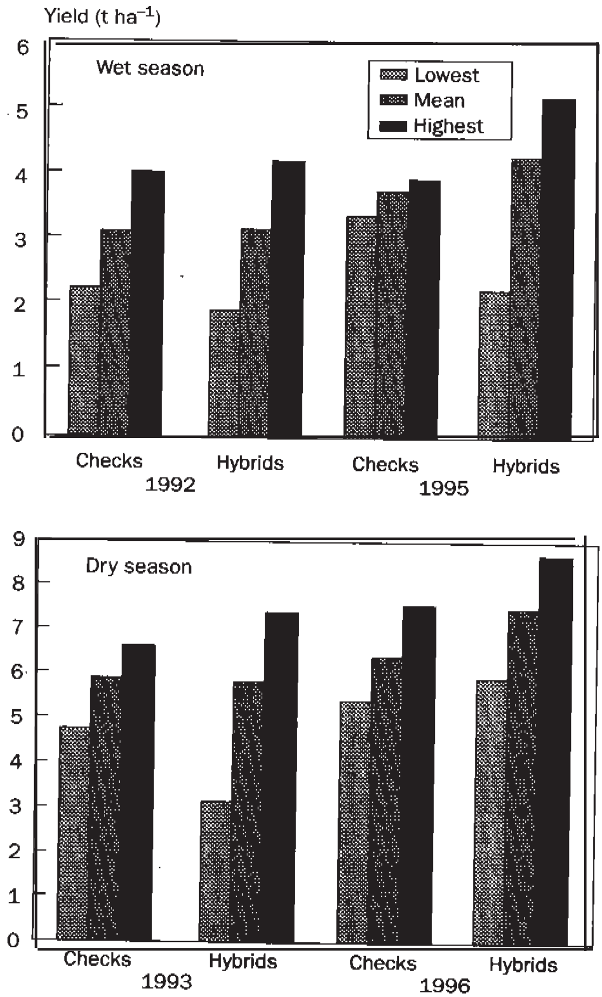


Fig. 2. Comparlson of lowest, mean, and highest yields of hybrids and check varieties evaluated In advanced yield trials, IRRI, 1992-96.

Heterotic rice hybrids had growth durations ranging from 105 to 136 d (Virmani 1987), indicating that growth duration did not correlate with heterosis expression.

Adaptability of rice hybrids to the boro season

A significant proportion of the flood-prone, floating, and deep-water rice areas m eastern India, Bangladesh, Myanmar, and Vietnam is grown to the boro or spring rice crop with irrigation during the city season. This crop experiences low temperature (10-15 °C) for 60-80 d during the seedling and early vegetative phases and often suffers from yellowing to death while in the seedbed, retarded seedling growth, slow

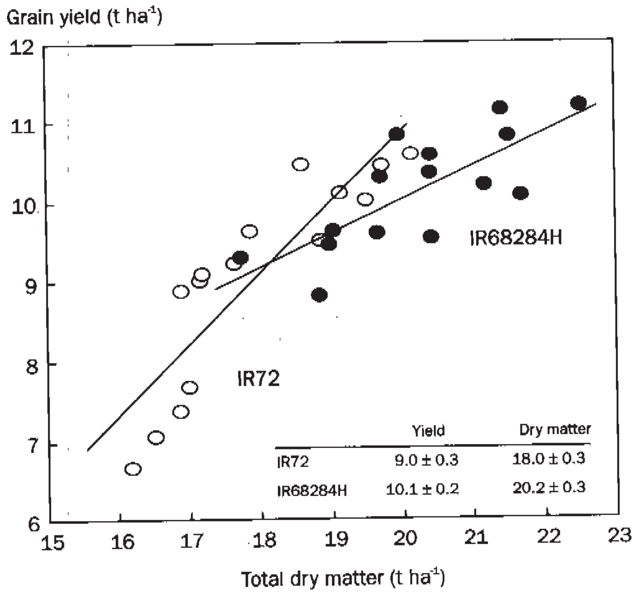


Fig. 3. Grain yield and total dry matter of IR72 and IR68284H grown In the dry seasons of 1994-96 at IRRI and PhilRice. Insert Is mean ± standard error. (Adapted from Khush et al 1998.)

and delayed tiller production, and prolonged tillering period, which delays flowering and maturity. Certain characteristic features of rice hybrids such as better seedling tolerance for low temperature (Kaw and Khush 1985), faster tillering, early vegeta-five vigor, and a better root system make them more adaptable to the boro season. Perhaps this is why hybrid rice has shown a dramatic yield advantage over inbred rice in on-farm demonstration-corn-yield trials in the boro season in West Bengal, India (Table 3). Encouraged by these results, the West Bengal State government released a rice hybrid, CNHR-3 (IR62829/Ajaya R), and started a campaign to popularize hybrid rice for the boro season. Several IRRI-bred rice hybrids have also shown a 1 t ha^{-1} yield advantage over inbred rice in trials conducted in the born season in India and Bangladesh and in the spring season in the Red River Delta in Vietnam (Table 4). These results indicate opportunities to increase rice production through rice hybrids in several countries, including Bangladesh. where boro rice cultivation is important and still expanding.

Hybrid rice seed production

At IRRI, an outcrossing rate of up to 37% has been observed in male-sterile lines used in hybrid seed production plots. In India, natural crossing of up to 42.8% has been reported in male-sterile lines (Anonymous 1995). Variability in the extent of outcrossing in male-sterile lines of rice can be attributed to variations in flowering

Table 3. Performance of rice hybrid CNHR-3 In on-farm trials in the 1994-95 boro season in Different districts of West Bengal.

District	Trials (no.)	Yield (t ha^{-1})		Maturity (d)		Yield advantage other HYV check (t ha^{-1})
		CNHR-3	HYV[a] (check)	CNHR-3	HYV (check)	
Burdwan	3	9.9	5.0 (IET 4786)	133	138	4.9[b]
Hooghly	1	7.8	6.2 (Khistish)	133	142	1.6
North 24- Parganas	3	6.8	5.0 (Khistish)	130	140	1.8
Nadia	3	8.0	6.0 (IET 4786)	132	137	2.0
Murshidabad	3	6.6	5.4 (IR36)	130	142	1.2
Birbhum	3	7.2	4.6 (IR36)	130	142	2.6
Midapur	3	5.4	4.8 (Sankar)	*[c]	*	0.6
Bankura	3	8.2	6.6 (PNR 381)	125	135	1.6

[a]HYV = high-yielding variety. [b]Yield advantage is unusually high. [c] * = premature harvest following severe moisture stress. Hence, yield data not included during calculation of mean.

Table 4. List of some rice hybrids identified as promising in the boro season in West Bengal, India, Bangladesh, and the Red River Delta in Vietnam.

Hybrid	Yield advantage[a] of at least 1 t ha^{-1} over check in		
	West Bengal	Bangladesh	Red River Delta
IR62829A/IR54742R	X[a]		
IR58025A/IR29723R	X[a]		
IR62829A/IR29723R	X[b]	X[b,c]	
IR62829A/IR46R	X[b]	X[b,c]	
IR62829A/IR47310R	X[b]	X[b]	
IR62829A/IR48491R	X[b]	X[c]	
IR58025A/IR21567-18-1R		X[b]	X[b]
IR58025A/IR34686-179R		X[b]	
IR62829A/BR 736-20-3-1		X[c]	X[b]
IR58025A/IR54742-22-19-3			X[b]
IR58025A/RP 633-76			X[b]
IR62829A/IR54791R			X[b]

[a]Supercripts a, b, and c in the three colums denote results based on trials conducted in 1993, 1995, and 1996, respectively.

behavior (duration time and angle of opening of spikelet) and floral characteristics of male-sterile (stigma size and stigma exsertion) and pollen parents (anther length, filament length, and pollen number per anther), and variation in environmental factors (temperature, relative humidity, light intensity, and wind velocity). Virmani (1994a, l996a) reviewed the outcrossing mechanism and hybrid seed production practices and described guidelines for hybrid rice seed production in the tropics. Seed producdon practices were also illustrated in a manual published by IRRI (Virmani and Sharma 1993).

Like in China, seed yields of CMS line IR58025A, grown at the IRRI farm, improved from 153 to 2050 kg ha^{-1} between 1989 (when the line was developed) and 1994, with increased familiarity and experience in handling this CMS line. Hybrid rice seed yields in tropical rice-growing countries have ranged from 0.2 to 2.5 t ha^{-1} (Virmani 1996a). The following technological innovations are important to further reduce the cost of hybrid rice seed production in the tropics:

- Improved outcrossing potential of male-sterile lines.
- Increased pollen load released from the male parent.
- Synchronization of flowering of female and male parents.
- Increased proportion of area for the female parent compared with the male parent.
- Economical use of gibberellic acid (GA_3) and/or finding a cheaper substitute to improve panicle exsertion and/or prolong the duration of the floret opening in the male-sterile parent.
- Selection of the ideal season and locations for seed production.

Environmental factors influencing natural outcrossing in rice include temperature, relative humidity, light intensity, and wind velocity. The seed set percentage and seed yield of CMS lines were negatively correlated to relative humidity at IRRI (Virmani 1994a). The highest seed yield was obtained when the seed and pollen parents flowered at the end of February to early March, when the relative humidity was 50-60%, maximum and minimum temperatures were 28-30 °C and 2 1-22 °C, respectively, and wind velocity was above 2.5 m s^{-1}. Seed yields at IRRI are generally higher in the dry season than in the wet season. Results obtained from India (Table 5) also showed variation in seed yield with changes in locations.

Table 5. Moan seed yield and outcrossing rate for IRRI-bred CMS line IR58025A at various locations in India, 1994-95.

Year (season)	Location	Yield (t ha^{-1})	Outcrossing rate (%)
1994-95 (rabi)	Hyderabad	1.6	33
	Coimbatore	1.0	30
	Bangalore	2.4	26
1995 (kharif)	Hyderabad	0.5	17
	Coimbatore	1.1	33
	Bangalore	2.2	26
	Maruteru	0.7	19
	Pantnagar	2.5	-

Source: Annual report 1994-95 and Wortsplan 1995-96 of the Development and Use of Hybrid Rice Technology Project, Directorate of Rice Research, Rajendranagar, Andhra Pradesh, India.

Factors affecting the development and use of hybrid rice technology

The pace of the development and use of hybrid rice technology in a country is determined by the

- extent of investment to develop the technology,
- availability and/or pace of breeding of commercially usable parental. lines,
- extent of yield heterosis m commercial rice hybrids,
- magnitude of hybrid seed yields in commercial seed production plots,
- number and quality of human resources available for hybrid rice research and seed production,
- extent of collaboration with other national and international centers working on hybrid rice,
- adequacy and effectivity of the seed production infrastructure,
- extent and quality of coordination between hybrid rice research and seed production systems, and
- extent of development of the private seed industry.

Virmani (1996b) has outlined strategies to expedite research and development for hybrid rice.

Economics of hybrid rice

The economics of hybrid rice technology has been reported from China (He et al 1984, 1987a,b, 1988; Lin 1990), India (Govindaraj 1993), and the Philippines (Lara et al 1994). These studies showed that hybrid rice is profitable if its yield advantage over inbreds is at least 1 t ha-′ and seed yields of 1.5--2.0 t ha^{-1} are obtained in seed production plots.

From economic analyses made on hybrid rice in China, Lin and Pingali (1994) made the following conclusions on the prospects for hybrid rice in other countries.

1. The technology would be relevant for those countries where the rice supply is projected to fall short of demand with an increasing population and land:labor ratio.
2. It would be suitable for irrigated rice ecosystems where yield gains associated with high-yielding inbred varieties have been exhausted. The proportion of irrigated rice land to total rice land is therefore an important determinant of the potential adoption of hybrid rice technology.
3. Because the relative profitability of hybrid rice over conventional rice is determined by the ratio of the rice price to the hybrid seed price, and given the high labor requirements in hybrid seed production, it is anticipated that hybrid rice technology will receive serious attention in countries where wages are lower due to high labor-land ratios.
4. In tropical Asia, countries with a high labor-land ratio and a high proportion of irrigated area (e.g., India, Indonesia, Philippines, Sri Lanka, and Vietnam) are like to have the highest potential demand for hybrid rice technology. On the

other hand; countries with a high proportion of irrigated area but a low labor-land ratio (e.g., Malaysia and Pakistan) would not find hybrid rice production profitable because agricultural wages would be relatively higher. Countries with a low proportion of irrigated rice area (e.g., Bangladesh, Nepal, Myanmar, and Thailand) would have a low potential demand for hybrid rice technology, irrespective of wage rates. In recent years. the irrigated rice area in Bangladesh appears to have increased, especially in the boro season, making it suitable for hybrid rice technology.

5. For the potential supply of hybrid rice, India (with 31% of the total irrigated area in tropical Asia) and Indonesia (with 13% of the total irrigated area in tropical Asia) would be the most important suppliers. Given the size of the market, seed producers in these countries would benefit from substantial economies of scale. Economies of scale would be important in providing hybrid seed adapted to specific ecological regions and inputs, especially GA_3 and technical skills.
6. Region-specific research and a seed production infrastructure for hybrid rice can be economically feasible to set up in large countries such as India and Indonesia. Region-specific institutions would not be cost-effective in countries with smaller irrigated areas. Such countries could possibly benefit from their neighbors' efforts. Sri Lanka, for instance, could benefit from technological spillover from hybrid rice research conducted in southern India. Similarly, Bangladesh could benefit from the efforts in eastern India; and Malaysia could benefit from the efforts made in West Java and Sumatra in Indonesia.
7. For input-supplies, the-unit cost of GA_3, an important component of hybrid rice seed production technology, would decrease with an increase in production scale.
8. Before making a large-scale commitment to hybrid rice-related infrastructure, a detailed assessment of the land and labor requirements ought to be made. In countries such as India, with low wages, high rural unemployment, and a high price of rice, it may be advantageous to pursue the technology. In the case of Thailand, however, with high and increasing wage rates and the high opportunity cost of irrigated land for growing high-value crops for export, hybrid rice may not be the best option.

Recent studies from India (Janaiah and Ilyas Ahmed 1996, Honnaiah et al 1996) indicated that hybrid rice seed yields of 1.5-1.9 t ha^{-1} were economically viable. In the initial stages of introducing this technology, when the seed yields are lower than the threshold levels, national programs will have to provide incentives to seed growers to produce hybrid seeds.

Swaminathan (1993) stated that hybrid varieties in any crop have three distinct advantages. First, they increase average yield; second, they provide more skilled jobs: in seed production in rural areas; and third, they also Provide a tool to improve crop management practices on-farm.

Future outlook

Hybrid rice has had a significant impact on rice yields and the development of the commercial seed industry in China. Outside China, India and Vietnam have started commercializing this technology during the past 3--4 yr and aim to cover 2 and 0.5 million ha, respectively, by 2000. Several other countries have also begun breeding and seed production work to develop and use this technology to shift the yield frontier in rice. Major challenges for plant breeders include the development of large numbers of stable CMS lines and effective restorers that would produce commercial heterotic hybrids. Breeding procedures to develop hybrids must be efficient so that the technology can compete with conventional breeding procedures in the production of good-quality products. Environment-sensitive genic male sterility appears to help increase the efficiency of breeding hybrid rice varieties (Shi 1981, 1985, Shi and Deng 1986, Maruyaina et al 1991, Yang et al 1989, Wu et al 1991, Virmani and Voc 1991). Similarly, indica x temperate japonica hybrids in temperate countries (Ikehasbi et al 1994, Yuan 1994), indica x tropical japonica hybrids in tropical countries (Khush and Aquino 1994, Khush et al 1996), and temperate x tropical japonica hybrids also in temperate countries (Virmani 1996a) should help enhance the level of heterosis in indica and japonica rice hybrids.

Pingali et al (1996) assessed the prospects of hybrid rice in tropical Asia and made the following conclusions:

1. Because of its higher yield, hybrid rice can help increase rice production in the so-called rice bowl regions where the yield gap between the potential yield and farmers' yield has for the most part been bridged.
2. It is quite likely that in the early stages of hybrid rice adoption, input use and management practices would be the same as with semidwarf inbred varieties, but over time farmers would learn to adopt management practices specifically recommended for rice hybrids.
3. The main factor determining the profitability of hybrid rice is seed price; hence, reducing seed costs should be the primary goal of hybrid rice seed production research.
4. Increased rice production in favorable irrigated lowland ecosystems would reduce pressure to intensify production in more fragile ecosystems, especially uplands. In favorable rainfed lowland ecosystems, where the use of modern rice varieties is already extensive, adopting hybrids could be profitable.
5. The widespread adoption of hybrid rice would almost certainly increase the demand for labor, especially for crop establishment, harvest, and postharvest operations.
6. As hybrid rice becomes profitable on-farm, interest in the technology is likely to increase, swelling the demand for commercial seed and creating a fertile environment for the emergence of a flourishing private seed industry.
7. As competition in the seed industry intensifies, private companies will come under increasing pressure to differentiate their products from those of their competitors. Eventually, a few companies are likely to launch their own in-house

research programs aimed at developing proprietary hybrids that can be sold on an exclusive basis.

8. Profit-oriented private companies are unlikely to serve resource-poor farmers in marginal environments, for whom alternative seed. delivery mechanisms may be required (e.g., public or NGO seed agencies).
9. At any time, within a given country, different regions or different groups of farmers are likely to find themselves at different stages of seed industry growth. This means that a mix of different types of organization (public, private, and NGO) will be needed to develop and deliver hybrid rice technology.

To transfer hybrid rice technology effectively, seed production and distribution systems need to be strengthened in several countries. Singh (1993) has proposed the following strategies:

- Establish and/or strengthen seed production, processing, and distribution, facilities in public, private, and/or NGO sectors.
- Share expertise and materials of countries that have a strong seed industry with those countries that do not have such infrastructure.
- Establish a high-level body in each country for overall coordination, supervision, and accountability of seed production, processing, and distribution programs.
- Establish such bodies at provincial and district/prefecture levels to get a multiplier effect.
- Formulate, strengthen, and/or enforce seed laws/acts in- each country.
- Establish seed-testing laboratories to test the quality of seeds produced by different component seed industries in the country.
- Develop human resources for the seed industry, using the facilities and skills available in Asian countries that have a strong seed industry (Japan, Korea, China, and India).

By deploying these strategies, national programs could be assisted by FAO and other agricultural development agencies in strengthening their seed industries to enable them to produce and distribute seeds of improved rice varieties and hybrids. This would give rice farmers access to high-quality seeds, which in turn would contribute to increased rice production.

To make hybrid rice technology accessible even to resource-poor farmers, research on apomixis has begun at IRRI and in China, USA, and elsewhere. Identifying or developing apomictic rice will be a major breakthrough in this direction. An International Task Force on Hybrid Rice (INTAFOHR) involving several national prograins, IRRI, and FAO has been formed to expedite the development and use of hybrid rice technology in selected countries including Bangladesh. With these developments, it can be concluded that hybrid rice has the potential of shifting the yield frontier in rice significantly in selected rice-growing countries.

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Citation: Bhuiyan SI, Karini, ANMR, editors. 1998. Increasing rice production in Bangladesh: challenges and strategies. Manila (Philippines): International Rice Research Institute, and Dhaka (Bangladesh): Bangladesh Rice Research Institute.

Accelerating the growth of agriculture in Bangladesh

Z. Karim

Agriculture's contribution in Bangladesh to accelerated economic growth comes from the initial large size of the agricultural sector and the powerful stimulus it provides to the growth of other sectors. This accelerated growth of agriculture also contributes to the gradual decrease in some risky activities, particularly from a poverty-risk point of view, and promotes favorable environmental effects. This is important within the context of signs of a growing degradation of the natural resource base as we endeavor to increase overall agricultural production with available technologies that are barely adequate to increase productivity for a range of crucial food and nonfood commodities.

The World Food Summit held in November 1996 cautioned that world agricultural growth would likely be slower in the future, and that developing countries would most likely continue to need to increase their net imports of cereals from 50 to more than 160 million t by the year 2010.

A view of the year 2020 for food, agriculture, and the environment made by the International Food Policy Research Institute (IFPRI) in 1995 projected that a failure to take action would lead to persisting hunger and poverty, continuing degradation of natural resources, increasing conflicts over scarce resources, and widening gaps between the rich and the poor.

The food situation, in different dimensions, has been undergoing radical changes globally. Surplus stocks of grain fell in 1996 to a level as low as the equivalent to 48 d of consumption, the lowest on record. Per capita grain production has fallen by 15% since 1984, after increasing by 40% since 1950, and crop land available for grain production is diminishing rapidly. Food aid was cut in half, to same 7.6 million t, between 1993 and 1996, and in December 1995 the European Union imposed an export tax of \$320 t^{-1} of wheat, a form of reverse protectionism that is an ominous sign for the future.

The degrading of productive lands through soil erosion, salination, and contamination is permanently undermining their productivity. A recent Worldwatch Institute report indicates that erosion affects more than one-third of China's crop land, that salination has reduced the yields of 7 million ha, and that another 7 million ha have been polluted by industrial waste. Lester Brown of the Worldwatch Institute has long been warning against complacency and pointing to the growing vulnerabilities of the world's food supply. In 1996, the Food and Agriculture Organization (FAO) and the Consultative Group on International Agricultural Research (CGIAR) called for massive new efforts to improve food security at both the national and household levels.

This call was based on a new Green Revolution, drawing on the social and economic lessons of the first Green Revolution and its advances in agricultural science.

In Bangladesh, the population is still growing rapidly, which creates more demand for food. Our land resources are also showing signs of fatigue, which has resuited in stagnation in the yield of important crops. To increase the productivity of our agriculture,, we urgently need to harness the maximum potential of natural resources coupled with the application of modem science and technology. This will require a strong commitment from the government, supported by priority investment in research and development in Bangladeshi agriculture.

Achievements in the Green Revolution era

The Green Revolution contributed significantly to increased agricultural productivity. All farmers within the same category, however, did not benefit equally from this technology shift. A limited irrigated area, weak seed sector and rural infrastructure, and inadequate knowledge of sustainable soil and crop management made the basic foundation of the Green Revolution weak.

Since independence, all successive governments have given high priority to attaining self-sufficiency in food grain production. Although Bangladesh has yet to become self-sufficient, the import requirement has remained steady at about 1.5 million t of rice annually, despite a significant growth in population. Because of the emphasis on rice production, we were unable to bring about any major changes in recent decades in the productivity of other crops and subsectors of agriculture. At the same time, some major socioeconomic reforms, notably a land ceiling on ownership of 25 *bighas* (3.3 ha), price supports for rice procurement, the privatization of groundwater irrigation facilities, structural adjustment programs, and a seed policy to encourage private-sector entrepreneurship, have represented changes in policy areas related to agricultural development. Unfortunately, for various reasons, we have been unable to fully exploit the opportunities arising out of these policy changes, although impressive gain's have been made in the crop sector.

In the past,. fanners were only recipients of modem technology for augmenting agricultural production, but now they have to produce food with modem technology not only without harming the ecology/environment but also by reversing the trends of environmental degradation arising out of unsound agricultural practices. Most developing counties, including our neighbors, are committed to providing economic and ecological access to food for their people, whereas we are only about to ensure physical access to food for our people.

The adoption of modern varieties (MVs) has contributed substantially to increasing production. These varieties now cover about 95% of the rice area in the boro season, about 39% in the T. aman season, and 22% in the aus season. Rice production increased from~ 10 million tin 197 1-72 to 19 million tin 1995-96, with a record production of 1.9.5 million tin 1992-93. Increases have resulted from cropping intensification rather than from increases in cultivated area. Considerable success has also been achieved in wheat production, which increased from 0.1 to 1.3 million t during the same period. Cropping intensity has grown from 143% in 1972-73 to 172% in 1994-95 because of increases in double- and triple-cropped area in the rabi season.

Potato production has increased slightly from 1.2 million t in 1990-91 to 1.5 million tin 1994-95, but its actual potential is much higher. Sugarcane production has remained at around 7.5 million t.

Second-generation problems in the production system

Of all the problems confronting agricultural production systems in the post-Green Revolution era, the most pressing one is our current state of productivity, which is either stagnating or declining in a range of food and nonfood crops. This has been demonstrated by trend analyses based on time-series data of the Bangladesh Bureau of Statistics (BBS), data on long-term yield trials at research institutions, and some surveys/studies on farmers' perceptions about the current status of harvestable yield in their fields. Evidently, the reasons behind the stagnation/decline in productivity are different in irrigated and rainfed farming, mainly because of the differences in production systems in those environments. The major causes leading to a decline in yield frontiers can be categorized in the following sections.

Soil problems

The organic matter (OM) content of mast Bangladeshi soils is low, and different studies show that it is declining alarmingly. More than 50% of our cultivated soils have an OM content below the critical level (1.5%). There are also deficiencies of sulfur in almost 4 million ha and of zinc in 2 million ha of arable land. This limits yield gains and productivity. At the onset of the Green Revolution, 1 kg of added N fertilizer produced 20 kg of grain, which is now 8-40 kg.

Intensive cropping has led to nutrient mining. About 250-300 kg ha-1 of nutrients are removed from the soil that grows two to three rice crops per year. The application of N fertilizers alone over the years has resulted in a considerable loss of productivity in almost all soils of the count. Other soil-related problems, such as salinity, soil erosion, micronutrient deficiency, waterlogging, and alkalinity, constrain growth in agricultural productivity. As a result, overall soil production and productivity are decreasing.

Cropping intensity in some areas is extremely low and far below the national average. Because of changes in rainfall patterns, most rainfed areas remain fallow in the kharif (aus) season. About 35% of the cultivable lands remain fallow in the rabi season after the harvesting of rice in the T. aman season. The potential of hilly areas and the coastal belt has not yet been assessed to exploit them for agricultural development.

Seed quality and varietal replacement

The physical quality of the seeds available to farmers has been deteriorating over time. Physical quality could be maintained through effective postharvest control, chemical dressing, handling, and storage. In Bangladesh, where farmers themselves provide 95% of seeds, it is very difficult to maintain seed quality. The tropical monsoon climate and inadequate technical knowledge constrain the preservation of seed quality on-farm. This problem could be addressed by the government's intervention and/ or private-sector entrepreneurship to provide high-quality seeds to farmers. But as of now, the Bangladesh Agricultural Development Corporation's seed supply capacity is limited to 4% for rice, 22% for wheat, and 5% for potato. To accelerate production growth, the annual seed replacement capacity must be increased and, for cereal crops, it should be more than 30% by the year 2000. Further, there is an unusually long time gap before farmers adopt a newly released variety. Farmers therefore have little choice but to continue to grow older MVs despite the declining trend of yield in their fields.

Irrigation-related problems

The share of pump-irrigated area (by shallow tubewell, deep tubewell, and low-lift power) increased from 17.2% in 1978-79 to 57.7% in 1990-91. Rice alone accounts for 82% of the irrigated area and wheat 9.6%. More than half of the installed capacity of existing irrigation equipment remains unused. Irrigation efficiency is extremely low. On average, crops use only about 25-30% of irrigation water and the remainder is lost on the way due to faulty irrigation systems and poor on-farm irrigation water management practices.

Sustaining the past level of expansion in irrigation by relying heavily on the use of groundwater will be increasingly difficult in the future because of the environmental and social cost of irrigation. The intensive use of groundwater has led to a lowering of the groundwater table in many areas of the north and northwest and the intrusion of saline water in the aquifer in some parts of southern districts. The quality of groundwater is deteriorating because it contains different types of salts, iron, arsenic, boron, sodium, chloride, etc., which adversely affect the operation of equipment and public health.

Increasing Intensity of pest outbreaks

Crop intensification through the use of early maturing MVs and irrigation water has increased pest problems in rice. The susceptibility of MVs to several major pests and diseases is a common reason for production losses. For example, brown planthopper was only a minor pest in the pre-Green Revolution period, but today it is a serious insect pest of rice. Among diseases, bacterial leaf blight, tungro, and ufra have become serious problems in recent years.

Climatic risks that affect agricultural growth

Agriculture has always been associated with risk. One of the major challenges to accelerating agricultural growth is to lessen risk and reduce its consequences by making proper management decisions. This should be based on the study of the most critical risk factors and the effects of different management decisions. The most damaging climatic: risk factors in Bangladesh are drought and flood, which drastically affect the livelihood of hundreds of thousands of farm households.

Drought

Drought annually affects about 2.3 million ha in the kharif season and 1.2 million ha in the dry (rabi and pre-kharit) season. Kharif drought severely affects T. aman rice, resulting in a reduction of about 1.5 million t of rice, about 8% of the total annual production. During the dry season, the adverse effects of drought on production are visible in wheat, potato, mustard, and aus rice. Drought intensity at a given location depends on evapotranspiration, condition of crops, the rainfall distribution pattern, water table depth, and soil structure. The agricultural production system, in drought-prone areas is further aggravated by soil constraints.

Flood

About 1 million ha of crop land are highly flood-prone and 5 million ha are moderately flood-prone. The record floods of 1988 and 1998 inundated about 6t1-65% of the country. In a normal year, flood affects about 2.6 million ha. Recently, it has been estimated that about 7.2 million ha, about half of the total land area, are flood-prone. Normally, flooding depth varies from 0.3 to 2.5 m. We therefore urgently need to develop a program of integrated flood-plain agriculture supported by appropriate research.

Challenges

Food demand

Demand for cereals by the year 2020 has been projected to reach 37.5 million t at an anticipated per capita income growth rate of 2% and 41.8 million t at a rate of 3%. This implies that cereal production will have to increase by 17.5-21.0 million t from the 1990 level to reach the amount needed by 2020. Similarly, demand for pulses is expected to reach L6-2.2 million t versus a baseline consumption of 0.9 million tin 1990. Around a 3-fold increase in demand from the current consumption level has been anticipated for tubers and a 44-fold increase for fruits. Demand for food items of plant origin is expected to reach 61.4 million t at the 2% income growth rate and 72.3 million at the 3% income growth rate from the 1990 consumption level, of 29.2 million t.

Demand for food products of animal origin is expected to increase at higher rates. By 2020, demand for milk will be around 2.8 million t at the 2% income growth rate and 3.8 million t at 3% income growth versus a baseline consumption of 0.9 million tin 1990. Similarly, demand for meat will be three to four times the 1990 consumption level. Demand for fish will be around 4.4-5.8 million t versus a baseline consumption of 1.6 million tin 1990. The total demand for food items of animal origin by 2020 is expected to reach 8.5 million t at the 2.0% income growth rate and 11.3 million t at the 3.0% rate, The projected demand figures mentioned in this context should, however, be interpreted cautiously because they are likely to vary with variation in assumptions and factors that affect the demand for various food items.

Food production is an important part of food security, but not the only one. Improving agricultural productivity through sustainable technologies and practices can substantially increase local food availability. But food sufficiency at the global, national, and regional levels does not rule out food insecurity locally. To ensure food security for everyone in Bangladesh, our activities should focus on household food production. Such activity can be successful if planning is carried out at the micro level.

Alleviating poverty

Bangladesh is one of the most densely populated countries in the world. The average population density is around 800 persons km^{-2}. The population was 70 million in 1971-72, but increased to about 120 million in 1995-96, wit a 2.2% annual growth rate.

Poverty is a serious and persistent problem in Bangladesh. A major consequence of poverty is hunger. Nearly 60-65% of the population, for whom farming is the main source of income and livelihood, lives below the poverty line. So, the lower productivity of Bangladeshi agriculture is the main cause of poverty, which leads to the overexploitation of natural resources. The extent, intensity, dimension, and nature of our poverty is diverse; getting out of this vicious circle is a major challenge. This would require packages of appropriate technologies, training of people at the grass roots, and the availability of credit for targeted production programs.

Planning production by relying on science and technology

The successful application of science and technology in agriculture is important for agricultural growth. Agricultural research has been successful in developing technologies that bring about major gains in productivity. Unfortunately, for several reasons, only one-third of the technologies developed have reached fanners so far, leaving room for fu~iher intensification of agriculture. On the other hand, gains in productivity have remained confined to selected crops, creating an intercrop disparity in production and a regional disparity in agricultural development. Local production planning using site-specific modern technologies and an agroecological database with location-specific extension programs can bring about breakthroughs in production.

Improving the productivity of pulses and oilseeds

To increase the production of pulses and oilseeds, efforts have to be made to increase the area under pulses by introducing short-duration modem varieties, intercropping, and using available moisture after harvesting kharif crops in rainfed areas- Action plans for seed supply and training of farmers should be developed and implemented for target area Major strategies for making breakthroughs in this field include

1. Intensive cultivation of high-yielding pulses and oilseeds with optimal inputs in all potential areas of the country in place of cereal crops.
2. Popularization of a number of viable pulses and oilseed-based cropping patterns and inter/relay cropping in raided and irrigated areas.

3. A major emphasis on developing modem varieties of pulses and oilseeds with such traits as early maturity, high yield, and drought and pest resistance.

The homestead production system

Bangladesh has about 15 million households in rural areas spread over 68,000 villages. The average national homestead area is about 525 m^2 and 13% of that is under homestead farming. These homestead areas represent one of the last frontiers in agricultural production in our struggle against malnutrition and food shortages. The environmental, social, economic, and technological benefits from the proper use of homestead areas are much higher than in crop field fanning. Therefore, special programs on integrated homestead development should be undertaken to increase agricultural production.

Improving the management of natural resources

Increasing the productivity of agricultural crops by regenerating and integrating the natural resource base should be the major Thrust to make agricultural development more sustainable. The full potential of agricultural crops and inputs can be realized without harming the natural resource base through the integrated use of soil, water, and crop management techniques. Increasing the productivity of degraded soils in rainfed and irrigated fanning, making agricultural inputs wore efficient, creating special programs to develop drought-prone areas, command area development programs, developing small and marginal farmers' farming systems, and other location-specific development programs should be undertaken urgently to restore the productivity of the natural resource base.

Opportunities to accelerate agricultural growth

How can agriculture in Bangladesh be induced to grow in a manner that would reduce risk, satisfy the increased demand for consumption, and increase human well-being? The importance of technology is obvious and any discussion on agricultural growth traditionally focuses on technological options. We can broadly classify growth opportunitiesin agriculture for three areas: (1) technological, (2) institutional, and human capital, and (3) policy environment.

Technological advancement

Closing the exploitable yield gap. The genetic potential of existing MVs has not been fully realized under real farming conditions because of low levels of management and other factors. This is evident in a range of crops that demonstrate gaps between the yield of on-station experiments and farmers' fields. Even the yields of demonstration trials conducted by extension agencies in farmers' fields and the yields of on-farm trials conducted under farming systems research and on-farm research and development programs are much higher than those achieved by farmers under their own practices. In rice, this gap averages about 1.6 t ha^{-1}.

The current yield of wheat is around 1.8 t ha^{-1}. Wheat yields increased from an average of 0.9 t ha^{-1} in the early 1970s to 2.5 t ha' in the early 1980s, but declined to 1.8 t ha^{-1} during t993-95. But experiment station yields have averaged about 4 t ha^{-1} and those of on-farm demonstration plots about 3 t ha-1 during the sane period, indicating a huge growth potential to be exploited (Morris et al 1997). Likewise, there is a major opportunity for raising yields of potato in Bangladesh, which has a national average of only 9.8 t ha^{-1} at present.

Creating new genetic potential for productivity. The short-statured, stiff-strawed MVs of the Green Revolution era must now be matched by similar yield-stimulating improvements in new rice varieties. The existing harvest index of MVs is 0.5. We can increase this index to 0.6 by redistributing photosynthates so that more dry matter is recovered in the form of grain. Changes in canopy architecture and delayed leaf senescence may increase the photosynthetic capacity of individual leaves.

A new plant type designed by IRRI has limited tillering capacity (no unproductive tillers), 200-250 grains panicle. sturdy stems, a vigorous root system, a height of 90-100 cm, and a growing period of 100-130 d with acceptable grain quality. This plant type could be more amenable to dense planting and direct seeding, with a capacity to produce a 20-40% increase in yield. It might be available in farmers' fields after 2000.

Exploiting hybrid vigor or heterosis in rice and wheat is another option for achieving yield gains Achievements in China in this area of research are well documented. In countries outside China, there have been, reports of 150-200% increases in yield because of hybrid varieties.

Imp roving the efficiency of scientfic breeding. Conventional breeding systems will play a key role in enhancing the yield potential of MVs, but the availability of rapidly changing biotechnology tools could accelerate development in the transfer of genes from one species to another This would open new opportunities for developing MVs that will grow well where we want them to grow.

Germplasm enhancement to increase yield potential will, be needed to obtain more efficiency in breeding programs. An expeditious breeding process, a shorter time gap between varietal development and adoption, more options for farmers to choose the right varieties to fit their farming environments, and farmers' participatory breeding could bring about breakthroughs in this area.

Improving input-use efficiency and crop management. Some crop management technologies with substantial potential are a crop-soil management system to nummize the loss of water, nutrients, and soil; methods to control the availability and release of chemical nutrients to growing plants; strategic combinations of organic and inorganic sources of nutrients; and improved varieties and cropping systems that maximize local land, water, and climatic resources. There i,s much to gain immediately from the proper use of existing improved crop varieties and management technologies that have not yet been extended to farmers.

Biofertilizer. This is a cost-effective and renewable source of plant nutrients to supplement chemical fertilizers. Bangladesh has made considerable progress in developing biofertiizer technologies for lentil, chickpea, mungbean, cowpea, groundnut, soybean, and dhaincha production. Yield increases from the adoption of biofertilizers range from 15% to 200% for different crops. Their use also improves chemical fertilizer-use efficiency. Though the benefits derived from biofertilizers are quite significant, they have not been popular due to various constraints in production, distribution, and marketing. Steps need to be taken for the large-scale manufacturing of inoculum in the country with the help of the private sector

Integrated pest management (IPM). So far, only 3,500 farmers have received training on IPM, whereas in Indonesia training reached 300,000. IPM-trained farmers obtained at least 1 t ha^{-1} more rice yield than untrained tanners. IPM-trained farmers spent only 150 Tk ha^{-1} on pesticides, whereas untrained farmers spent 660 Tk hat. It is wont mentioning that the use of pesticides in Bangladesh is only about 8,000 t yr^{-1}, which is very low compared with other developing countries. So, through IPM, we should promote the judicious application of fertilizer and pesticides. The main idea of the IPM concept is to adopt environment-friendly plant protection measures that harmonize with other segments of crop husbandry to attain higher crop productivity.

Integrated plant nutrient system (IPNS). Combining the use of organic and inorganic fertilizers, promoting the balanced application of fertilizer, improving conditions for biological nitrogen fixation, and correcting problems of micronutrient deficiencies are urgently needed for long-term environment-friendly farming practices. For this goal, using the IPNS concept can help us formulate fertilizer reconirnendations to achieve the desired level of crop production without reducing native soil fertility.

Irrigation water management. Irrigated fanning by far offers the largest opportunity for exploiting growth potentials over an extended period of time. Irrigated agriculture can be extended from its current one-third of the cultivated area to more than one-half. But water is a costly resource and its efficient use means bringing additional area under irrigation without making extra investments. Where water scarcity is high, a partial irrigation option can be considered, For example, one supplemental irrigation in T. aman rice, the major rainfed lice crop, during October holds promise for increasing yield by 40% to more than 100%.

An irrigation system that provides assured water when needed at the farm gate is a simple innovation that can reduce water withdrawals. Water consumption can be reduced by scheduling irrigation according to weather conditions and crop moisture needs. Productivity per unit of available water can be increased by lining field channels, reducing irrigation frequencies, and maintaining wet conditions in the field, but not always standing water, which is a common feature of our rice fields. Other ways of increasing efficiency are, for example, by upgrading pump efficiency and fully exploiting the irrigation command area serviced by an irrigation unit. Developing new sources of surface water for irrigation and rehabilitating deteriorated sources could open vast opportunities for increasing irrigated area, although this may require considerable public investment.

This is not to deny that growth opportunities still exist in rainfed farming. Much can still be achieved in areas with no access to irrigation water by taking advantage of minimum/zero tillage, moisture conservation, sequential cropping, varietal selection for late planting; fertilizer use, etc. Evidence suggests, however, that, in aggregate, growth opportunities are not strong enough for a quantum jump in output sufficient to match the required higher growth rates of production for a range of noncereal crops.

Institutional and human capital

Developing appropriate institutions in response to changing economic environments is a precondition for accelerating growth in agriculture. Institutional development in Bangladeshi agriculture has not kept up with the emerging challenges. The 1970s and early 1980s were marked by the development of an impressive agricultural research system in the public sector An ISNAR survey conducted in 1988 ranked Bangladeshi NARS, in terms of national impact, at number 14 out of the 130 NAPS in less developed countries. But inadequate public investment in research over the years, which now stands at 0.2% of the GDP, has resulted in the underfunctioning of this research system. To reap the full benefit from investments made in strengthening the research system, annual investments in agricultural research must be increased substantially to at least 2% of the GDP as recommended by the World Bank and FAO.

Developing scientific and professional human capital is another important factor in harnessing the benefit from technological innovations. There should be a clear policy framework for implementing a human resource development program that especially addresses gaps in high-technology areas. To realize the maximum benefit from human resources, we also need to create a conducive working environment so that scientists can give their best to the country. The incentive and reward system should be restructured in a way that promotes creativity and excellence, sustains the high morale of scientists and discourages them from looking for better opportunities abroad.

The present democratic policy in Bangladesh is expected to lead to decentralization of the government and growth of the nongovernmental institutions that are essential to a broad-based agricultural growth strategy. The pace at which these institutions would grow and evolve depends on the level of public spending in agriculture.

The emerging private sector can play a useful role in adopting and refining technology, in developing targeted technology, and in undertaking research, especially for export commodities and technologies. Agricultural support service is another area where involvement of the private sector would promote efficiency and reduce the time lag in getting technological innovations to end users. Privatization of the business in inputs has created a favorable environment for the private sector to make investments that would spur the growth of business related to fertilizer, pesticides, seeds, and tubewells and pumps. Further opportunities for exploiting the potential of the private sector lie in such areas as joint-venture projects in agro-processing, the export-oriented food-processing industry, and the production and distribution of improved seeds.

Policy environment

Policy interventions in support of rapid agricultural growth should build on a more market-oriented approach to agricultural development with greater reliance on the private sector This should be balanced, however, with a deep concern for food security and the need to ensure adequate quantities of food and relatively stable prices for food staples. These concerns could be addressed effectively through government policies for trade, the exchange rate, and price stabilization.

Agricultural policy should be an integral part of the overall economic policy of the country. Agriculture has to be treated as an industry to attract primary investment from home and abroad, with the ultimate goal of meeting the challenges of the 21st century.

To ensure a proper functioning and coordinated research network of NARS under the umbrella of the BARC, drastic policy interventions are urgently needed. Scientific environments should be nurtured through international linkages, exchange visits, seminars, and symposia to improve the capabilities of scientific professionals. Agricultural research and extension systems should be demand-driven, more participatory, and accountable.

In view of the country's growing needs for agricultural development, the private sector should take the lead in delivering to end users appropriate technologies such as inputs, credit, training, processing, and marketing services. We need policy guidelines to harmonize these private-sector activities with those of NARS.

We must look into the future, beyond the issues of self-sufficiency in agricultural production. For the long-term sustenance of agricultural growth, commercial agriculture must be encouraged, with appropriate policy support. Area and commodity development programs for varied agroecological zones and commercial zoning of agricultural commodities based on market potentials should be undertaken.

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Citation: Bhuiyan SI, Karim ANMR, editors. 1998. Increasing rice production in Bangladesh: challenges and strategies. Manila (Philippines): International Rice Research Institute, and Dhaka (Bangladesh): Bangladesh Rice Research Institute.

Sustainable agricultural development in Bangladesh: challenges and issues

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Reducing poverty to socially acceptable levels by 2025 will remain an elusive goal for Bangladesh unless the country can sustain a long-term economic growth of 6-7% yr1. To support economic progress at this rate and to generate a marketed surplus of food for the growing urban population, agriculture must grow at a rate of 3.5-4.0%, compared with the historical record of only 2.0% yr^{-1}. Agriculture can achieve this only through faster diversification-through improved performance of nonrice crops, fisher les, homestead-based agroforestry, and livestock production; and through exploitation of foreign markets for vegetables, fruits, and spices. Rice, which now occupies more than three-fourths of the cropped land, must release land and labor resources for other agricultural activities and achieve greater efficiency in the use of water to support agricultural diversification. This calls for further technological progress that increases the productivity of resources now tied to rice cultivation. Therefore, Bangladesh must continue to strengthen the infrastructure of rice research for faster development and diffusion of improved technologies. Major challenges for Bangladesh include developing appropriate technologies for unfavorable environments, particularly for the flood-prone and coastal areas, shifting the yield ceiling for irrigated lands, and devising appropriate crop and natural resource management practices that would mitigate adverse ecological consequences of intensification of the rice cultivation system.

Alleviating poverty and attaining food security for its fast-growing population are the most critical challenges that Bangladesh has faced since its independence in 1971. Successive 5-yr plans have set these as the twin goals of development, but so far only moderate progress has been achieved, Today, at the doorstep of the 21st century, much remains to be done to attain these goals. The “business-as-usual” scenario is clearly not acceptable if these chronic problems must be solved within a reasonable time and if a better society for the next generation must be established. This paper attempts to identify the critical challenges and issues that agriculture will face if Bangladesh is to succeed in accelerating the overall economic growth needed to make substantial progress in alleviating poverty. It also draws some implications for rice research for sustainable food security and balanced agricultural development.

A vision for alleviating poverty

The economic miracle that has so clearly distinguished Asia from the other continents in the developing world during the last three decades has bypassed Bangladesh. The first decade after 1973 (when the economy barely recovered from the ravages of the war of independence) saw national income grow at 3.2% yr^{-1}, which was largely absorbed by the growth of population (Table 1). The paltry growth of 0.8% yr^{-1} in per capita income that Bangladesh gained during this decade hardly trickled down to low-income groups. Growth in national income accelerated to 4.6% yr^{-1} over the next decade (1983-93). The impact of growth in national income on per capita income was stronger because the population growth rate declined from 2.4% to about 2.2% yr^{1}. A 27% increase in per capita income representing total growth for the entire decade (l983-84––1993-94) made a moderate impact on poverty alleviation––from more than 60% of the population below the poverty line in the early 1980s to about 50% in 1994 (Rahman 1989, Hossain et al 1996, Hossain and Sen 1992). The agricultural sector grew at a rate of only 1.9% yr^{-1} during both decades, while growth of the crop production sector decelerated substantially. The productivity of both land and labor in agriculture, however, increased at a respectable rate, as the country experienced a large-scale migration of population from rural to urban areas and of workers from farm to nonfarm activities in both rural and urban areas (Rahman 1989, Hossain et al 1996). The increase in rice production was on a par with population growth, almost entirely due to the increase in yield (Fig. 1). Per capita rice production, however, has yet to regain the pre-independence level. Although in years of good harvest when self-sufficiency in rice Production is claimed, the government has been maintaining a yearly import of 1.5 million t of cereals (mostly wheat) to feed the growing population.

Since land, capital, and economic opportunities are fairly unequally distributed and underemployment is widespread, the trickle-down effect of economic growth on low-income groups is fairly weak. Thus, eradication of poverty will remain an illu-

Table 1. Growth and Structural change of the economy in Bangladesh, 1973-74-1993-94.

Sector	Annual growth rate (%)		Share (%) of gross domestic product	
	1973-74-1983-84	1983-84 1993-94	1973-74	1993-94
Agriculture	1.9	1.9	51.0	34.5
Crops	2.1	1.6	42.0	24.5
Fisheries	2.9	3.7	3.9	3.4
Livestock	1.1	3.4	3.0	3.4
Forestry	4.2	1.9	2.1	3.4
Nonagriculture	4.2	5.4	49.0	65.5
Gross domestic product	2.9	3.8	100.0	100.0
National income	3.2	4.6	-	-
Per capita income	0.8	2.4	-	-

Source: BBS (1993, 1995a)

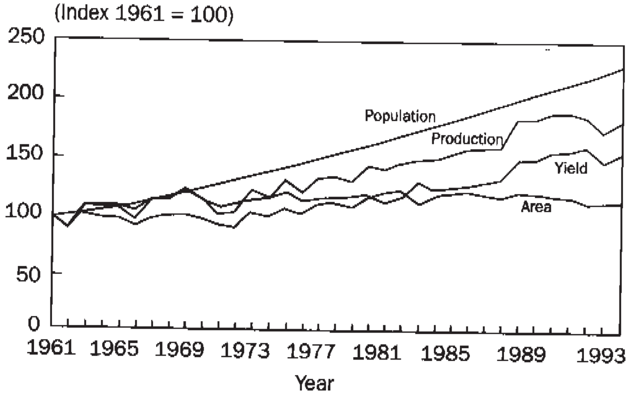

Fig. 1. Trends In rice production, area, and yield, Bangladesh, 1961.95 (FAO 1996).

sion if the economy continues to grow at the historic rate. If per capita income grows at 2.6% yr^{-1}, it will take 28 yr to double it from US$250 today to $500 by the year 2025. At that level. of income (which is now enjoyed by Pakistan), nearly a third of the population will live in poverty If Bangladesh were to reduce poverty to around 20% over the next quarter century, it must target to reach an income level of around US$1000 within that time horizon. Indonesia had been able to reduce poverty to 15% with that level of income, before the recent economic crisis hit the country in 1997. To attain that goal, the target for the growth of national income must be set at 6.5% yr [1] With political stability, prudent economic policies, moderate inflow of foreign private investment, and efficient implementation of development projects, that growth target should not be difficult to achieve.

Challenges for agriculture

Intensification. The continued high growth of population in a country that is already the most densely settled in the world poses the greatest challenge to agriculture. Almost 70% of the total land area in Bangladesh is already cultivated, and 95% of the cropped land is used for food production, 75% to grow rice alone (BBS 1995a). Because an increased population must be fed, the pressure on agriculture to produce more food will continue until Bangladesh reaches a stationary population. The pressure will, of course, be lower if a favorable growth in export earnings enables the country to achieve self-reliance in food through imports.

Bangladesh has achieved moderate success in population control; the annual growth of population has declined from 3.0% in the 1960s to 1.8% in the 1990s. But even with this declining growth rate, the population is projected to increase from 120 million in 1995 to 173 million by 2020 (Fig. 2). At that time, the population will still grow at 1.1 % yr^{-1} and will not reach a stationary state before the end of the 21st

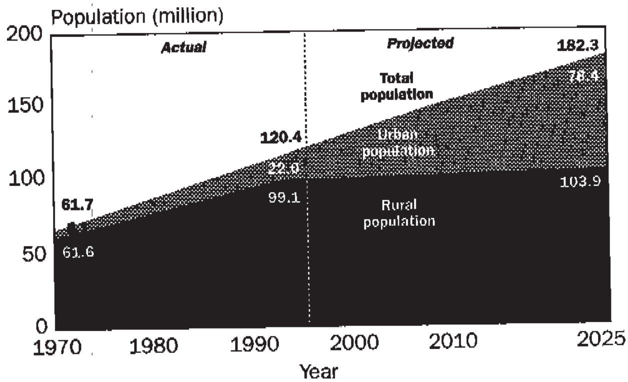

Fig. 2. Trends In Bangladesh population, 1970-95 and projection for 1995-2025 (World Bank 1994, World Population Projection 1994-95).

century (Bos et al 1994). With its present population size, Bangladesh supports 14 persons ha^{-1} of arable land, comparable with the levels in southeastern China and Java, Indonesia, the most intensively cultivated regions in the world. The intensity of cultivation that Bangladesh will, have to practice to feed the growing population and the care with which it has to be done to sustain the natural resource base from which all food must come can hardly be overemphasized.

Commercialization. Because rural areas can no longer provide adequate employment to the new entrants in the labor force, rural-urban migration has been taking place at a rapid rate. The urban population as a proportion of the total population. increased from! only 5.2% in 1961 to about 18.3% in 1991. The United Nations projections show that tost of the additional population over the next quarter century will be located in urban areas and urbanization will reach 40% by 2020. With rapid urbanization, theorganization of production will change from a subsistence orientation to production for markets. Thus, relative prices and profits will become a more important driving force behind the growth in food production than they were in the past. The government will therefore have to use technology, wade, and pricing policies more judiciously to promote a balanced agricultural development.

Diversification. Bangladesh is no exception to the general rule (known as Engle's law) that as incomes go up, the proportion of income spent on nonfarm goods and services goes up more rapidly. Hence, it is natural, that the importance of agriculture in the national economy declines with economic progress. In Bangladesh, agriculture's contribution to national income has already declined from 51% in 1973274 to 35% in 1993-94, even with the moderate economic progress that was achieved over the last two decades (Table 1). If Bangladesh succeeds in accelerating economic growth, the importance of agriculture will decline more rapidly, although the value added will continue to increase in absolute terms. This structural transformation will take place within the agricultural sector itself because the increase in demand induced by income growth varies depending on the food item. Within food, the budget is allocated in favor of vegetables, fruits, fish, and livestock products, away from staple grains, as household income increases. The expenditure pattern changes further with changes in consumer tastes and preferences associated with urbanization.

Projections of the changing pattern of demand for different food, items at different income levels based on the report of the household expenditure survey conducted by the Bangladesh Bureau of Statistics in 1992--93 (BBS 1995b) can be seen from Appendix Tables 1--4. In general, urban households spend a relatively smaller share of their income on food than do rural households. The demand is strong for livestock products, fish, and edible oils, followed by pulses and vegetables, and is weak for rice and wheat. A 10% increase in per capita income for rural households will increase the demand by 16% for livestock products, by 8--9% for fish and edible oils, by 5--6% for potato and vegetables and pulses, and by only 2% for rice and wheat. If Bangladesh succeeds in tripling per capita income over the next quarter century, the allocation of budget to food will decline substantially. Rice consumption has almost reached saturation points, and per capita consumption will start declining in absolute terms within the next 10--15 yr. The changes in food composition generated by this differential pattern of demand growth will make Bangladesh agriculture much more diversified in the early 21st century.

Required rate of growth. Table 2 illustrates the estimates of the rate at which agriculture and its various subsectors must grow to support overall economic growth if the government wants to keep the terms of trade unchanged. Under a scenario of accelerated growth, the pressure on the agricultural sector will be much higher than today; agricultural production must increase from 2.6% to 3.6% yr^{-1}.

Most of the additional increase in agricultural production must come from livestock, fisheries, and nonrice crops. If the food supply fails to increase at these rates, relative prices will increase and the worsening terms of trade for the nonagricultural sectors will adversely affect their growth. The supply situation could be eased through

Table 2. Required rate of growth (% yr^{-1}) of agriculture to support alternative development scenarios.

Activity	Business as usual[a]		Accelerated growth[d]	
	1992-2010	2010-2020	1992-2010	2010-2020
Crop production				
Rice	2.2	1.9	2.9	1.4
Nonrice	2.0	1.4	2.3	0.5
Fisheries	3.2	2.9	4.0	2.9
Livestock	4.7	4.1	7.0	4.2
Agriculture	2.6	2.5	3.6	2.2
Nonagriculture	5.3	5.1	7.6	7.4

[a]Assumes a growth of national income at 4.5% yr^{-1}. [b]Assumes a growth of national income at 6.5% yr^{-1}. Source: Estimates based - on projection on changing patterns of demand for different food items (see Appendix Tables 1-4 for details).

imports, but that will require a favorable growth in exports and a large increase in the allocation of scarce foreign exchange. The import bill on account of edible oils alone escalated from U S$88 million to $204 million within the 1983-93 period.

If economic growth accelerates, the pressure to increase rice production will be substantially reduced beyond 2010, as consumers will have the economic capacity to go for a more balanced diet that substitutes food containing more proteins and vitamins for rice, which is the cheapest source of energy. To support a 6.5% rate of growth of national. income, rice production should increase at 2.3% yr^{-1} till 2010 and at only 0.5% yr^{-1} during the next decade. In 2010, rice production needed to meet the growing demand is projected at 46.4 million t (in paddy terms, after allowing 10% for seed, feed, and wastage) under the business-as-usual scenario, and 49.5 million t under accelerated growth. In 2020, the required growth in rice production is 52.0 million t. Failure to increase production to this level or to meet the demand-supply gap through imports will lead to an increase in rice prices relative to other commodities.

Issues in agricultural development

Balanced nutrition and diversification of farming systems. Table 3 relates the normative minimum requirement of different types of food, as specified by the Food and Agriculture Organization for balanced nutrition (FAO 1996), to the actual intake estimated by the household expenditure survey of 1991-92 for different income groups. The poor have a just adequate intake of staple grains and their consumption of vegetables was only 20% lower than the minimum requirement in rural areas and 5% lower in urban areas. But for pulses, fish, and livestock products (which are rich in protein or which provide balanced nutrition), the poor eat less than 50% of the minimum requirement. Also, the difference in food intake between the poor and the rich is not very large for grains and, vegetables but is substantial for the other types of food. The unbalanced nutritional status of the people is partly the result of the past agricultural development strategy that focused only on staple grain production (mostly rice) and the development of irrigation, flood control, and drainage that also largely benefited the production of staple grains. The increased profitability of rice vis-a-vis other crops and the expansion of irrigated rice cultivation in the dry season have reduced the area under nonrice crops (particularly pulses and oilseed), and the embankments constructed for flood protection and irrigation have reduced the production of fish in the vast floodplains of Bangladesh. The government's crop diversification efforts since the early 1980s have had limited success because the program was pushed without 'considering farmers' alternative economic opportunities. Bangladesh must intensify its efforts to diversify the farm economy to achieve balanced nutrition for its people.

From an agronomic standpoint, the determining factors for crop diversification are how noncereal crops and noncrop enterprises will fit into rice-based farming systems (Rahman 1989). Minor crops such as pulses and oii.seeds compete with other dry-season crops grown on retained soil moisture or under irrigation. The extent to which fanners will adopt improved varieties will depend on the characteristics of

Table 3. Adequacy of food Intake (g capita^{-1}d^{-1}) for different Income groups, rural-urban areas, 1991-92.

Type of Food	Minimum requirement (g capita^{-1}d^{-1})	Estimated rural area consumption			Estimated urban area consumption		
		Poor	Medium	Rich	Poor	Medium	Rich
Cereals	437	465	581	574	495	553	526
Pulses	40	13	19	29	18	24	25
Fish	48	19	35	76	32	54	59
Meat & Eggs	12	6	15	25	9	23	46
Vegetables	177	142	195	250	168	232	266
Milk	58	10	19	48	10	30	43

Source: BBS (1995b).

such varieties, income opportunities forgone, and the way they fit into and complement farming systems (Ateng 1995). Fish and livestock production may involve conflicts with the current form of land use and the extent to which farmers are prepared to change will depend on, among other things, macroeconomic policies, the development of marketing infrastructure, the quality of the extension system, and the avail ability of credit and other facilities.

Agricultural research and development of Improved technologies

In the past, allocation of research resources has taken little account of either the average or marginal contribution of different crops to the overall value added in agriculture. In the future, efforts will be required to ensure that allocation closely reflects these factors so that research does not ignore potentially important crops. Major research efforts should be directed to

- fish, livestock, and agroforestry-based technologies, with special emphasis on home-based production systems that can be adopted by landless and marginal farmers;
- improved varieties of noncereal crops, particularly pulses and oilseeds, to meet the growing shortage of these food items that are very important for low-income groups; and
- improved varieties of rice suitable for submergence-prone environments.

Slackening of the demand for rice does not imply that the government should abandon or reduce its support for rice research. Rice now accounts for 55% of the agricultural value added compared with 10% for fisheries and 8% for livestock production. Even under the accelerated-growth scenario, the share office in agricultural value added will remain 34% in 2020, still higher than the combined share of the livestock and forestry sectors (Table 4). Also, rice now occupies 75% of the total cropped area in Bangladesh. Unless some land is released from rice cultivation for use by nonrice crops, it will be difficult to achieve the target of 3--4% growth in supply for these crops, even under the most favorable scenario of technological progress. If the area under nonrice crops has to increase at 1% yr^{-1}, rice land area must

Table 4. Projected change (% share of output) in the composition of the agricultural sector, 2010 and 2020.

Subsector	Actual 1992	Business-usual scenario		Accelerated-growth scenario	
		2010	2020	2010	2020
Rice	49.6	43.5	39.1	40.3	34.0
Nonrice Crops	21.9	23.3	24.5	23.7	25.6
Fisheries	10.4	11.4	12.6	13.2	13.2
Livestock	8.2	11.8	13.9	18.2	18.2
Forestry	9.9	9.9	9.9	9.9	9.9
Agriculture	100.0	100.0	100.0	100.0	100.0

[a]Estimates are based on the changing pattern of food consumption.

Table 5. The share (%) of the urban population in the total consumption of various food items Under alternative development scenarios.

Food Item	Actual 1992	Business-usual scenario		Accelerated-growth scenario	
		2010	2020	2010	2020
Rice	15.6	28.1	36.3	24.8	30.2
Nonrice crops	20.8	34.2	41.4	36.3	42.4
Fisheries	23.8	39.3	48.3	43.1	49.7
Livestok products	23.8	35.6	43.7	45.4	49.9
Total	18.0	31.1	39.2	31.4	38.0

be reduced by about 1.0 million ha over the next 25 yr, almost the same amount of land now occupied by the traditional aus crop, which farmers will be willing to reallocate because of its low productivity and profitability. To produce the 52 million t of rice targeted for 2020 with the reduced land area, the national average rice yield must increase to 5.5 t ha^{-1} from the present level of 2.8 t ha' (an annual. growth of 2.9% yr^{-1}). Without further technological progress in rice cultivation, achieving this rate of growth will be a tall order

Development of rural infrastructure. Rapid urbanization and faster growth in the nonfarm sectors imply that the share of urban areas in total food consumption will continue to increase. Projections of food consumption made separately for rural and urban areas (see Appendix Tables) show that for rice, urban consumption as a proportion of total consumption will increase from 16% to 30% within the 1992-2020 penod; for fisheries and livestock, the share will increase from 24% to 50% (Table 5). Because food will be produced mostly in rural, areas, the surplus will have to be processed, stored, and transported tb reach urban consumers. The private sector will come forward to invest in these economic activities in response to market opportunities. But the government will have to invest in rural infrastructure such as electrification and farm-to-market and feeder roads to connect villages to secondary markets

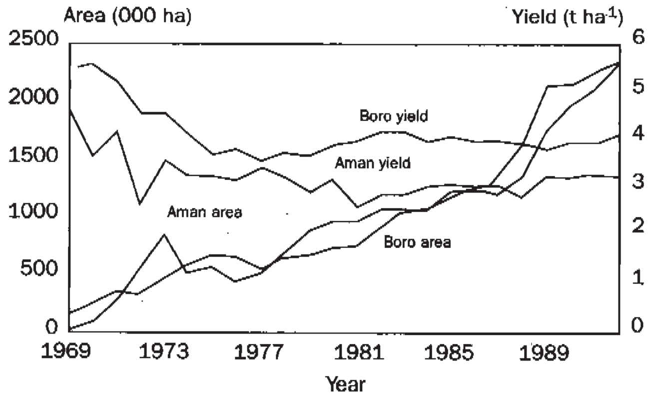

Fig. 3. Trends In yield and area of modem varieties, aman and boro rice, Bangladesh, 1969-92 (BBS 1993).

(Asaduzzaman 1989). The lack of infrastructure facilities will depress farm-gate prices and will constrain the growth of perishable food items. The provision of rural infrastructure has been shown to have a major impact on agricultural production, employment, incomes, consumption patterns, and investment behavior in Bangladesh (Alimed and Hossain 1990).

Ecological sustainability of intensive agriculture. Concerns regarding the sustainability of the Green Revolution technology have been growing in recent years, following a recent World Bank study that showed a long-term downward trend in the yield of modem varieties at the district level (Pagiola 1995, Asaduzzaman 1995, Brandon 1995). Figure 3 shows the long-term trend in the expansion of area under modem rice varieties and their yields at the national level. The decline in yield took place mostly during the early 1970s, at the time of early adoption of modem rice Varieties. Yield is expected to decline in the initial stage of adoption with the spread of the technology from entrepreneurial to average farmers. Since the mid-1970s, there has been no further decline in yield, which fluctuated around a horizontal trend line depending on climatic conditions.

No serious attempt has yet been made in Bangladesh to examine the impact of intensive rice cultivation on the deterioration of soil quality or the soil's nutrient-supplying capacity. Farm survey data are not very helpful in addressing this issue. Information on variation in crop yield at the parcel level (as collected by the Bangladesh Institute of Development Studies from the same set of farmers in 62 villages in Bangladesh during 1987 and 1994) is reported in Tables 6 and 7. The yield in land parcels used to grow two modern varieties consecutively in the dry and wet seasons was not necessarily lower than that obtained in parcels where a single modem rice variety was grown or where a modem rice variety followed a traditional rice or nonrice crop. Yield did not decline in modem rice varieties during the 1987-94 period. For

Table 6. Yield (t ha^{-1}) of modern varieties (MV) under different cropping systems, 1994.

Cropping pattern	Wet season	Dry season
MV-fallow	2.8	4.6
MV-MV	3.3	4.8
MV-traditional rice variety	2.7	5.2
MV-nonrice	2.8	4.3
Total	3.1	4.8

Source: Unpublished data from a survey conducted under the Analysis of Poverty Trend Project, Bangladesh Institute of Development Studies (BIDS).

Table 7. Change in rice yield (t ha^{-1}) of modern varieties at different topsequence positions, 1987-94.

Flooding depth	Wet season		Dry season	
	1987	1994	1987	1994
Not flooded	2.9	2.7	3.8	4.6
Up to 30 cm	3.4	3.2	3.9	4.8
30-100 cm	3.0	3.1	4.7	5.0
More than 100 cm	-	-	4.8	4.7
Total	3.2	3.1	4.3	4.8

Source: BIDS survey of 62 villages under the Analysis of Poverty Trend Project and BIDS-IRRI Differential Impact Study.

the dry season, yield was substantially higher in 1994 than in 1987 for all land types. Only in the uplands (which are not flooded) was the wet-season yield somewhat lower in 1994.

Because 40% of arable land is regularly flooded by a river overflow that carries silt (this becomes 60% during times of disastrous floods), Bangladesh should have less serious problems in maintaining soil health than countries with larger areas under upland farming. The risks of deterioration in water quality and human health because of the heavy use of agrochemicals, micronutrient deficiencies in soils due to the unbalanced use of chemical fertilizers, and a reduction in fish habitat are, however, serious environmental issues that need to be addressed for sustainable agricultural development. The efficient management of natural resources soil, water, and biodiversity-will be critical in establishing sustainable agricultural practices for higher and more stable food production.

Conclusions

The response to the changing pattern of demand, the future strategy for agricultural growth must contain elements to promote noncereal crops and fish and livestock production. Faster development of livestock and fisheries may promote both equity and food security by focusing attention on disadvantaged social groups and regions where the crop production environment is unfavorable. Livestock and poultry raising are usually performed by women who can do the work within homesteads, while doing their usual household chores. Because women from poor families are under pressure to engage in income-earning work, providing them access to credit for poultry and livestock raising could support their efforts to raise family incomes and improve their access to food. Commercial fishermen belong to low-income groups and community fishing in the floodplains is done by the rural poor The promotion of the rice-fish cropping system in the deepwater floodplains and saline-affected coastal areas (the areas bypassed by the Green Revolution) could help improve economic conditions of the rural poor, particularly in Bangladesh's less developed regions.

Because of severe land constraints, sustainability of growth in crop production in the 21st century will depend on the government's continued support for agricultural research to further develop technologies and improved farming practices and on its efforts to disseminate these technologies to fanners. Technological progress in rice and wheat has reduced the competitiveness of pulses and oilseeds and the area under these crops has continued to decline. Research on these crops must be intensified. A systems approach has to be taken for broad-based agricultural research that requires collaboration and coordination among various research institutions. Rice research should explore ways to fit nonrice crops in rice-based farming, taking into account the seasonal distribution of rainfall and other agroclimatic factors. Crop diversification programs must ensure that production and farmers' income from rice cultivation are maintained. The target for productivity growth in rice cultivation should be set much higher than the demand for rice to provide incentives to fanners to release low-yielding rice land for the cultivation of nonrice crops. Future strategies for rice research should include elements for shifting upward the yield potential of modem varieties during the dry season, as tanners have already achieved high yields; developing submergence-tolerant varieties for the rainfed ecosystems; and saving water and fertilizer to reduce the costs of cultivating modem varieties.

Appendix Table 1. Estimates of consumer demand functions for food items, rural Bangladesh, 1991-92.

Food item	Regression coefficients			R^2	Income elasticity of demand		
	Intercept	Log of per capita income	Inverse of per capita income		US$200	$400	$600
Rice	275.0	-18.21	-474.2	0.96	0.25	0.06	-0.08
Wheat	-3.0	6.33	35.1	0.72	0.12	0.25	0.26
Pulses	-0.8	3.82	-0.1	0.96	0.61	0.43	0.35
Oilseeds	-4.9	3.87	6.6	0.99	0.91	0.63	0.51
Potato	-12.4	13.10	20.8	0.97	0.61	0.47	0.41
Vegetables	-25.1	34.63	64.69	0.98	0.53	0.41	0.37
Fish	-10.3	10.69	8.11	0.99	0.81	0.60	0.44
Meat & Eggs	-16.6	9.37	21.81	0.96	1.52	0.84	0.65
Milk	-36.4	17.81	54.11	0.98	1.61	1.08	0.81

Source: Own estimates from the Report of The Household Expenditure Survey, 1991-92, BBS (1995b).

Appendix Table 2. Estimates of consumer demand function for food items, urban Bangladesh, 1991-92.

Food item	Regression coefficients			R^2	Income elasticity of demand		
	Intercept	Log of per capita income	Inverse of per capita income		US$200	$400	$600
Rice	223.0	-19.73	-257.5	0.70	0.01	-0.05	-0.08
Other cereals	-11.9	10.93	51.2	0.63	0.16	0.35	0.33
Pulses	5.5	1.57	-8.7	0.97	0.67	0.52	0.48
Edible oils	-6.3	5.16	7.1	0.99	0.77	0.53	0.40
Potato	10.5	5.84	-17.3	0.93	0.34	0.25	0.21
Vegetables	22.1	16.54	-28.5	0.96	0.44	0.26	0.23
Fish	-25.1	17.46	37.0	0.98	0.83	0.63	0.55
Meat & Eggs	-37.22	16.59	61.2	0.96	1.25	0.77	0.62
Milk	-26.54	13.85	35.3	0.97	1.00	0.65	0.53

Source: Own estimates from the Report of the Household Expenditure Survey, 1991-92, BBS (1995b)

Appendix Table 3. Projection of per capita consumption of food (kg) at different income levels, Rural and urban Bangladesh.

Type of food/ Per capita income	Rural area				Urban area			
	US$200	$300	$400	$600	$300	$ 600	$900	$1200
Rice	176.0	200.0	209.0	205.0	152.0	173.0	160.0	140.0
Other cereals	15.2	15.7	16.6	18.4	20.0	25.1	28.8	31.0
Pulses	6.3	7.7	8.9	10.8	7.9	9.4	10.9	11.4
Edible oils	3.3	4.4	5.5	7.0	5.9	9.2	12.5	13.9
Potato	15.1	19.3	21.8	27.1	21.3	26.5	30.0	32.7
Vegetables	49.4	59.7	66.7	77.2	55.0	67.0	75.8	74.6
Fish	11.9	14.5	17.0	20.5	17.4	25.1	29.8	32.0
Meat and eggs	4.3	6.9	9.5	12.9	7.4	14.8	19.7	22.5
Milk	6.7	9.7	13.2	19.1	8.5	17.1	24.1	27.9

Source: Estimated from the parameters of Tables 1 and 2.

Appendix Table 4. Projections of the requirement for major food items under alternative development scenarios, 2010 and 2020.

Food item	Actual consumption (million t)	Projected requirements (million t)			
		Business as usual[a]		Accelerated growth[b]	
	1992	2010	2020	2010	2020
Rice	19.60	27.83	31.95	29.72	31.11
Other cereals	1.83	2.74	3.44	3.10	4.03
Pulses	0.75	1.23	1.68	1.45	1.91
Edible oils	0.43	0.91	1.28	1.16	1.67
Potato	1.85	3.17	4.41	3.71	5.06
Other vegetables	5.74	9.05	11.62	10.62	13.18
Fish	1.47	2.57	3.60	3.20	4.31
Meat and eggs	0.55	1.29	1.92	1.93	2.88
Milk	0.80	1.74	2.61	2.52	3.89

[a]Assumes a growth of national income at 4.5% yr^{-1} [b]Assumes a growth of national Income at 6.5% yr^{-1}. Source: Own estimates based on Table 3 and the projection of population for Bangladesh, Bos and Associates, 1994.

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Notes

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Citation: Bhuiyan SI, KarimAINMR, editors. 1998. Increasing rice production in Bangladesh: challenges and strategies. Manila (Philippines): International Rice Research Institute, and Dhaka (Bangladesh): Bangladesh Rice Research Institute.

Rice research in Bangladesh: preparing for the 21st century

M.S.U. Chowdhury

Rice is the staple food of Bangladesh's population and the mainstay of the country's agricultural sector. Historically, the importance attached to rice research goes as far back as the early 19th century. The Bangladesh Rice Research Institute (BRRI), established in 1970 as the country's primary institution for rice research, has successfully developed technologies that have helped increase rice production at rates more or less equal to population growth rates. But as the population continues to increase, with no scope for expanding agricultural land, the challenge becomes enormous, especially as increases in production must be achieved without degrading the resource base. BRRI will have to continue its current research strategies and apply new ones, maintain excellent research capacity in scientific manpower and facilities, and provide a conducive institutional environment for innovative work to successfully generate appropriate technologies to meet the challenge. This paper identifies some important opportunities for generating such technologies, discusses some related issues, and makes specific recommendations.

Rice is life in Bangladesh. It is the staple fox about 125 million people (BBS 1998b), is by far the largest component of the country's agricultural sector, and is the mainstay of the rural economy:

- Rice contributes 51% of the agricultural sector's portion of the national gross domestic product (GDP); by itself, rice contributes 17% to the national GDP (BBS 1997 a,b).
- Rice supplies 71% of the total calories and 51% of the protein in a typical Bangladesbi diet (BBS 1998a).
- About 75% of the total cropped area and more than 80% of the total irrigated area are planted to rice.
- Rice accounts for about 40% of all employment; the rural and urban poor spend up to 60% of their income on rice.

Research on rice began in this part of the world in the early 20th century. Formal rice research was first conducted in 1911 at the Dhaka Agricultural Farm, the first agricultural research station in South Asia under British rule. Research emphasized aus (upland) and aman (rainfed) rice crops. In 1934, the first experiment station was established at Habiganj to investigate deepwater (broadcast aman) and boro rice. The Bangladesh Rice Research Institute (BRRI) (then called the East Pakistan Rice Research Institute) was established in October 1970 at Joydebpur, Gazipur. BRRI became an autonomous institute through the Parliament's Act X of 1973, which was subsequently amended in 1996.

As the primary rice research institute of Bangladesh, BRRI is mandated to

1. conduct research on all aspects of the rice plant, including the development of new rice varieties and associated production techniques, stabilizing yield by incorporating resistance to pests, diseases, and stresses such as salinity, submergence, drought, cold, flood, etc.;
2. develop appropriate farm machinery and postharvest technologies;
3. develop a package of improved production practices and disseminate these trough training courses and use of mass media;
4. develop facilities for location-specific research with suitable cropping systems;
5. collaborate with national and international organizations and institutes to broaden and strengthen rice research; and
6. provide training to extension personnel on rice production technologies and publish research and training-related books, bulletins, newsletters, etc.

BRRI's research is implemented following annual plans developed at its headquarters and in its nine regional stations, each representing a major agroecology. The stations are located at Gazipur (headquarters), Comilla, Habiganj, Sonagazi, Barisal, Rajshahi, Bhanga, Chuadanga, and Rangpur. The 45-ha headquarters includes the experimental farm, offices, and laboratories. The Institute has a personnel of 662: 228 are scientific staff, 79 are nontechnical officers, and 355 are support staff.

Rice research planning and implementation at BRRI are carried out through seven multidisciplinary programs:

- Variety development
- Crop-soil-water management
- Pest management
- Rice fanning systems
- Farm machinery and postharvest technology
- Socioeconomics and policies
- Training and technology transfer

The programs provide the basic, field-oriented framework for scientists from various disciplinary backgrounds to work in teams in identifying and solving problems. The scientific staff work under 15 discipline-based research divisions: adaptive research, agricultural economics, agricultural statistics, agronomy, biotechnology, entomology, fann machinery and postharvest technology, grain quality and nutrition, genetic resources and seed, irrigation and water management, plant breeding, plant pathology, plant physiology, rice farming systems, and soil chemistry. The traning division plans and conducts all activities related to the enhancement of rice production skills of stiff of BRRI and other agencies such as the Department of Agricultural

Extension (DAE) and Bangladesh Agricultural Development Corporation, nongov-Ernment organizations, and rice farmers.

BRRI has its R&D partners several institutions in the country—the Bangladesh Agricultural University (BAU), the Bangladesh Agricultural Research Institute, DAE, and some nongovernment organizations. Historically, BRRI has maintained a strong collaborative relationship in research and training with the International Rice Research Institue (IRRI). It maintains a linkeage with other relevant international organizations and national research organizations of the major rice-growing countries. These relationships allow BRRI to remain an active member in global rice research efforts and to benefit from advances taking place in other parts of the world.

Impressive gains from rice research

Since it establishment, BRRI has rendered an invaluable service to the nation by developing high-yielding or modern varieties (MVs) of rice and improved production technologies. By 1998, 35 MVs had been released for farmers' use (Table 1). Twenty-three of these MVs are suitable for cultivation in the aus and boro seasons; 12 can be grown in the transplanted aman season. Many of them have high-quality grains that are popular in the export market. Several BRRI MVs have been released and are widely grown in India, Nepal, Bhutan, Myanmar, Vietnam, and western Africa. In addition, the BAU and the Bangladesh Instutute of Nuclear Agriculture have released four MVs. Four other varities developed outside of Bangladesh have been introduced. To date, MVs developed by BRRI now cover approximately 90% of the boro, 25-30% of the aus, and 50-55% of the transplanted aman areas—this is more than 50% of the rice area of Bangladesh (Fig. 1). More areas could be covered with MVs If appropriate support facilities and services are provided.

Currently, MV contribute about 65% of annual rice production, which averaged 17.5 million t in the 1990-95 period (Fig. 2). This represents a 76% increase from the 1972-73 production (BBS 1981, 1997b). The contribution of modern rice technology to total rice production was about 2.9 million t in 1976; it grew to 5.1 million t in 1985 and to 8.9 million t in 1993. In absolute terms, the output from MVs met the food requirements of almost 70 million people annually from 1990 to 1995. Clearly, without this growth in rice production made possible by the use of modern rice technologies, food security problems and poverty in Bangladesh would have been overwhelming.

BRRI-developed MVs and other production technologies benefited the nation both directly (cost savings in rice production) and indirectly (foreign exchange savings for meeting the food grain deficit through imports). Table 2 shows a recent estimate of the two components of savings (Hossain 1998). The total benefits in 1993 US$ were 13,040 million during 1973-93, an average of US$652 million yr^1. The present value of the total benefits accrued during the same period is about US$33.5 billion. The total investment for research and extension services during this period, which came from government and donor sources, is US$18.1 million yr^{-1}. The benefit-cost ratio in rice research and technology transfer wsa estimated at 16.6 if only

Table 1. High-yielding modem rice varieties developed by BRRI.

Variety (popular name)	Year of release	Growing season	Growth duration (d)	Yield (t ha^{-1})
BRI (Chandina)	1970	T. aus	110-115	4.5-5.5
		Boro	145-150	5.5-6.5
BR2 (Mala)	1971	T. aus	120-125	4.5-5.5
		Boro	150-160	5.5-6.5
BR3 (Biplab)	1973	T. aus	120-125	2.5-3.0
		Boro	165-170	5.5-6.5
BR4 (Brrisail)	1975	T. aman	145-150	5.5-6.5
BR5 (Dulabhog)	1976	T. aman	145-150	2.5-3.0
BR6	1977	T. aus	105-110	3.0-3.5
		Boro	135-140	3.5-4.0
BR7 (Brribalam)	1977	T. aus	115-120	3.0-3.5
		Boro	150-155	4.0-4.5
BR8 (Asha)	1978	T. aus	120-125	4.0-4.5
		Boro	155-160	5.0-5.5
BR9 (Sufala)	1978	T. aus	115-120	3.0-3.5
		Boro	150-155	4.0-4.5
BR10 (Progoti)	1980	T. aman	145-150	5.5-6.5
BR11 (Mukta)	1980	T. aman	140-145	5.5-6.5
BR12(Moyna)	1983	T. aus	125-130	4.0-4.5
		Boro	180-165	4.5-5.0
BR14 (Gazi)	1983	T. aus	115-125	4.0-5.0
		Boro	155-160	5.0-5.5
BR15 (Mohini)	1983	T. aus	120-125	4.0-5.0
		Boro	150-160	5.0-5.5
BR16 (Shahibalan)	1983	T. aus	125-130	4.0-5.0
		Boro	180-165	5.0-6.0
BR17 (Hashi)	1985	Boro	150-155	5.0-5.5
BR18 (Shahjalal)	1985	Boro	170-175	5.0-6.0
BR19 (Mongol)	1985	Boro	160-165	5.5-6.0
BR20 (Nizami)	1986	Upland aus	110-115	3.0-3.5
BR21 (Niamat)	1986	Upland aus	95-100	3.0-3.5
BR22 (Kiron)	1988	T. aman	135-150	4.5-5.5
BR23 (Dishari)	1988	T. aman	135-150	4.5-5.5
BR24 (Rahmat	1992	Upland aus	100-105	2.5-3.0
BR25 (Naya Pajam)	1992	T. aman	135-140	4.0-45
BR26 (Sraboni)	1993	T. aus	110-115	3.5-4.0
BRRI Dhan 27	1994	T. aus	110-115	3.0-3.5
		T. aus	115-120	3.5-4.0
BRRI Dhan28	1994	Boro	135-140	4.0-4.5
BRRI Dhan29	1994	Boro	155-160	5.5-6.0
BRRI Dhan30	1994	T. aman	140-145	4.5-5.0
BRRI Dhan31	1994	T. aman	135-140	4.5-5.0
BRRI Dhan32	1994	T. aman	130-135	4.0-4.5
BRRI Dhan33	1997	T. aman	118-120	5.0-5.5
BRRI Dhan34	1997	T. aman	135-140	3.0-3.5
BRRI Dhan35	1998	Boro	?	?
BRRI Dhan36	1998	Boro	?	?

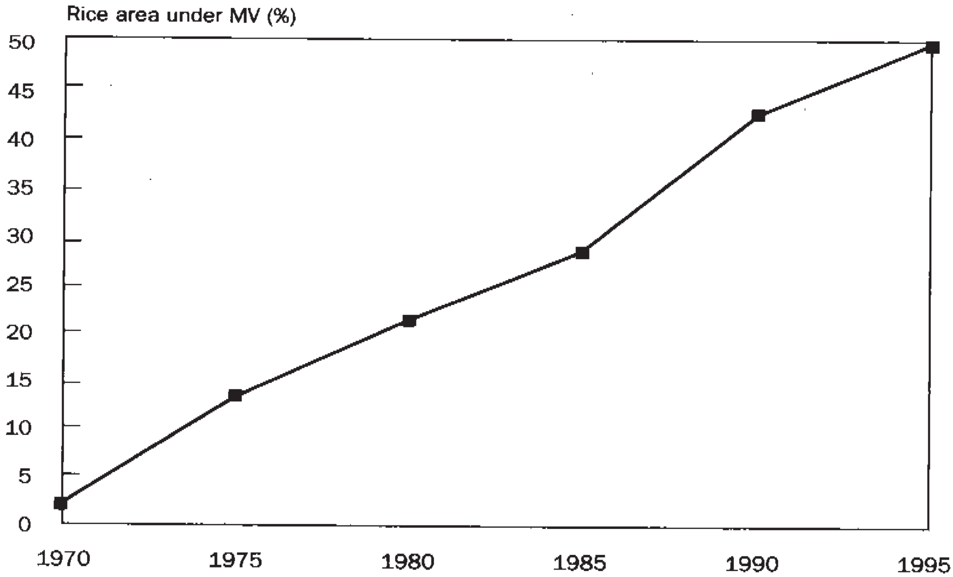

Fig. 1. Trends in MV rice coverage In Bangladesh, 1970-95.

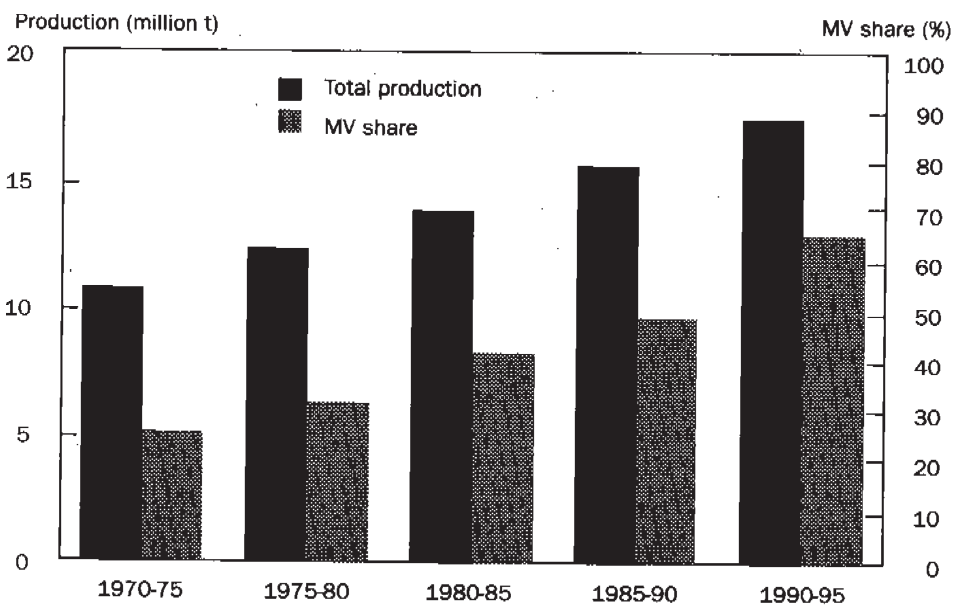

Fig. 2. Contribution of MV rices to production In Bangladesh, 1970-75 to 1990.95 (5-yr my).

Table 2. Estimates of benefits tram rice research, Bangladesh, 1973-93.

Year	Rice production (million t)			Unit cost of production (1993 US$ t^{-1})			Rice prices (1993 US$)		Benefits (US$ million)	
	Counter-factual	Actual	Contribu-tion of new technology	TV[a]	MV[b]	All rice	Domestic market	Internaitonal market	Cost savings	Exchange savings
1973	13.8	16.4	2.61	154	117	145	227	170	136	138
1974	13.5	16.6	3.16	153	119	143	297	313	150	612
1975	15.6	18.8	3.17	152	119	142	205	181	172	196
1976	15.4	18.3	2.86	151	120	143	204	146	134	74
1977	15.9	18.5	2.60	150	119	141	213	155	144	197
1978	16.3	19.4	3.18	151	118	141	230	213	178	302
1979	15.0	18.1	3.07	150	117	139	211	195	182	113
1980	16.5	20.5	3.99	151	117	139	194	254	222	311
1981	16.0	19.7	3.65	152	118	140	203	264	21	497
1982	16.2	20.7	4.49	151	117	138	204	164	241	660
1983	17.2	22.1	4.82	151	118	137	221	162	275	704
1984	16.6	21.1	4.54	150	117	136	219	158	263	213
1985	17.8	22.9	5.14	149	117	135	174	136	285	98
1986	17.6	22.6	5.04	151	117	136	203	125	301	40
1987	14.7	20.8	6.14	154	117	135	192	140	337	141
1988	15.8	21.7	5.87	154	117	134	183	183	352	387
1989	19.3	26.3	6.95	150	115	130	180	194	456	549
1990	18.5	26.2	7.69	149	115	129	180	192	447	592
1991	18.2	26.8	8.47	148	115	127	180	208	472	787
1992	18.9	27.8	8.97	148	115	126	147	192	519	685
1993	18.2	26.8	8.62	147	115	125	147	180	495	560

[a]TV = traditional variety. [b]MV=modern variety. Source: Hossain (1998).

direct benefits were considered and at 36.2 if indirect benefits were also accounted for (Hossain 1998).

The technologies developed by BRRI have helped generate income and employment in rural areas. A recent survey showed that the incidence and severity of poverty were lower for farm households with higher rates of adoption of MVs compared with low-adoption households, clearly indicating the positive effect of technological progress on poverty alleviation (Hossain 1998).

The challenge ahead

The demand for rice is constantly increasing. The present population growth rate is about 1.8%, which means that more than 2 million people are added to the population every year. To maintain the present level of "near self- sufficiency" in rice, (milled) rice production will have to reach about 29 million t by 2010, which is 66% more than the 19 million t produced in 1996-97. The challenge to meet future production needs is indeed enormous because

- cultivable land could not expand toward meeting this target and is also constantly shrinking as more and more agricultural land is diverted to other uses such as housing, roads, and industry;
- cultivated land is constantly being fragmented; this process is reducing the landholding size and limiting the scope for adoption of certain production technologies;
- opportunities for expansion of irrigation facilities (presently, about 40% of rice area has access to irrigation water) is limited; and
- intensively cultivated areas are facing difficulties in maintaining their productivity using currently available technologies.

Moreover, there is a pressing demand to reduce land allocation to rice in the dry season when other crops can be grown well. Therefore, rice production growth in the coming years must come mostly from productivity gains-i.e., from increases in production per unit of land, using improved technologies that will not degrade the natural resource base or the social environment. Simply put, to meet the future rice demand through increased production, new technologies will be needed to substantially increase rice yield per crop and to grow more crops per year from the same land.

Undoubtedly, this is a great challenge. The ingenious application of science that ushered in the Green Revolution in the early 1960s succeeded in proving the Malthusian theory wrong. I believe that the intelligent application of science can duplicate that feat in the future.

Need for sound institutional research strategies

In the past, I3RRI formulated its research plans and programs based on a strategic analysis of critical parameters such as the physical resource base, climate, socioeconomic environment of growers, and national demand. These strategies are periodically reviewed and adjusted in relation to changing conditions and perspectives. While this process must be continued, rice research strategies and future directions will require much greater analytical support than in the past. Research planning will need to give special. attention to the following strategic elements.

Agroecosystem and socioeconomic perspectives should continue to be the basis for identifying research issues and priorities. Bangladesh has a wide range of soil, hydrology, and climatic conditions, with 30 well-defined agroecological regions. Each region is characterized by uniquely strong (favorable) and weak (unfavorable) factors that determine the potential for success in research for improving its production potential. The regions often also differ in the growers socioeconomic backgrounds. These characteristics are critical determinants of strategic research issues and they must be fully considered when deciding priorities for resource allocation for research. Farmers' production environments and constraints and the impact of adopted technologies must be continually assessed and the findings adequately used in the planning process.

Because BRRI's research capacity has been seriously eroded by a continual exodus of trained scientists, this must be reversed. About 60 highly trained rice scientists, 25% of the total scientific strength of BRRI, have left the Institute during the past 9 yr to take jobs outside the country. Plant breeding, one of the most crucial disciplines, was most seriously hurt in the process. BRRI's plant breeding and genetic resources divisions lost 15 of their scientists during the period. This exodus weakened the Institute's research capacity disproportionately because those who left were among the most highly trained and skilled staff who occupied positions of major responsibility. BRRI management must work especially hard to recruit new talent to fill the vacant positions as soon as possible and give these people the required academic and on-the-job training to build their research capacity to the desired level, Serious deliberations at the highest policy-making level are needed to identify measures that would help the national research system retain its highly trained manpower.

Research on variety development needs much greater efforts. The MVs were the centerpiece of' the rice production technologies that ushered in the Green Revolutio in the 1960s. Subsequent production breakthroughs are likely to be achieved a similar process. The role of conventional breeding toward achieving tat goal will remain critical. BRRI's capacity for rice variety development must be strengthened to maintain a steady flow of MVs to the farming communities in the various production environments within the shortest possible time. Special emphasis should be given to developing varieties with

- higher yield potential-these will replace current popular varieties as needed;
- resistance to/tolerance for major pests (e.g.. stem borer, rice hispa, brown planthopper, whitebacked planthopper, green leafhopper) and diseases (e.g., blast, bacterial leaf blight, sheath blight, tungro, ufra)-so tat losses and the need for chemicals are minimized;
- earlier maturity-this will enable increased cropping intensity to be sustainable, with all the associated benefits;

- tolerance for cold in boro rice-this will enable boro rice to grow better, mature earlier, and give higher yield, especially in the northern regions, where cold temperatures adversely affect the early stages of growth;
- drought tolerance-this trait, which has eluded scientists in the past, is highly desirable for rainfed rice areas that dominate the rice landscape in Bangladesh;
- tolerance for short-duration submergence and high yield potential regardless of whether submergence takes place in a given year; and
- higher dormancy in rice seeds-this will solve the problem of seeds germinating too quickly in the field and suffering from loss of quality.

Capacity for conventional research at BRRI must be further strengthened. We must realize that in variety development much is still to be gained, at least in the short term, from the use of conventional research techniques for improving and sustaining rice-land productivity in Bangladesh. But we must simultaneously give serious efforts to conducting new frontier research that can usher in new opportunities. We will need optimal combinations of conventional and new frontier research to address the increasingly complex and difficult problems of developing higher yielding rice varieties that will raise productivity without harming the natural resource base. Among the new frontier technologies, the following deserve immediate attention:

1. ***Hybrid rice***. For various reasons, research on hybrid rice at BRRI did not take off. Apart from China, where about 50% of all rice areas grow hybrid varieties, hybrid rice technology has made remarkable progress only in India and Vietnam in recent years. We must devote adequate resources to exploit the advantage of hybrids in increasing rice production in Bangladesh. The initial thrust should be for the boro season, which has already achieved a relatively high level of productivity with the use of modem inbred varieties and support services.
2. ***Breaking the yield barrier with a more efficient plant type***. IRRI has made major progress in developing new cultivars based on a new plant type concept, which are significantly more efficient in converting energy inputs than the current MVs. BRRI must start, in collaboration with IRRI, research on this type of cultivar as soon as possible and prepare to release new varieties based on the research.
3. ***Using modern biotechnology***. Advanced laboratories in several countries have made much progress in the past decade in applying modem concepts of biotechnology and genetic engineering for developing rice cultivars with specific traits that are difficult to achieve through conventional breeding techniques. There is little doubt that modern biotechnology holds the key to solving some of the pressing problems of increasing rice productivity-.-e.g., lack of specific disease and insect resistance, drought tolerance, and salinity tolerance. Bangladesh must develop an appropriate policy on bio-safety in agricultural research without further delay. BRRI may not have, in the immediate future, the resources to conduct basic biotechnology and genetic engineering research in rice, but it is important for BRRJ to immediately develop its laboratory facilities and maintain its scientific capacity to collaborate with IRRI or other advanced institutions to evaluate

promising cultivars for local ecological adaptability, following national bio-safety guidelines.

Exploiting existing opportunities to increase the productivity of tidal areas. The tidal areas, including both coastal saline and nonsaline areas, constitute about 0.8 million ha of rice land with low productivity. Most of these areas are kept fallow during the dry season, but they could produce rice if appropriate technologies were available. About half of the land is affected by salinity (negligible in the wet season but increasing in the dry season when rainfall is scanty). For these areas, modem high-yielding varieties with early maturity and salt tolerance are needed. Simultaneously, crop, soil, and water management techniques must be developed to overcome the deleterious effects of salt on rice and nonrice crops. Likewise, to increase the productivity of the vast nonsaline areas that are submerged to various depths, appropriate rice varieties and effective water and fertilizer management techniques are essential. If more priority were given to tidal areas in the BRRI research program, their production potential could be better exploited in the near future.

Renewed emphasis needed on research for improving selected knowledge-based technologies. Farmers' adoption of improved technologies (other than varieties) for managing production inputs requires a greater understanding of the processes involved and their consequences inasmuch as the effects of using such technologies are often less clear-cut aid visible over a short time span (compared with the use of new varieties). These technologies are often termed "knowledge-based," in contrast to varieties, which are " seed-based." The sustainability of an intensive production system using MVs depends on the ability to maintain soil fertility and to have access to adequate good-quality irrigation water, a conducive biotic environment, and economic incentives for farmers to produce more. BRRI has active research programs that tackle these issues, but they should be further strengthened. One important research area that has not received attention in the past is seed health. Research at IRRI has shown that using better quality seed alone could increase rice yields of an average farmer by 10-15%. In Bangladesh, where farmers themselves provide 95% office seeds, awareness of seed quality is very low. Major gains could be achieved through appropriate research and programs to improve the quality of rice seed used by farmers. Also, a significant opportunity exists for improving rice postharvest processing and management systems for adding value and enhancing income. BRRI's research in soil fertility management, integrated pest management, and field water management needs to be strengthened.

Slow rate of technology transfer affects production. We need determined and systematic efforts for the fast and effective transfer of new technologies to farmers. For lack of a strong research-extension linkage, new technologies from BRRI reach farmers slowly For example, some of the recently released rice varieties (BR28, BR29, BR3 1, and BR32), which are superior to the current ones, remain unknown to many farmers in the tar' get areas because they do not have access to seeds and information. National rice production is thus adversely affected. BRRI should be involved and play a more active role in planning and implementing programs for technology dissemination to farmers. BRRI should maintain a database of the current and potential adoption of its various technologies, and update it regularly. In collaboration with other agencies, BRRI must conduct research that aims to identify bottlenecks in technology transfer and to recommend ways to overcome them.

A sound institutional culture and a conducive working environment are prerequisites to good performance. As a leading research institute, BRRI must continue to maintain an institutional culture and working environment conducive to promoting dedication, commitment, and motivation among the staff to pursue its mission. BRRI scientists should be proud of their institutional identity. All the needed support (technical, administrative, or financial) should be provided. BRRI's goal can be successfully achieved only by fully harnessing the ingenuity of its scientists. At the same time, a culture where staff members demonstrate a high standard of accountability and responsibility in the pursuit of their work must prevail.

Conclusions

For Bangladesh, achieving sustainable increases in rice production commensurate to the growing demand over the next two or three decades poses an enormous challenge. To meet this challenge, BRRI must gear up its research capacity, facilities, and management system. BRRI has so far been successful in developing the needed technologies for meeting the demand for rice in the past three decades. Bangladeshi farmers are hard-working, innovative, and willing to use appropriate new technologies readily if they are given adequate access to them. No stone should be left unturned in the pursuit of BRRI's goal as the future of Bangladesh is interwoven with the performance of this organization.

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Notes

Author: Dr. Chowdhury retired in 1997 as the director general of the Bangladesh Rice Research Institute (BRRI). Previously, be was the executive vice chairman of the Bangladesh Agricultural Research Council. At present, he is a free-lance consultant.

Citation: Bhuiya2n SI, Karim ANMR, editors. 1998. Increasing rice production in Bangladesh: challenges and strategies. Manila (Philippines): International Rice Research Institute, and Dhaka (Bangladesh): Bangladesh Rice Research Institute.

Acknowledgment: The contributions of Dr. N.H. Karim, Dr. K.A. Kabir, and Dr. M.A. Quddus of BRRI to an earlier version of this paper are gratefully acknowledged.

Priorities of rice research in Bangladesh

Md. Nasiruddin

By 2020, Bangladesh will require 35.5 million t of rice to meet the food demand of its population, which Is expected to increase to 173 million. To attain this production target, average yield will have to increase from the present level of about 1.8 t ha'to 3.4 t ha^{-1}. Meeting this formidable challenge will need the concerted efforts of rice scientists, policymakers, and program implementors in identifying field problems that constrain productivity and in implementing measures to improve the whole production system. This paper attempts to identify the research issues that rice scientists should address to achieve that production goal. With a focus on achieving production gains without causing any degradation in the natural resource base, the following critical areas are discussed: yield potential of the rice plant, water management, nutrient management, pest management, postharvest technology and farm mechanization, farming systems, socioeconomic and policy aspects, and protection of the environment. Rice production (present status, rate of growth, and future demand) and adoption of modern varieties in different ecosystems in Bangladesh are briefly described.

Bangladesh has a total area of 14.4 million ha, 62% of which are arable. It is one of the most densely populated countries in the world, with 833 persons km-2. Agriculture is the mainstay of the economy, accounting for 35% of gross domestic product (GDP) and 60% of employment. Subsistence agriculture dominates the rural scenario: 45% of the fanners are landless and per capita landholding is only 0.1 ha.

Rice, the staple food crop of Bangladesh, covers about 10 million ha of cropped area and accounts for 94% of food grain production. More than 90% of the population derives 70% of its daily calories and 54% of its protein needs from rice. Rice alone contributes 18% to GDP and accounts for 55% of labor employment in its production, processing, and marketing sectors.

Of the 26 rice-growing countries in the world, Bangladesh is third in total rice area and fourth in total rice production. But for yield per hectare, Bangladesh is sixth.

Production growth and future demand for rice

Bangladesh made modest but steady progress in agriculture in the post-independence period from 1970-71 to 1992-93, when cropping intensity increased from 148% to 179% and food grain production almost doubled. As the dominant crop, rice largely determines the rate of progress in the agricultural sector. In fact, the entire growth in crop production is explained by the growth in food crop production, particularly rice.

During the last two decades, the area grown to rice remained more or less static, while both total production and yield almost doubled (Table 1). Yields of other noncereal crops, such as pulses, oilseeds, and vegetables stagnated, while that of wheat declined.

Though total production and yield showed steady progress over the last two decades, the yield of modem rice varieties (MVs) has gradually declined (Table 1). This decrease can be attributed to several factors. First, varieties released in recent years to cover specific ecotypes included those that have lower yield potentials compared wit varieties released earlier Second, continuous adoption of MVs shifted from the more favorable to the less favorable areas. Third, inadequate crop and soil-water management practices, increased biotic pressures from disease and insect pests, and overall degradation of soil resources causing micronutrient deficiencies hampered productivity.

The replacement of traditional varieties by MVs propelled the increase in rice production and yield (Table 1). Expansion of the irrigated area during the boro season, when sunshine is abundant and biotic pressure is less, and the use of higher doses of fertilizers contributed to greater rice production. The aus and deepwater rice areas decreased over the last two decades, while the transplanted aman (T. aman) area remained more or less the same (Table 2).

Table 1. Area, production, and yield trends of rice in Bangladesh, 1970-95.

Year	Area (million ha)	Produciton (million t)	Yield ($t\ ha^{-1}$)		MV rice area (%)
			Total	MV	
1970-71	9.74	10.97	1.1	3.3	4.7
1980-81	10.30	13.88	1.3	2.3	21.3
1990-91	10.40	16.79	1.6	2.1	44.1
1994-95	9.82	17.06	1.8	2.4	50.3

Source: BBS (1997)

Table 2. Change in rice area under four seasons, 1970-95

Year	Area (million ha)				
	Boro (irrigated)	Aus	Deepwater rice	T. Aman (rainfed lowland)	Total (million ha)
1970-71	0.80	3.19	1.82	3.91	9.70
1980-81	1.16	3.11	1.58	4.46	10.30
1990-91	2.52	2.10	0.93	4.83	10.43
1994-95	2.58	1.66	0.95	4.63	9.82

Source: BBS (1997)

Table 3. Projected population, population growth rate, land-man ratio, and demand and yield of rice, 1990-2020.

Year	Population (million)	Population growth rate (%)	Land-man ratio	Demand for rice (million t)	Present and required yield (t ha^{-1})
1995	109.8	2.03	0.087	16.8	1.8
2000	132.4	1.79	0.072	23.9	2.4
2010	153.4	1.36	0.062	29.8	2.8
2020	172.9	1.16	0.053	35.5	3.4

Source: BARC (1994)

For a small country, Bangladesh has a large population. Its population, currently increasing at 1.8% $annum^{-1}$, will swell to 173 million by 2020. To feed these people, 35.5 million t of rice are required (Table 3). To achieve this production target, average rice yield will have to increase from 1.8 t ha' to 3.4 t ha^{-1}. The challenge facing policymakers, administrators, and rice scientists is formidable inasmuch as there is little scope to expand the rice area. It is assumed that rice area would further decrease with increases in population.

Rice culture types and MV adoption

Modern rice varieties cover varying proportions of cultivated rice areas, depending on the season and culture type (Table 1). The highest MV area (90%) is in the boro season, producing the maximum yield, followed by 40% in rainfed lowland T. Aman, and 24% in direct-seeded aus and transplanted aus. The lowest MV area (15%) is in the tidal wetland, nonsaline area grown mostly to the T. aman crop. No MV rice variety is suitable for the tidal wetland saline and deepwater rice areas. Table 4 summarizes the present levels of adoption of MVs in rice areas under different crop cultural practices and ecotypes.

To meet the future demand for rice, the area under MVs has to be increased from the present 50% to at least 80%. To achieve this goal, varietal development, improved production practices, and improved cropping patterns are needed; socioeconomic and environmental issues must also be addressed. Varietal characteristics of plants needed for the different ecotypes vary for yield, plant height, growth duration, and reaction to physiological and biotic stresses. Nasiruddin (1994) discussed the characteristics required for each ecotype.

Improvement of production systems

Most arable lands of Bangladesh are already under cultivation. The population is expected to double in the next 35 yr. further reducing the size of already small farmholdings. Moreover, agriculture in general and rice culture in particular will continue to be an effective vehicle for alleviating rural poverty. As indicated earlier, one

Table 4. Season, crop outturn type, MV coverage area, and yield of rice In Bangladesh, 1993-94.

Season	Season and time	Rice culture type	Cultivated area (million ha)	Yield milled rice (t ha^{-1})	MV coverage (%)
Boro	Nov-May	Irrigated boro (lowland)	2.58 (26%)[b]	2.6	90.5
Aus	Mar-Aug	Direct-seeded aus (upland)[a]	1.25 (12%)	1.1	24.3[d]
	May-Aug	Transplanted aus (medium lowland)	0.40 (4%)	[c]	(4%)[a]
Aman	Jul-Dec	Transplanted aus (medium highland)	3.29 (33%)	1.8	40.0
	Jul-Dec	Transplanted aman (tidal wetland, nonsaline)	1.65	1.8	15.0
	Mar-Nov	Broadcast aman (deepwater)	0.90 (9%)	1.0	0.0

[a]Descriptions in parentheses indicate the ecotype. [b]Percent of total rice area; [c]No information available. [d]This is for both direct-seeded and transplanted aus crops combined. Source: BBS (1996). Rice yields are estimates.

major problem is how to break the stagnation (or even decline) of rice yields in intensively cultivated areas. The Food and Agriculture Organization has identified five constraints to increasing the yield of MVs (FAO 1996): degradation of land and soil resources, water management problems, socioeconomic and policy-related limitations, buildup of biotic stresses, and degradation of seed quality.

Increasing the yield potential

Modem rice technology, which is characterized by the use of dwarf varieties such as IRS, ushered in the Green Revolution in the tropics in the mid-1960s. The MVs produced 2--3 times more yield than did the traditional varieties. The later generation MVs have been improved further-they have shorter growth duration, better grain quality, and greater tolerance for biotic and biotic stresses. But increasing yield potential remains a challenge. To overcome this problem, plant breeders have to redesign the rice plant to break the present yield ceiling by either changing the morphology of the rice plant or using a physiological approach for more efficient partitioning of dry matter and better energy use by the rice plant, especially for increasing preheading sta cli storage (Khush 1991. Bollich 1991).

Another possibility is the use of tropical hybrid rice, which gives 15--20% higher yield than conventional inbred varieties. Hybrid seed production requires trained manpower; cooperation between the public and private sector is thus needed. Increased production through hybrid rice technology would release some land currently used for growing nonrice crops and thereby increase rural employment. This has happened in China, where more than half of the rice land is grown to hybrid rice.

Significant developments in both approaches have taken place in recent years, particularly at IRRI. A new plant type capable of producing significantly higher yield has been conceived and is now under rigorous investigation and testing (Khush 1995, Peng and Senadhira 1998). Tropical hybrids are developed at IIRRI in collaboration with several national institutions. Hybrid rice varieties have already been released in India, Vietnam, and the Philippines (Virmani 1996). Significant areas in India and Vietnam are already growing tropical hybrids. Research on hybrid rice has been strengthened recently at the Bangladesh Rice Research Institute (BRRI) and the release of suitable hybrid varieties is expected in the near future.

Water management

Water is a scarce resource during the dry season. Projections suggest that most Asian countries will face severe water problems by 2025 (IRRI 1995), As the population increases and as economic development intensifies, the government will find it very difficult to allocate, regulate, and use its limited water resources m the long term. Demand for water will increase for agriculture, fisheries, navigation, and domestic and industrial uses. Agriculture is by far the biggest consumer of water worldwide, with irrigated rice heading the list. Rice production is less efficient in the way it uses water-rice consumes nearly two times more water than wheat for each unit of grain produced (Bhuiyan 1992).

Water was the critical input to the Green Revolution. Irrigation, flood control, and drainage contributed the most to higher rice production. To meet the future demand for rice, adequate water of good quality must be provided in the field. In Bangladesh, water problems are caused by the uneven distribution of rainfall; about 80% of the monsoon rainfall occurs during a short period from June to October Average annual rainfall varies from 1,190 mm (northwestern part) to 3,450 mm (eastern part). Moreover, the monsoon is erratic and can cause floods and droughts in the same year.

In recent years, water quality problems have been a source of great concern. There are many reports of widespread arsenic problems in the irrigation and drinking water pumped from underground aquifers in the western and northwestern parts of the country, causing serious health problems. Moreover, about 0.8 million ha of land are affected by coastal salinity in the dry season. Management of saline water and selection of appropriate crops and cultivars will help increase the productivity of the coastal land.

Irrigation facilities are now operated at about 50% of their capacities. As water is an increasingly limiting resource, future rice production growth will depend heavily on the development of efficient water management systems to produce more rice per unit of water input.

Nutrient management

The use of fertilizers in Bangladesh is generally low, and nutrient removal rates exceed application rates (Table 5). For example, the application rate is far below the recommended dose of 100-80-60 kg NPK ha^{-1} for MVs. The inadequate and unbalanced use of NPK fertilizers, the decreasing availability of sulfur and zinc, and the declining level of soil organic mailer are the major factors responsible for the decline in soil fertility and rice yield.

To meet the future rice demand, the use of fertilizers, especially nitrogenous ones, should be increased. At the same time, N use efficiency should be raised to 33--50% from its present level of 20--25%. Research on increasing the nutrient use efficiencies of various nutrients should have priority in Bangladesh. It is also necessary to improve the research-extension-fanner linkage to ensure the proper use of improved technologies.

Pest management

BRRI scientists have identified 31 rice diseases (10 are major), 175 species of rice insect pests (30 are major), and 45 weed species (20 are major). Pest-induced yield losses are considerable. But most biotic organisms found in rice crops are not harmful; many are beneficial. BRRI entomologists have recorded 99 parasites and 88 predators of different rice insect pests, but the pest-suppressing efficacy of these natural enemies, their composition, and community structures in different rice ecosystems are not well known. Bangladesh, being located in the tropics, has enormous opportunities to explore the use of natural control systems to manage pests. The use of pest-resistant varieties and biological control practices are the fundamental components of integrated pest management. These measures will reduce crop losses and minimize the undesirable effects of pesticides on beneficial organisms, human health, and the natural environment. The importance of the above measures can be better appreciated

Table 5. Apparent nutrient balance sheet for three rice crops per year over 8 yr, BRRI, 1984-91.

Factor	Target yield 10.5 t ha^{-1}						
	N	P	K	Ca	Mg	S	Zn
Nutrient added ($kg\ ha^{-1}\ yr^{-1}$)	286	87	134	100	12	48	0.36
Nutrient removed ($kg\ ha^{-1}\ yr^{-1}$)	179	29	179	46	39	19	0.47
Gross balance	+107	+58	-45	+54	-27	+29	-0.01
Net balance[a]	-79	-12	-112	-26	-36	-19	-0.43

[a]Net balance is calculated based on nutrient use efficiency at the following rates: N = 35%, P = 20%, K = 50%, S = 20%, Mg = 20%,: Ca 20%, Zn = 10% from chemical fertilizers. Source: Bhuiyan (1992).

by recalling that about 90% of all pesticides used in Bangladesh are applied on rice fields. BRRI's rice breeding program should be further strengthened in order to release new varieties with resistance to major pests and diseases.

Postharvest technology and farm mechanization

More than 50% of the country's labor force is employed in rice production, processing, and marketing. A scarcity of labor during the peak season is frequently experienced in intensive rice-cropping areas. With greater access to education and with a higher standard of living, labor for agricultural activities will decrease further. Moreover, the constant decrease in draft animal power and the migration of labor from rural areas to cities further aggravate the labor shortage for agriculture. Selective mechanization for land preparation, harvesting, threshing, and drying will help reduce pressure on draft animal power as well as on the labor force.

Postharvest losses in rice during milling are generally high and farmers' storage facilities are mostly inadequate. Research on improving rice milling quality and storage facilities and on diversifying rice products and byproducts is needed. Research to harness energy from renewable sources (such as rice straw and rice hulls) and to develop appropriate technology to separate bran, germ, and husk for diverse uses should be given priority.

Farming systems

Research must identify and address the complex problems of commodity-based farming systems and intensive production systems that farmers practice. The major role of nonrice crops in improving the economic status of poor farmers must be recognized. Farmers in Bangladesh practice more than two dozen major cropping patterns, almost all of which involve one or two rice crops a year. Except in some limited areas, planting three rice crops per year on the same land is not practiced. Important nonrice crops that follow rice are wheat, jute, potato, pulses, oilseed, and cotton. Research on farming systems to address problems of water, nutrient, and pest management and socioeconomics should follow a systems approach in the context of the seven crop culture types in Bangladesh (Table 4). Research to improve and maintain the productivity of intensive production systems with important cropping patterns in the major agroecological regions of the country should be given high priority in the next 5-yr research program. Long-term planning should focus on total factor productivity, m-creased and more efficient use of inputs, efficient production systems, control and management of water, balanced use of nutrients, and integrated pest management. Concerns about appropriate mechanization, marketing, and diversification of products and byproducts should also be addressed.

Socioeconomic and policy issues

The future expansion of MV areas and increases in yield will large1y depend on government policies related to the development of irrigation facilities, distribution and quality of inputs, pricing of inputs and outputs, land reform, and credit facilities for farmers. In-depth studies on water resources, both ground and surface, and their planned use for various competing sectors, including agriculture, are essential. Laws on efficient water management at the irrigation system and on-farm levels are needed, and their effective implementation is crucial to sustaining growth in rice production.

To satisfy demand, the issues of input and output prices and farmer incentives must be examined. In the same context, the rice marketing system should be evaluated and the producers' and middlemen's share in the consumer price should be studied.

In Bangladesh, most farmers are landless or have small farmholdings, practicing subsistence agriculture. Therefore, an efficient service-oriented credit system that gives marginal farmers easy access to credit is needed.

Protection of the environment

To meet the future food demand through higher yield and production, the land and water resources of the country are subjected to increasing pressure. In making plans for long-term agricultural development, we have to take into account the problems of environmental sustainability-soil degradation, water quality degradation, and water shortage.

Overdependence on groundwater has been a concern in recent years. Future irrigation development based on groundwater pumping may not be sustainable as intensive dry-season irrigation will cause a further fail in the water table and will aggravate the arsenic problem. A greater use of surface water should be considered for future irrigation growth. On the other hand, in the coastal region, expansion of surface water irrigation in the dry season and of shrimp culture will cause further salinity intrusion, limiting the scope for expansion of rice production. Coastal embankments and inland polders are already causing serious waterlogging in some areas due to siltation outside the embankment and the drainage canal. Sustainable water resource management will require a delicate balance of natural and artificially induced forces to prevent the deleterious effects of regulating water for new agricultural development.

The government must strengthen its policy and policy implementation tools to ensure that hazardous agricultural chemicals are not imported or used in agriculture. Because it is so easy to sell these chemicals in the market, we clearly need serious thinking and action in this regard. Wide-scale farmer education and rigorous monitoring of field-level soil and water conditions are essential to prevent serious degradation of the natural resource base.

Poverty causes many environment-degrading activities. Poor farmers or landless laborers have to face the pressure of survival daily or, if they are lucky, on a season-to-season basis, which hardly allows for thinking or acting with a long-term perspecfive. Eliminating poverty will be the fundamental prerequisite to any sustainable environmental protection program. All agricultural development strategies should therefore strive toward building a poverty- and hunger-free society.

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Citation: Bhuiyan SI, Karim ANMR, editors. 1998. Increasing rice production in Bangladesh: challenges and strategies. Manila (Philippines): International Rice Research Institute, and Dhaka (Bangladesh): Bangladesh Rice Research Institute.

Food grain production strategies for the 21st century

M. Enamul Hoque

Agriculture, the single largest sector and mainstay of the Bangladesh economy, made steady progress in the post-independence period. Cropping intensity increased from 148% in 1969-10 to 180% in 1992-93 and food grain production nearly doubled. But because of increasing demand from the growing population, the country has remained a net importer of food grains. The factors constraining further increases in food production and its stability are manifold. The net cultivable land area, now 9.72 million ha, is constantly shrinking due to shifts to nonagricultural activities. The prevalent land tenure system discourages tenant farmers from freely applying their investment options and consequently restricts achievement of optimal cropping intensity and choice of improved inputs to manage. Furthermore, problems of poor seed quality and lack of access to appropriate farm machinery and agricultural credit have reduced the pace of agricultural growth. Bangladesh also suffers from inherent agroecological constraints that are difficult to overcome: annual widespread flooding, salinity intrusion in coastal areas, cyclones, hailstorms, and drought. These have contributed substantially to the prevailing low productivity and the high year-to-year fluctuations in crop production at the national level, thus affecting food security. In the face of these limitations, the major challenge to researchers is to continue developing technologies that will enable small farmers in various ecological zones of Bangladesh to increase food grain production at a rate equal to or greater than the rate of growth in demand for food grains, without creating undesirable effects on the natural resource base or the social environment. Likewise, the agricultural extension system of the country must be strengthened and better mobilized to effectively meet the concomitant challenge of delivering new technologies to target farmers, monitoring their impact, and supporting national research and policy planning.

Agriculture is the single largest sector and the mainstay of the Bangladesh economy. It accounts for almost one-third of the gross domestic product and provides employment for two-thirds of the labor force. With this vast majority of the population-87% residing in rural areas and more than half living below the poverty line-no growth and poverty alleviation strategy for Bangladesh can succeed without a healthy agricultural sector. Bangladesh needs a dynamic agricultural sector in the 21st century and an effective strategy to achieve it.

A vibrant agricultural sector is crucial to economic growth, poverty alleviation, and improvement of nutritional standards of a majority of the poor and the landless. The rural poor's: access to food is considerably determined by what happens in the food economy, particularly through demand for labor in food production, and the price of food, which greatly influences the inflation rate because of the substantial share of food in consumer expenditure in the county.

The country has made steady progress in agriculture in the post-independence period. Cropping intensity has increased from 148% in 1969-70 to 180% in 1992-93, thereby almost doubling food grain production. But the agricultural sector has yet to exploit its full potential. Bangladesh remains a net importer of food despite its comparative advantage in producing a number of crops for both domestic consumption and export. Poor nutritional indicators point to significant gaps in food consumption with serious implications for the country's development in the future (FAO 1994).

Food grain requirements in Bangladesh

Being an agriculture-dependent economy with a growing population and one of the world's lowest land-people ratio, the major issue in Bangladesh agriculture is to enhance and sustain growth in crop productivity. Figure 1 gives a rough idea of the food grain requirement and production in Bangladesh. Current projections on food grain demand and supply have shown that even with a modest growth rate of 4% in demand, the requirement will increase to 25 million t by the year 2000 and to 30 million t by 2010 (Karim 1995). Assuming annual growth rates of 2% in irrigated areas and a 3.5% growth rate in rice yield, supply could reach only 24 million t by 2000 and 28

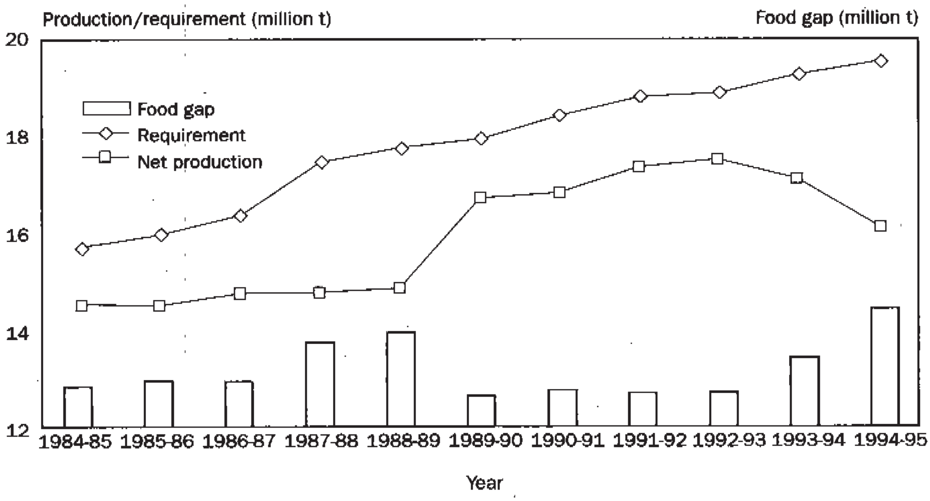

Fig. 1. Met production and requirement of food grains and the food gap in Bangladesh (Source: Adapted from BBS 1996)

million t by 2010 (Shahabuddin and Zobir 1995). This would amount to a supply gap of nearly 1 and 2 million t by 2000 and 2010, respectively (Tables 1 and 2). A more pessimistic scenario would put this gap at about 3 and 6 million t. The widening supply gap indicated by these projections emphasizes the need for accelerated and sustained food production. Meeting the shortfall trough commercial imports may not be a sustainable proposition as an analysis of comparative advantage shows that accelerated food production is a better option for Bangladesh.

Major issues in Bangladesh agricultural production

Several issues confront the-agricultural sector in Bangladesh. The first relates to the low and stagnating yields of most crops, including rice, which dominates the crop sector Though the country recorded bumper harvests of food grains from 1989-90 to 1992-93 (Table 3) (an average of 19.1 million t yr^{-1}. which was much higher than the average of 16.4 million t recorded during the preceding 4 yr), growth in food grain production declined in the subsequent 2 yr---from 19.5 million tin 1992-93 to 18.1 million tin 1994-95. There was again a production upturn in 1995-96. These trends show that instability of output and sustainability of growth have emerged as important sectoral issues in Bangladesh agriculture.

Wide gaps exist between potential and actual yields for all crops in Bangladesh. Although average rice yield remains at 2.0 t ha^{-1}, the potential yield of most high-yielding varieties is reported to be more than 4.0 t ha′ of clean rice (6.0 t ha^{-1} of rough rice). In wheat, the gap is still bigger---1.8 t ha^{-1} average vs 4.0 t ha^{-1} potential. Thus, the first priority for Bangladesh is to accelerate and sustain growth in crop productivity by closing existing yield gaps and enhancing the level of cropping intensity.

The second issue is related to crop diversification and its potential contribution toward enhancing farmers' real income and nutritional balance; diversifying the crop mix, farm products, and byproducts to support agribusiness opportunities; enhancing the biological stability and productivity of cropping systems in lands marginally suited to rice; and recovering soil health and productive capacity in the long run. The country has a wide range of agroecological conditions suitable for growing various crops and these possibilities could be better exploited by addressing specific constraints to more diversified cropping patterns by using the BARC-AEZ database.

The third issue touches on environmental sustainability and the implications of agricultural development efforts involving the use of increased irrigation, chemical fertilizers, seeds of modem varieties, pesticides and other agricultural inputs that lead to increased land erosion and degradation of the resource base, rise of salinity levels, declining organic matter status of soils, and receding groundwater tables. Because these are all associated with increased cropping intensity and increased input use, it is possible that some efforts to enhance yields will be offset by the loss of productivity due to degradation of soil and water resources.

Finally, an agricultural development strategy for Bangladesh should tackle all the interrelated issues of poverty alleviation, malnutrition, and food security because of their intimate linkages with the state and with the performance of the agricultural

Table 1. Projected food grain demand (million t) under an alternative scenario-

Scenario	1999-2000	2004-05	2009-10	2019-20
Constant per capita availability				
Rice	20.89	22.50	24.24	27.58
Wheat	2.72	2.93	3.16	3.59
Food grain	23.61	25.43	27.40	31.17
Income-induced consumption				
High				
Rice	23.63	26.31	28.57	29.85
Wheat	2.71	2.97	3.30	4.19
Food grain	26.34	29.28	31.87	34.04
Medium				
Rice	23.11	25.71	28.20	31.66
Wheat	2.71	2.94	3.22	3.89
Food grain	25.82	28.56	31.42	35.55
Low				
Rice	22.54	24.93	27.39	31.79
Wheat	2.70	2.92	3.16	3.70
Food grain	25.24	27.85	30.55	35.49

Source: Shahabuddin and Zohir (1995).

Table 2. Projected food grain production (million t) under an alternative scenario (at constant prices).[a]

Scenario	1999-2000	2004-05	2009-10	2019-20
Base case				
Rice	22.91	24.86	26.88	31.32
Wheat	0.89	0.90	0.91	0.92
Food grain	23.80	25.76	27.79	32.24
Optimistic scenario				
Rice	23.66	26.60	29.80	37.68
Wheat	0.89	0.91	0.93	0.91
Food grain	24.55	25.71	30.72	38.59
Pessimistic scenario				
Rice	21.07	22.08	23.08	25.64
Wheat	0.86	0.86	0.87	0.90
Food grain	21.93	22.95	23.95	26.54

[a]Base year (1989-90) production of rice and wheat are 17.86 million t and 0.90 million t, respectively. Source: Shahabuddin and Zobir (1995).

sector (MOA 1996). More than 50 million of a total population of nearly 123 million are categorized as poor in Bangladesh, many of them landless; these are people with low income, low calorie intake, poor health, low level of education, and limited access to social services. Because of severe constraints on available land area, low yields, and increasing population pressure, most rural households become net buyers of food. The incidence of bard-core poverty (calorie consumption below 1805 kcal d^{-1}) is higher

Table 3. Food grain availability and requirements in Bangladesh.

Year	Domestic production (gross. 000 t)			Net production (deduction of 10% for seed, feed, & wastage) (000 t)	Mid-year popu-lation (million)	Food grain consump-tion at 454 g d^{-1} cap^{-1} (000 t)	Food gap (000 t)	Private import of food grain (000 t)	Public distri-bution (000 t)	Internal procure-ment (000 t)	Food grain avail-ability (000 t)	Per capita avail-ability (g d^{-1})
	Rice	Wheat	Total									
1984-85	14,623	1,464	16,087	14,478	98.1	15,734	1,256		2,562	349	16,692	466.5
1985-86	15,038	1,042	16,080	14,472	100.2	16,087	1,615		1,541	349	15,664	428.2
1986-87	15,406	1,091	16,497	14,847	102.5	16,440	1,592		2,120	188	16,779	448.9
1987-88	15,413	1,048	15,461	14,815	104.7	17,334	2,519		2,503	375	16,943	443.8
1988-89	15,544	1,021	16,565	14,909	106.8	17,682	2,773		2,941	416	17,433	447.5
1989-90	17,856	890	19,746	16,871	108.9	18,030	1,158		2,164	960	18,075	455.1
1990-91	17,852	1,004	18,856	16,970	111.0	18,377	1,407		2,372	783	18,559	458.5
1991-92	18,252	1,065	19,317	17,385	113.0	18,708	1,323		2,345	1,016	18,714	454.0
1992-93	18,341	1,176	19,517	17,565	115.0	19,040	1,474	355	1,073	233	18,761	445.5
1993-94	18,041	1,131	19,172	17,255	117.0	19,371	2,116	312	1,376	166	18,777	440.1
1994-95	16,833	1,245	18,078	16,270	119.0	19,702	3,432	1,013	1,573	277	18,579	428.2

Source: Bangladesh Bureau of Statistics and Directorate of Food.

among agricultural households than among nonagricultural ones. A reduction in poverty is critical to food security. Enhancing the ability to buy more food also contributes to sustained growth in agriculture. Agricultural growth is inherently beneficial to the poor as it enhances land productivity and intensifies the farm/nonfarm sector linkages through rapid agroindustrial development based on indigenous produce.

An issue of paramount importance to Bangladesh is food being available and accessible to all at all times. Although self-sufficiency in food grain can be achieved in a normal year, food security-defined as the undisrupted and timely access of the population to food supply for a nutritionally healthy diet-has yet to be achieved. A sizeable proportion of the rural population, who are landless, depend on casual labor for their livelihood. Because of the seasonal nature of agricultural employment and the limited employment opportunities in the nonfarm sector, millions suffer from chronic and transitory food insecurity.

Factors constraining increased and stable food production

Limited land availability and land tenure systems

The area of cultivable land in Bangladesh is 9.7 million ha (67.5% of total land area). Because of double and triple cropping, total cropped area amounted to about 14 million ha, with a cropping intensity of 179%, which is considered high. In addition, land previously devoted to agriculture is now being used for nonagricultural purposes, thereby limiting the availability of cultivable land. The land tenure system is also unfavorable for higher crop productivity. A sizeable proportion of the large and medium landowners are absentee farmers; sharecroppers and tenant tanners do not enjoy decision-making freedom for crop intensification, varietal choice, and management practices.

Poor seed quality

Traditionally, farmers themselves produce most of the required seeds, but the quality is poor. The rice seed requirement now stands at about 0.3 million t, of which only about 4.5% comes from the Bangladesh Agricultural Development Corporation (BADC) as high-quality seed. A major reason for stagnant yields over the years is deteriorating seed quality. The main thrust of the government's 1992 seed policy is therefore to permit the private sector to multiply, process, and market improved seeds. But the private sector has yet to make a significant start in meeting farmers' seed requirements.

Slow pace of farm mechanization

A few years ago, power tillers were seldom used for cultivation. But the shortage of draft animal power contributed to an increased use of power tillers, resulting in an increase in cropping intensity. The government has liberalized the importation of agricultural machinery, including power tillers, to promote selective small-farm mechanization. This has a positive effect on the import of power tillers. The area under cultivation with power fillers is expected to expand, tillage and tilth are expected to improve, and the turnaround time between the harvest of one crop and the sowing of the next should diminish. But the process of mechanization is still slow.

Unbalanced and Improper management of fertilizers

Most Bangladesh soils are highly depleted due to the continuous removal of nutrients from them. Soil fertility is declining as a result of intensive cropping with modem varieties, little or no use of organic manures, and improper soil and crop management practices. Compared with other Asian countries, fertilizer use in Bangladesh is relatively low and is not balanced. For a modem rice variety, 75% of the fertilizer applied is nitrogen, 12% is phosphate, and only 6% is potash, as against the recommended NPK rate of 100:80:60. The need for applying sulfur, zinc, and boron has now become widespread. It is estimated that about 4 million ha of land are sulfur-deficient and 2 million ha are zinc-deficient. Most Bangladesh soils have low organic matter content. About 60% of the arable land is now reported to have organic matter far below the critical level, and the rate of organic matter depletion is alarming. Unless a conjunctive use of balanced fertilizers and organic mailer in soils is promoted through such practices as green manuring, it will be difficult to sustain increased crop productivity.

Agroecological constraints

Bangladesh has diverse agroecological conditions. Based on its physiographic, edaphic, hydrologic, and climatic conditions, the country is divided into 30 major agroecological regions, which are subdivided into 88 subregions. Crop production systems in the different regions and subregions therefore vary widely and face various types and degrees of ecological risks.

Normal floods during the monsoon submerge about 47% of the land area annually to a depth of 60-300 cm. Estimates show that about 38% of the net cropped area is flood-prone, making crop production risky.

Nearly 1 million ha in southern Bangladesh are affected by coastal salinity, especially during the dry season. This limitation restricts the productive use of the land as suitable salt-tolerant crops are not available.

In addition, natural calamities such as cyclones, abnormal tidal surges, hailstorms, and flash floods are regular events that put crop production in significant areas under high risks most years.

Inefficiency of on-farm water management and Inadequate drainage

The estimated irrigation potential from the point of water availability is around 6 million ha, but only about half the potential area is in use. The area of irrigable land, however, is much larger-about 8 million ha.

The inefficient use of water on-farm has contributed to stagnant or declining yields, under both irrigated and rainfed conditions. Primary or supplementary irrigation could be extended to relatively drier areas. Irrigation is mainly practiced for a single crop, boro rice, which has a field duration of 120-130 d. Water use efficiency during the boro season is low because of high evaporative demands. For the rest of the year, the irrigation machinery remains idle tough increasing evidence suggests that water stress at the grain-filling stage of T. aman rice can account for a yield loss of as high as 40% and that one or two critical irrigations at this stage would be quite productive and cost-effective.

Although irrigation is a powerful tool for increasing crop productivity, the deleterious effects of improper water management should not be ignored. The effects were noticed, particularly in rice-rice cropping patterns where continuous wetting of the land and the resultant reduced conditions of the soil caused an accumulated effect of declining yields and unavailability of certain plant nutrients, particularly sulfur and zinc.

Limited crop diversification

Apart from research information, data from a baseline survey covering large, medium, small, and marginal farmers have concluded that the cost-benefit ratios for a variety of noncereal crops are very favorable. In spite of this, the area under noncereal crops has progressively declined since the late 1970s with the expansion of modem irrigation. A lack of market infrastructure and the very high price risks associated with the marketing of these crops may have discouraged farmers from growing noncereal crops. Inadequate extension of on-farm water management technology for upland crops also discouraged farmers from engaging in nonrice crop production. In view of the extra emphasis on rice self sufficiency, the production of most noncereal crops either stagnated or fell during the 1980s and early 1990s. This was mainly due to the reallocation of land that was under rainfed nonrice winter crops, principally pulses and oilseeds, to irrigated boro rice, which was by and large more profitable.

Inadequate credit for agriculture

The institutional sources of agricultural finance serve only a handful of farmers. Small and marginal farmers generally lack access to institutional credit because of difficulties in meeting the collateral requirement. It has been reported that in 1983-84, Tk 10.05 billion was disbursed as agricultural credit, about 20.8% of the total credit to the private sector. This proportion declined to 4.3% in 1989-90, and disbursement in nominal terms hit an all-time low of 1k 5.96 billion in 1990-91. It recovered somewhat in 1991-92 and 1992-93. From 198041 to 1985-86, the net disbursement was positive. The net disbursement from 1986-87 to 1990-91 was negative, by a total of Tk 700 million Since 1985-86, there has been a consistent gap between actual disbursements and targets set for agricultural credit. This gap was around 44% from 1985-86 to 1992-93.

Opportunities and strategies for agricultural development

An agricultural development strategy for Bangladesh should explicitly consider its implications for reducing poverty and should specifically propagate technology, promote investment to improve the productivity of land cultivated by the poor, and increase returns to labor. This would call for a balanced emphasis on developing prime lands and poor and degraded lands and a focus on rainfed technology for crops grown by the poor. Because most of the poor are small and marginal farmers, agricultural strategies must be geared toward improving the productivity of their farms (MOA 1996).

Opportunities

Bangladesh is sufficiently endowed with human and natural resources to enable it to produce its food requirements in an economical and ecologically viable and sustainable manner. There is considerable scope for harnessing these resources. Excellent opportunities exist for accelerating the development of cost-effective minor irrigation facilities, thereby increasing cropping intensity as well as yield. The actual average yields of most cereals and other food crops are less than half their potential levels, and there are ample opportunities for closing the yield gaps.

The intensity of land and resource use is still low. For example, average cropping intensity even in irrigated areas fluctuates from 160% to 180%, depending on the extent and duration of wet-season flooding. The intensity of use of irrigation facilities is also very low (about 111%), which means that supplemental wet-season irrigation is practiced in only 10-15% of the irrigation command areas. It is estimated that barely half of the potential benefits from irrigation development are now being realized. Hence, vast opportunities for substantially increasing food crop production exist.

The potentials for diversifying our major cropping systems---to take advantage of the favorable agroecological conditions---and for diversifying farm products and byproducts for greater value added, better market opportunities, and proper coordination of agribusiness activities have not been fully explored. Crop intensification and diversification will necessitate primary processing of farm products and an assured supply of raw materials for secondary and tertiary processing of farm products and byproducts (e.g., food and feed processing). These offer ample opportunities for generating employment and livelihood by bringing women and other underprivileged members of rural society into the mainstream of agricultural development.

Strategies

The challenge faced by Bangladesh in its agricultural development effort is twofold: to increase the levels of production to meet the requirements of the population (which is expected to double in the next 35 yr) and, at the same time, to achieve sustainable and equitable and socially desirable agricultural growth. The equitable growth objecfive implies that the problems brought about by the year-to-year fluctuation in production to poor consumers and producers should be viewed with equal concern. Socially desirable growth implies that it provides secure employment and livelihood for the poor.

One obvious implication of the abovementioned agricultural development tinperative is that additional efforts must be directed not only at intensifying and diver-

Table 4. Potential and existing yields (t ha1) of major crops.

Crop	Experiment stations	Demonstration plots	National av yield
Rice	4.9	3.7	1.8
Aus	3.6	2.6	1.2
Aman	4.7	4.2	1.7
Boro	6.5	6.3	2.5
Jute	4.3	2.5	1.6
Cotton	2.1	1.8	0.8
Sugarcane	32.0	100.0	40.7
Wheat	4.0	3.0	1.8
Pulses	1.9	1.5	0.7
Mustard	1.6-2.4	1.4	0.8
Maize	3.0	3.0	1.1
Potato	26.4	22.5	10.7
Onion	16.0	9.0	4.0
Banana	37.2	25.0	16.4
Pineapple	96.8	47.5	10.6

Source: Hemid Miah 1995. National av yields from Bangladesh Bureau of Statistics, 1994.

sifying fanning systems but also at bridging the gaps between potential and realized yields (Table 4). Other implications include the vertical integration of production systems, improved water control and on-farm water management, more targeted and efficient use of inputs, a broader and deeper technology base, timely and effective agricultural support services, and an adequate institutional mechanism for the planning and delivery of essential services and functions.

Recent experience has shown that it is possible to accelerate irrigation development in a sustainable manner by continuing to foster a policy environment conducive to the privatization of minor irrigation and removal of restrictions to the importation and trade of minor irrigation facilities. Also, improvements in the placement of tubewells, irrigation support services, and the allocation and use of irrigation water have contributed to increased productivity. It is also feasible to intensify a cropping system through improved water control and management, the proper use of crop mixes and improved crop varieties, selective farm mechanization, and the adoption of other promising technologies.

It is likewise possible to bridge yield gaps by using appropriate technology buttressed by improved extension, expanded marketing facilities, the selection of cropping systems adaptable to various agroecological zones, and the adoption of improved cultural practices. Cropping systems, however, must be conceived in such a way that risks from floods, drought, hailstorms, and salinity are minimized. It should also be possible to diversify cropping systems through the provision of adequate drainage and on-farm water management facilities; the development and extension of appropriate on-farm water management technologies for crops other than rice; suitable machinery for the harvest and postharvest handling of diversified crops; a timely supply of good-quality seeds of major crops; and improved transport, storage, pro-

Table 5. Future crap production plan for Bangladesh (1995-2010).

Crop	1999-2000 Area (million ha)	1999-2000 Yield (t ha^{-1})	1999-2000 Production (million t)	2004-05 Area (million ha)	2004-05 Yield (t ha^{-1})	2004-05 Production (million t)	2009-10 Area (million ha)	2009-10 Yield (t ha^{-1})	2009-10 Production (million t)
Rice	10.46	2.2	22.75	10.49	2.4	25.15	10.43	2.6	27.08
MV	5.98	2.9	17.31	6.76	3.1	20.61	7.33	3.2	23.32
Local	4.48	1.2	5.44	3.73	1.2	4.54	3.10	1.2	3.76
Wheat	0.73	2.3	1.66	0.69	2.6	1.78	0.66	2.9	1.89
Minor Cereals	0.12	1.0	0.12	0.12	1.0	0.12	0.12	1.0	0.12
Food Grains	11.31	2.4	24.53	11.30	2.5	27.05	11.21	2.6	29.10
Potato	0.15	14.2	2.15	0.17	17.0	2.93	0.19	20.0	3.86
Oilseeds	0.64	1.0	0.63	0.79	1.2	0.98	0.80	1.5	1.20
Pulses	0.76	1.0	0.76	0.81	1.3	1.01	0.86	1.5	1.27
Spices	0.21	2.2	0.47	0.24	2.4	0.58	0.29	2.6	0.67
Vegetables	0.21	7.7	1.64	0.21	7.7	1.64	0.27	9.8	2.66
Fruits	0.24	12.4	2.96	0.24	12.4	2.96	0.35	19.1	6.67

Source: MOA 1995.

cessing, and marketing systems. For Bangladesh to be competitive in agriculture, there should be adequate provisions for high-quality infrastructure such as irrigation, roads, and support services to facilitate the low-cost production of agricultural commodities, competitive and efficient markets for agricultural inputs, and a conducive environment for investment in agricultural processing facilities. Table 5 provides the production targets of the most important crops up to year 2010.

Within this framework, agricultural development needs for Bangladesh can be addressed through the following major strategies:

- Increasing crop productivity
  - Accelerated irrigation development focusing on cost-effective and efficient irrigation systems,
  - Development of highly productive, intensified, and diversified cropping systems in irrigated areas to maximize output and economic returns,
  - Development of suitable technologies in raided systems to close the yield gap and enhance the productivity of the majority of the farmers, and
  - Development of support facilities and services for diversified production systems and coordination of agribusiness concerns in crop agriculture.

- Reducing instability in production with particular attention to
  - Development of irrigation, drainage, and flood control systems and improvemerit in water control and on-farm water management,
  - Use of pest/disease-tolerant varieties and improved crop management practices,

- Improved quality, increased quantity, and targeted use of production inputs,
- Reduction in postharvest losses, and
- Judicious choice or manipulation of cropping systems, crop mixes, and varieties to minimize crop losses from droughts, floods, and soil toxicity problems.

- Strengthening of agricultural research and extension systems
    - Develop appropriate varieties suited to specific ecosystem niches and new technologies suitable for diverse agroecological situations;
    - Develop location-specific, integrated, intensive, and sustainable farming systems;
    - Develop ecologically sound technologies for the appropriate and balanced use of chemical fertilizers, organic fertilizers, and biofertilizers, and for the safe use of pesticides, giving due emphasis to integrated pest management practices;
    - Develop strong research and extension linkages for technology identificadon, on-farm verification, suitability assessment, adaptive modification, and packaging for large-scale dissemination;
    - Promote diffusion of proven technologies in different agroecological zones;
    - Promote a favorable policy environment for good infrastructure and effective support services, and private-sector investment and initiatives in the agricultural sector;
    - Promote competitive markets for the supply of agricultural inputs;
    - Develop agroprocessing technologies including postharvest handling, food processing, storage, and preservation, and promote their use through private-sector initiatives;
    - Enhance women's contribution to household income and nutrition by upgrading their knowledge and skills on homestead gardening and food processing and in areas of child nutrition;
    - Formulate gender-sensitive agricultural development programs and projects to enhance women's participation in decision making and sharing of benefits;
    - Promote rural institutions (e.g., fanners' groups, cooperatives and credit societies, water users' groups~), infrastructure (e.g., rural electrification, feeder roads, organized markets), and public support services; and
    - Promote effective and timely delivery of need-based agricultural support services.

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Citation: Bhuiyan SI, Karim ANMR, editors. 1998. Increasing rice production in Bangladesh: challenges and strategies. Manila (Philippines): International Rice Research Institute, and Dhaka (Bangladesh): Bangladesh Rice Research Institute.

Coping with water scarcity: What can rice science offer?

S. I. Bhuiyan

Excessive supply during monsoon and acute shortages in the dry season characterize the water scenario in Bangladesh. Future agricultural growth in the country, including growth in rice production, is intimately linked with the further development and improved management of its water resources. In the past two decades, most agricultural water needs have been met through increasing withdrawal of water from shallow groundwater reservoirs. But this process cannot be continued too long as it has already created problems of high concentrations of arsenic in pumped water and a drinking water crisis for the rural poor due to excessive lowering of the water table in meeting the high irrigation demands of boro rice in the dry season. Therefore, the current level of water productivity in rice culture must be improved substantially if a severe water crisis and environmental calamity were to be avoided in the future. This paper identifies and analyzes three scientific approaches for improving water productivity in rice culture: (l) management of water as a production factor, (2) chemical weed control, and (3) the use of genetic potential. In reality, all three approaches need to be used meticulously to minimize wastage of water and produce more food per unit of water used.

Few countries in the world face the striking contrast between a huge surplus of water in the wet (monsoon) season and an acute water shortage in the dry season as does Bangladesh. About one-third of the country's land area is expected to be submerged by monsoon flood in a normal year. Yet, without irrigation, no decent crop can be grown in the post-monsoon months from November to March, when rainfall is negligible in most parts of the country.

Today, only about 1.7% of the total renewable water resource in Bangladesh is withdrawn for consumption, equivalent to about 211 m3 of per capita annual supply, which is lower than that in most other Asian developing countries (Frederiksen et al 1993). This amount is far below the 1,000-1,700 m3 per capita renewable water supply that is globally considered to be on the border line between water adequacy and water stress conditions (Gleick 1993). Although annual withdrawal figures often do not reflect the true water availability situation, the low withdrawal rate is indicative of the high potential for developing water resources in the future. But, in reality, several factors that are commonly found in countries located in river deltas of the humid tropics, such as Bangladesh, restrict the expansion of water resources: (1) lack

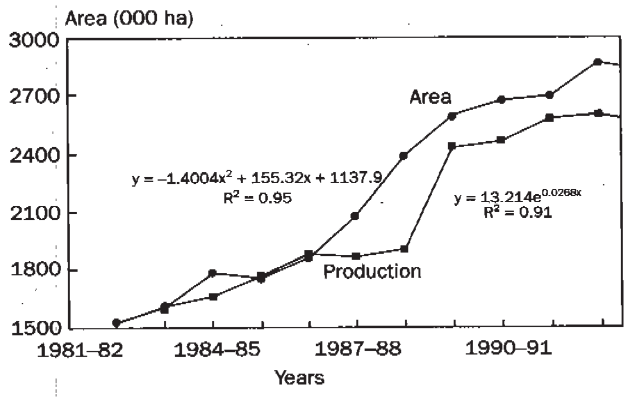

Fig. 1. Growth in rice production and irrigated area, Bangladesh, 1982-83 ro 1993-94. FAO (1996).

of suitable sites for surface water storage, (2) relatively high cost of water development, (3) heavy dependence on limited groundwater, which is expensive to lift, and (4) large coastal areas with a salinity problem.

Water resource development in the past has not kept pace with the expanding demand for water in most countries of Asia; therefore, the per capita water resource available for use has declined. Bangladesh is no exception; about 96% of all the de- veloped water resource in the country is used for agricultural purposes (WRI 1992). As the population continues to grow at about 2% annually and as industrial develop- ment and urbanization are expected to proceed at an accelerated rate, demand for fresh water will increase sharply in the near future. Feder and Kech (1994) projected that between 1995 and 2025, water demand for domestic and industrial uses in South Asia will rise by 304% and 331%, respectively. This development will undoubtedly lead to a serious water crisis, the most likely result of which would be a reduction of agriculture's share of water.

In Bangladesh, the growth rice in production in recent years (Figure 1) has come mostly from the expansion of boro rice area, which has been possible with the increased use of groundwater through shallow tubewells (Shahabuddin and Zohir 1995). But only about 40% of the potentially irrigable area of 7.56 million ha has irrigation facilities now. About 70% of the irrigated area uses groundwater as the source and the remaining area receives water from surface sources (FAO 1996).

Much has been written about the large gaps between created irrigation potential (command) and actual use of the potential, and their causes. But reliable data on the actual use of the irrigation potential are scanty. In general, the larger the system's irrigable area, the higher is the gap as the distributional problems are often amplified directly with expansion in target areas. Thus, per unit of water resources, large gravity irrigation systems are generally less effective in serving the command area than smaller low-lift pump systems. Likewise, shallow tubewell systems are expected to be more effective in covering target areas than deep tubewells, which have higher discharge capacities and larger command areas.

In the past, estimates of potential areas that could be supported by groundwater were based mostly on the concept of "hydrologically safe" discharges or withdrawals from aquifers to prevent irreversible lowering of the water table. Past experience has indicated that issues of environment, water quality, social equity, and others must be adequately considered in planning the development and use of groundwater as a common property resource. The true extent of groundwater irrigation that is economically, socially, and environmentally sustainable in the long term has yet to be determined for various parts of the country. in some areas, intense competition over the finite groundwater resource between deep tubewells used for irrigating boro rice and shallow hand pumps drawing water for domestic use is creating a crisis in drinking water, with a serious negative impact on the poor in rural society (Sadeque 1996). In several districts in the Gangetic floodplains, arsenic contamination of groundwater and consequent health problems from drinking the water have been reported recently. Furthermore, the cost of lifting groundwater is becoming increasingly high for farmers to bear.

Similarly, there is a lot to be learned from the experience with surface-water schemes developed in the past, including flood control and drainage/irrigation systems. The reasons for the large gaps between potential and actual use, the true economic viability of these projects, and their long-term impact at both the project and larger basin levels should be assessed systematically to facilitate making decisions about future investments in this type of development.

In the next 30 yr, to meet the total rice demand from domestic supply, rice production in Bangladesh has to be increased by about 80%. The development and expanded use of water will be a major driving force for increasing future rice production. The water shortage will become a more severe limitation to increasing production in the future. How can future rice production needs be met in an environment of declining water availability? What can rice science contribute to coping with the looming water crisis? This paper addresses these questions, and focuses on water as a critical factor in rice production.

How much water is needed and used in producing rice?

As an aquatic plant, rice performs well in a water-abundant environment. Rice is also adapted to a wide range of enviromnents-from uplands to lowlands, and from tropical to temperate climates. In Japan, rice is grown in areas as far north as latitude 53ºN (Barker and Herdt 1985).

Water performs the following main functions in rice fields:

- Preparing the land to facilitate establishment of the crop. The amount of water needed for this varies widely depending on the soil-water condition and the method of crop establishment to be used. A large quantity of water is used for preparing the land, including puddling and transplanting rice seedlings. On the average, about one-third of the total water requirement for growing transplanted rice is used up before the rice plants have been established in the field.

- Meeting the evapotranspirational (Et) demand of the crop in the field, which is determined by the surrounding climate. The Et rate is higher in the dry season when the solar radiation load is higher and air humidity is lower than in the wet season. The average rates of Et in rice fields in the tropics and subtropics vary between 4 and 8 mm d^{-1} in the dry season and 3 and 5 mm d^{-1} in the wet season. Crop growth duration determines the total Et demand at a given location for the crop season.
- Maintaining a plant-root environment tat allows roots to take up nutrients. Saturated soil offers the least resistance to plant root development and to nutrient movement from the soil to the plant roots. It has long been established that in irrigated rice culture, the crop performs best when the water status in the root zone is not allowed to fall below the saturation level. This has greatly influenced the design and operation of irrigation systems and the management of water on the farm. For example, in cropped fields, a continuous process of water loss by percolation (which is the inevitable consequence of maintaining a positive water depth above the soil surface) has been accepted as a requirement for growing irrigated rice. Percolation rates are higher in soils that are lighter in texture. Most rice soils in Asia have percolation rates between 1 and 6 mm d^{-1}.

For various reasons––e.g., to have insurance against possible water shortage, to control weeds, and to save on labor––rice farmers maintain standing water depths that vary from very shallow to as high as 15 or 20cm throughout the growing season. This causes the percolation rate to be higher, such that too much water is lost to the water table or to drainage channels. Some argue that this Water can be tapped by others and is therefore not really a loss when we consider the greater water basin rather than the irrigation system or the farm itself. The reality, however, is that, even in the context of the same water basin, the displacement of water is associated with loss of "head'' or elevation and practical use of such displaced water requires expenditure of energy and money.

To produce each unit of grain or calorie of energy; more water is used in rice than m most other cereal crops (Bhuiyan 1992). Currently, for each kilogram of rice produced on a farm served by a large irrigation system, about 5,000 liters of water is diverted at its source (Bhuiyan et al 1995). The actual amount of water needed in the field is normally 25-30% of this amount. Only about 30-50% of the amount of water applied to the field is effectively used for crop biomass production. The gap between the "true need" and "current use" of water in producing rice is thus very large.

Excessive water use in land preparation accounts for a substantial portion of the gap. About 150-250 mm of water is needed to make the land ready for transplanting, but several times more water is often used-as high as 1500 mm has been reported for some areas in the G-K irrigation project (Ghani et al 1989). The high amount of water used is often a direct consequence of the long period of time (often 1 mo) during which seedlings grow in the seedbed before they are ready for transplanting (Bhuiyan et al 1995). Also, if the soil is allowed to crack, more water is needed to soak (saturate) and prepare the land. In heavy clay soils, the cracks may remain open even after keeping the field under water for many days, allowing water to be lost to the deeper soil layers or the water table.

During crop irrigation, much more water is generally applied on the field than is needed to maintain the saturated root zone condition. Most farmers do this to control rice field weeds, but this benefit comes at the expense of substantial water loss by percolation and seepage through the soil profile. Puddling seals the pore spaces in the soil and thus reduces the percolation rate. However, large amounts of water can be lost to the water table through patchy areas of the field left unpuddled due to nonuniform puddling activities and through areas below the permanent field bunds which remain untouched during puddling.

Approaches to addressing the water crisis

The shortage in water supply can be addressed in two ways: by developing new irrigation facilities through appropriate investments and by improving the efficiency of water use in rice production systems. Clearly, both approaches should be pursued seriously in Bangladesh if future rice demand is to be met from domestic production. Estimates (MWR 1991) show that total water demand for the agricultural and nonagricultural sectors will exceed total available water resources (80% dependable surface source plus groundwater source in March, the most critical month) by 2018. Even without considering costs, the inadequacy of averting the future water crisis with new water resource developments alone is clear. There is therfore no alternative to devising sustainable means of increasing water productivity in rice culture—i.e., growing rice with less water.

Increasing water productivity in rice culture

Scientifically established means of increasing water productivity in rice culture are discussed under the following themes: (1) water management as a production factor, (2) chemical weed control, and (3) pursuing the genetic potential of rice through varietal improvement.

Water management as a production factor

Reducing water requirement for land preparation. Puddling is an excellent way of reducing loss of water through percolation. But much water is generally wasted during the process of puddling, especially when water is used for long periods. The period is long in most cases because farmers grow their own seedlings, which require about 1 mo in the seedbed or nursery before being ready for transplanting. An opportunity to conserve water arises when farmers do not have to wait for 1 mo after starting the seedbed before the crop is established (Bhuiyan et al 1995). The introduction of a system where farmers raise their seedlings in community seedbeds would help reduce the amount of water used.

To reduce Water loss in land preparation, Thong and Cabangon (1995) showed that the water requirement for land soaking can be significantly decreased by giving the soil a shallow dry tillage soon after harvest of the previous crop; this acts as a mulch against soil, cracking.

Controlling irrigation supply to better match demand. Research has been conducted to find sustainable ways of reducing excessive water supply to both irrigation canals and farms. But most recommendations have not been accepted by farmers being served by the public-sector irrigation schemes that dominate the rice production scene in many countries of Asia. Various forms of rotational irrigation schemes had shown promise in addressing the inequity in, water delivery between the head-end and the tail-end areas of larger canal-based rice irrigation systems, but most of them required intense technical and social inputs that have been difficult to sustain over the long run.

Experimentation over the years has shown that water use in transplanted rice culture can be reduced by 30-50% when the soil is maintained at a saturation level throughout the cropping season, compared with the popularly practiced continuous shallow-flooding regime (Tabbal et al 1992). Weeds can be controlled by the use of chemicals or hand weeding. Such a system can give yields comparable with those obtained using the standard method of rice culture. In case of high weed infestation, when the use of chemicals alone may not be adequate to control weeds, shallow water depth maintained up to the time the crop canopies have fully covered the field and a saturated soil regime maintained after that up to crop maturity are recommended. Such a strategy of water-cum-chemical control of weeds will allow 25-35% less water to be used than the popular method of water management. The savings in water are higher for soils of lighter texture.

Reducing water demand through direct seeding. Recent research has shown that the wet-seeded system of rice culture, in which pregerminated seeds are sown on puddled soil, is significantly less water-demanding than the traditional transplanted rice system. Farmers who practice wet seeding use water for land preparation over a much shorter duration as they can get the seeds ready for sowing after 1-2 d of soaking at home. In contrast, tanners using transplanted rice have to wait for about 1 mo, during which time they also use the water for preparing the main farmland for crop establishment Farmers who grow wet-seeded rice maintain a very shallow depth of water in the field, which results in rice plants with stronger culms. This practice reduces water loss by percolation and seepage.

Wet-seeded rice has been found to be more tolerant of drought than transplanted rice (Bhuiyan et al 1995). Another big advantage of the wet-seeded rice system over the transplanted 'rice system is its lower labor requirement and consequent higher return from rice production, Understandably, wet-seeded rice is becoming increasingly popular in different countries of Southeast Asia, such as Thailand, the Philippines, and Malaysia.

Chemical wood control

Most traditional rice farmers use water as a tool to control weeds. Some mechanical or manual weeding is often needed to keep the rice field weed-free even when a few centimeters of water depth has been maintained in the field through most of the growing period. Herbicide use is becoming a popular weed control method in some Asian countries, especially where a range of effective chemicals is available at reasonable prices. In the Philippines, Thailand, and Malaysia, for example, using herbicides for weed control is substantially cheaper than using labor. In direct-seeded (wet-seeded and dry-seeded) rice, manual or mechanical weeding is not feasible. That is why substitution of transplanted rice by wet-seeded rice in irrigated areas and by dry-seeded rice in ratted areas is spreading in countries where herbicides are available and the cost of labor is relatively high. Many farmers also use herbicides in transplanted rice to save on labor Concerns have been raised, however about the indiscriminate use of herbicides and the possible development of herbicide resistance in weeds. There is also concern about the possible toxic effects of some chemicals when they reach freshwater bodies, both surface water and groundwater.

The use of herbicides for weed control opens up the opportunity for reducing water use in rice culture. This trade-off will be advantageous where water has a premium value.

Pursuing genetic potential

Modem varieties (MVs), with their high yield potentials, have contributed significandy to increasing the productivity of water. Most of today's MVs have a higher yield potential and tolerance for a wide array of pests and diseases; many of them also mature earlier than traditional varieties. This "earliness" confers water productivity gains by completing the crop growth cycle earlier, which has allowed an increase in cropping intensity in irrigated and favorable rainfed areas.

The development of indica hybrids in recent years, which have 15 and 20% higher yield potential than their inbred counterparts but which require the same water inputs, is another milestone tat will allow improvement of water productivity over and above that imparted by modem (inbred) varieties.

Bangladesh has about 1 million ha of coastal salinity-prone rice area that produces very low yields. This area would have a quantum jump in production if suitable improved varieties could be developed. The rice plant's resistance to salinity is known to be a complex character controlled by a number of genes or groups of genes. Given the biotechnological knowledge and innovations that are or should be available in the near future, we can expect some major developments in breeding varieties for at least the mildly saline areas. Significant progress can also be made in increasing productivity through appropriate management of soil and water resources in these areas.

Tolerance for drought is another complex area. High priority should be given to research on breeding for drought tolerance in rainfed rice areas that suffer from inadequacy of rainfall in both amount and timing. In many situations with relatively lighter soils, MVs in direct-seeded conditions have shown better performance than transplanted rice in using the limited rainfall early in the season. After harvesting direct-seeded rice, which matures earlier than transplanted rice, fanners can make better use of the residual soil water by growing a legume crop (IRRI 1994). The varieties used for direct seeding are those that were bred for transplanting. For higher productivity of direct-seeded rice, new varieties bred especially for early maturity, high yield stability, drought tolerance, and weed competitiveness are needed. Significant efforts are currently under way to identify lines with (and molecular markers for) a greater maximum rooting depth (Champoux et al 1995), a capacity to penetrate hardpans, or a capacity to osmotically adjust to declining water availability (Lilley and Ludlow 1996).

Concluding comments

Water in the dry season is already a scarce commodity in Bangladesh. Most of the current irrigation systems use groundwater, which is limited and expensive to lift. The future will probably see a greater degree of water scarcity than today. As rice production consumes more than 90% of all developed water, it is imperative that ways to produce more rice with less water be found.

For a sustainable solution, the worsening scarcity of water for rice cultivation must be addressed from various scientific angles. Greater attention should be given to developing water management systems that will maximize the efficiency and productivity of water in rice culture. Concurrently, we need to harness the biological potential of the crop to a fuller extent, with advanced technologies, as necessary, so that production gains can be achieved and sustained with less irrigation required.

Although groundwater is costly to farmers and its scarcity is increasing, surface water irrigation systems in the public sector are often seen from a different perspective. Little value is attached to surface water. Appropriate policies are needed to remedy this conflicting situation and to treat water as an economic good on a national scale.

Future water development schemes (both surface water and groundwater) must adequately take into account concerns related to water quality, social equity, and the environment. The issues concerning the crisis in drinking water during the dry season because of deepwell irrigation in the boro season, arsenic contamination of groundwater, and salinity encroachment in coastal areas should be resolved with top priority. Likewise, we need to carefully monitor the impact of the increasing use of agochemicals (such as pesticides and herbicides) and nitrogen on water quality.

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Citation: Bhuiyan SI, Karim ANMR, editors. 1998. Increasing rice production in Bangladesh: challenges and strategies. Manila (Philippines): International Rice Research Institute, and Dhaka (Bangladesh): Bangladesh Rice Research Institue.

Potential of nonrice crops in rice-based cropping systems in Bangladesh

M.A. Razzaque

Production of nonrice crops in rice-based cropping systems in Bangladesh is vital to attaining food security. Nonrice crops are mostly grown in the winter season, when the risk of crop failure is very low. Large areas in Bangladesh have light-tenured soils that are suitable for producing winter crops such as wheat, potato, pulses, and oilseeds. But farmers prefer to grow boro rice wherever they have access to sufficient water. This trend can be reversed only if higher productivity in nonrice crops can be achieved-with high-yielding varieties, improved management practices, and adequate marketing facilities and incentives. All of these become increasingly important as the economic condition of the people improves and as their diet becomes more diversified. In the face of less land devoted to agriculture, massive crop diversification will not take place unless the productivity of rice, the staple crop, is enhanced. Appropriate policy support can accelerate this transformation. This paper describes the prospects for using different nonrice crops in the predominant rice-based cropping systems in Bangladesh.

Nonrice crops are vital for meeting the food requirements of the increasing population of Bangladesh. Annual deficits amount 15% for rice, more than 75% for pulses, 70% for edible oil, and 55% for vegetables. Increased and balanced production of nom-ice crops is needed to meet demand for food and improve the nutritional status of consumers.

By sustaining growth in food production, the consequences of a demographic disaster can be partly overcome. Achievements in the food sector show that the desired growth rate is not beyond reach. Although the scope for expanding cropping area is limited, production growth can be achieved by raising crops following a well-planned cropping system and using high-yielding crop varieties, balanced fertilizers, and standard crop management practices. Bangladesh has a total cropped area of 13.7 million ha, with a cropping intensity of 179%. About 34% of the cropped area is occupied by a single crop, 53% is double-cropped, and 13% is triple-cropped (Table 1). In spite of the intensive land use, the country has deficits in crop production and farm families face economic dislocation. Two of the major causes of these deficits are low growth in crop productivity and the low adoption of appropriate technologies. Moreover, floods, droughts, cyclones, and tidal waves damage crops almost every year.

Table 1. Land use for agriculture In Bangladesh, 1992-93.

Nature of land use	Area (000 ha)	Percent of total land
Forest	1,893	12.8
Nonavailable cultivable land	4,195	28.2
Cultivable waste	445	3.0
Current fallow	665	4.5
Net cropped area	7,649	51.5
Total land	14,847	100
		Percent of net cropped area
Single-cropped area (a)	2,596	33.9
Double-cropped area (b)	4,047	52.9
Triple-cropped area: (c)	1,006	13.2
Net cropped area 7,649 (a+b+c) = d		100
Total cropped area (a+2b+3c) = e	13,708	
Cropping intensity (e/d x 100)		179.2

Source: BBS (1996).

The winter season is almost free from natural hazards and is a relatively safe period for producing nonrice crops. Rice-wheat is the major cropping system in Bangladesh; wheat is grown in the winter in rotation with rice in about 85% of the area. The scope for growing other nonrice crops in the winter in rice-based cropping systems should be broadened in relation to their demand. We need to improve systems-based productivity and the emphasis on increased production should include not only rice and wheat but also other nonrice crops.

Role of nonrice crops

Of the total cropped, area of 13.7 million ha, rice covers 74% (aus, aman, and boro), wheat 4.6%, pulses 5.2%, potato 1.2%, edible oilseeds 4.2%, vegetables 1.3%, and others 9.5% (Fig. 1). The last group includes sugar crops, minor cereals, fiber crops, spices, fruits, an4 crops from which narcotics are produced. Nonrice crops cover 26% of the total cropped area; of this, wheat occupies 17.7%, pulses 20%, potato 4.6%, oilseeds 16.2%, vegetables 5%, and others 36.5% (Fig 1.).

Table 2 shows the area, production, and yield of nonrice crops. Pulses are predominant, followed by wheat, jute, and edible oilseeds. The other nonrice crops, though covering a limited area, are important in the human diet and their productivity must be improved to meet the national demand. The potential. to intensify cultivation and enhance the productivity of some major nonrice crops is briefly discussed in the following sections.

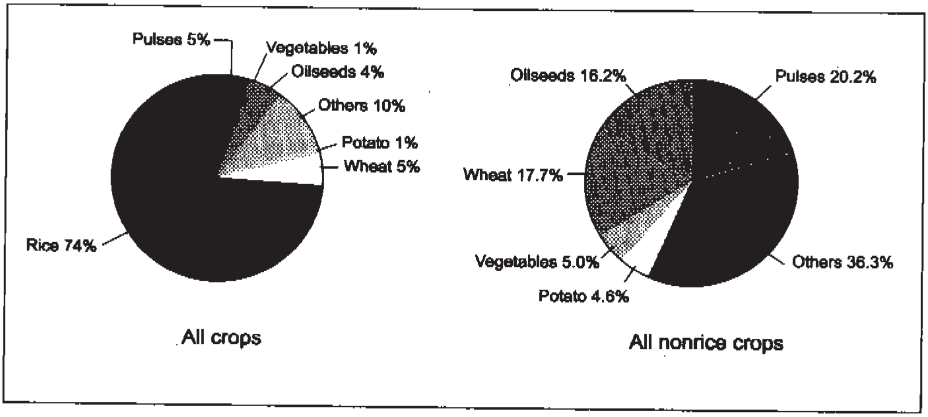

Fig. 1. Percent coverage of rice and nonrice crops.

Table 2. Area, production, and yield of rice and nonrice crops, 1993-94.

Crop	Area (000 ha)	Production (000 t)	Yield (t ha')
Aus rice	1,650	1,850	1.1
T aman rice	5,753	9,419	1.6
Boro rice	2,582	6,772	2.6
Wheat	615	1,131	1.8
Minor cereals	97	72	0.7
Pulses	709	531	0.8
Oilseeds			
Edible	452	329	0.7
Nonedible	107	143	1.3
Potato	131	1,438	11.0
Sweet potato	45	427	9.5
Sugar crops	195	7,416	38.0
Jute	479	4,453	9.3
Minor fibers	34	150	4.4
Vegetables	181	1,164	6.4
Spices and condiments	144	325	2.3
Fruits	174	1,460	8.4
Crops from which narcotics are produced	134	185	1.4
Nonfood crops	7	51	7.3
Total cropped area	13,489		

Source: BBS (1996).

Wheat

Wheat is the second most important cereal crop after rice. High-yielding wheat varieties cover almost 100% of the area. In Bangladesh, only bread wheat is grown for making chapati (handmade bread) and other industrial products—as many as 56 items are prepared from wheat. Because of the crop's diversified use and important role in food security, more emphasis should be given to increasing wheat cultivation area and its productivity. The Bangladesh Agricultural Research Institute (BARI) has recently developed high-yielding wheat varieties that are heat-tolerant and about 15% better yielding than existing ones. Similarly. the Bangladesh Rice Research Institute (BRRI) has developed early maturing T. aman varieties that can be used in the rice-wheat cropping system. Lands that remain fallow or those that could not be planted to another crop due to late harvest of T. aman rice can now be used for wheat. As improved rice and wheat varieties become available, farmers can use their land with more flexibility and wheat planting time can be manipulated without losing yield.

Pulses

Pulses are the most important food crops among the nonrice crops in Bangladesh. They are the main source of protein in the daily diet. These crops include grass pea, lentil, chickpea. black gram, green gram, field pea, cowpea, pigeon pea, and soybean. Grass pea, lentil, gram, and mash *kalai* are the principal pulses, occupying 82% of the pulse-cultivated area and contributing 85% to total production. Other pulses are considered minor in both area and production. In rice-based cropping systems, pulses are grown after harvest of the T. aman rice crop. One of the main reasons for the low productivity of pulses is late sowing because the land is first used to grow T. aman rice. This problem has largely been solved through the release of early maturing T. aman varieties by BRRI. High-yielding pulse varieties have also been released by BARI and the Bangladesh Institute of Nuclear Agriculture (BINA). The development of improved varieties of pulses and early maturing modem varieties of rice has opened up more scope for farmers to expand the area under pulses and to obtain better yield.

Potato and sweet potato

Potato is the most important tuber crop and a common item in the daily diet of the Bangladeshi people irrespective of social class. Sweet potato, on the other hand, is more popular among rural people. Recently, potato production has increased significandy because of the release of several high-yielding varieties and the consequent higher economic returns from their cultivation. Moreover, farmers can now select appropriate varieties for their areas because varieties suitable to different agroecological regions have become available. Besides their extensive use as a vegetable, potatoes are now in great demand for their use in a variety of food products.

Oilseeds

Several oilseed crops grow in Bangladesh. Of these, rape and mustard occupy about 70% of the total oilseed cropped area. Recently, BARI and BINA have developed several improved varieties of rape, mustard, and groundnut. There is a potential for doubling oilseed production by replacing traditional low-yielding varieties with high-yielding ones. Groundnut, which has more oil and protein content, can be grown profitably in marginal soils in both the summer and winter seasons. The production of sesame and other oilseed crops can be enhanced by adopting optimum management practices. High-yielding varieties that are responsive to inputs need to be propagated. We also need to improve existing oil extraction processes along with marketing facilities.

Vegetables

Diverse vegetable crops are grown in Bangladesh almost throughout the year. Most summer vegetables (pointed gourd, Indian spinach, bottle gourd, ribbed gourd, snake gourd, and bitter gourd) are indigenous, while most winter vegetables (cabbage, cauliflower, broccoli, radish, hyacinth bean, and tomato) are exotic. Because of the low production of vegetables, consumption is as low as 30 g person-′ 4t which is much lower than in other countries. Several improved varieties of radish, tomato, eggplant, and cabbage have recently been released. About 25% of the total vegetable area is covered by these improved BARI varieties. There is an enormous scope for growing vegetables to supplement rice.

Major cropping patterns

In Bangladesh, cropping patterns are largely rice-based, except in sugarcane areas (Table 3). The single-cropping pattern is common in heavy-textured soils, and double and triple cropping are practiced in loamy to sandy loam areas with irrigation. The major crops planted are boro rice, wheat, pulses, oilseeds, potato, and vegetables. These crops are mostly raised on a monocrop basis, but mixed cropping is also observed at an insignificant scale in certain locations. Lentil, gram, or grass pea is mixed with the wheat-mustard cropping system, usually resulting in poor yields.

Table 4 shows the major crops grown and their productivity. Crop productivity can be improved by adopting technologies pertinent to the farmers' situation. Based on performance, cropping zones with proven cropping systems can be developed in a particular region. For example, farmers in the districts of Rajshahi, Bogra, Rangpur, and Dinajpur are engaged in wheat and not boro cultivation; in Comilla, Mymensingh, and Syilhet, the boro crop is preferred. Similarly, pulses are widely cultivated in the districts of Pabna, Faridpur, and Rajshahi.

Table 3. Major cropping patterns In Bangladesh and their suitability.

1st crop	2nd crop	3rd crop	Suitability
High land			
Aus/jute	Potato/wheat/pulses/ oilseeds/sweet potato/ tobacco/spices/ winter vegetables.	-	This system prevails all over Bangladesh where there is loamy to sandy loam soil.
Aus/jute	Transplanted aman	-	This system is similar to the first one. It is used in loamy to clay loam soils where enough water is available after the harvest of aus/jute.
Sugarcane	-	-	This system covers most areas with loamy to clay soils.
Jute/T. aman	Winter crops	-	This system is practiced mainly in the northeastern part of Comilla and also in places with enough water to raise T. aman.
Summer vegetables	Monsoon vegetables	Winter vegatables	This system is followed in homesteads all over Bangladesh.
Medium land			
Aus/T. aman	T. aman Continuous	Wheat/potato/ pulses/ oilseeds/ barley/spices	This system is practiced in almost all districts except in Dinajpur, Rangpur, Bogra, Rajshahi, Kushtia, and Jessore.
Aus/jute	T. aman	-	This system is practiced all over Bangladesh.
T. aman	-	-	This system prevails in Dinajpur, Rajshahi, Bogra, Rangpur, and coastal areas.
T. aman	Boro rice	-	This system is practiced in Comilla, Chittagong, Dhaka, and in some parts of Rajshahi and Khulna.
Low land			
Broadcast aman	Boro/wheat/pulses/ oilseeds/spices	-	This system exists all over low-lying areas of Bangladesh.
Broadcast aman	-	-	This system exists in low areas where flood comes early and recedes late—Comilla, Pabna, Tangail, Faridpur, and Mymensingh.
Boro rice	-	-	This system is in practice in the low-lying (haor??) areas of Sylhet and Mymensingh.

Table 4. Growth rats and productivity (% yr^{-1}) of nonrice Crops compared with rice, 1970-71-1992-93.

Crop	Parameter	1970-71-1980-81	1981-82-1992-93	1970-71-1982-92
Aus rice	Area	0.24	-5.22	-1.98
	Production	2.56	-3.56	-0.50
	Yield	2.00	1.76	1.51
T. aman rice	Area	0.71	-0.57	0.05
	Production	3.41	2.14	2.05
	Yield	3.00	2.72	2.00
Boro rice	Area	1.75	7.68	5.26
	Production	1.60	8.10	6.58
	Yield	-	0.40	1.26
All rice	Area	0.68	0.22	0.34
	Production	2.86	2.86	2.70
	Yield	2.00	3.09	2.36
Wheat	Area	15.76	0.97	8.11
	Production	28.31	-0.37	13.07
	Yield	10.85	01.33	4.58
Pulses	Area	-0.32	6.86	3.21
	Production	-2.29	7.54	2.51
	Yield	-1.97	0.64	-0.67
Oilseeds	Area	0.39	4.90	2.62
	Production	0.74	4.73	2.71
	Yield	0.34	-0.16	0.09
Vegetables	Area	na[a]	4.31	na
	Production	na	4.54	2.57
	Yield	na	0.22	na
Potato	Area	2.18	1.88	2.03
	Production	2.04	1.84	1.94
	Yield	-0.14	0.03	-0.09
Sweet potato	Area	0.69	-3.45	-1.40
	Production	0.25	-4.79	-2.30
	Yield	-0.43	-1.39	-0.91
Jute	Area	-1.57	-2.96	-2.27
	Production	-0.02	-1.72	-0.87
	Yield	1.57	1.28	1.43

[a]NA = not available. Source: BBS (1973,1996Z).

Understanding growers' problems

Growing nonrice crops profitably in a predominantly rice-based cropping system depends on an array of physiographic, edaphic, hydrologic, climatic, and socioeconomic factors that vary by agroecology. Various parameters of these factors have not been properly investigated and assessed. Likewise, farmers' problems have not been clearly identified. To make the production of nonrice crops sustainable, systematic surveys addressing these factors must be conducted to facilitate suitable interventions (e.g., improved technologies).

The major problems observed in growing nonrice crops in rice-based systems are not new or unique. They have existed for a long time and efforts to solve them are often inadequate. Some of the major problems are briefly discussed here.

Improper selection of cropping pattern

In rice-based systems, farmers select varieties of nonrice crops based on their own or their neighbors' experience rather than on research results. On-farm trials conducted by BARI and BRRI have shown that productivity of nonrice crops can be greatly increased by replacing the crap or variety with one that fits the overall agroecological conditions of the area. For example, the recently introduced rice-chickpea cropping pattern in the Rajshahi area, in which an earlier maturing rice variety and a higher yielding chickpea variety have been introduced, has significantly enhanced total productivity of the system. Fanners tend to grow boro rice in the winter season in areas where irrigation is available. Studies have shown that in certain areas with light soil, nonrice crops can be grown more profitably than rice. The Crop Diversification Program of the Department of Agricultural Extension recently launched a campaign to motivate farmers to grow nonrice crops. These efforts should be supported by a strong research unit to enable program participants to use the improved cropping patterns recommended by researchers.

Poor crop establishment

In rice-based systems, particularly in situations where nonrice crops are grown after rice, poor crop establishment is a common problem. This is attributed to excessive or inadequate soil moisture, soil-inhabiting pests and pathogens, and poor seed quality. Recently, satisfactory establishment of the wheat crop in a rice-wheat system in Dinajpur and Chuadanga districts was achieved by preparing the land with an engine-driven rototiller. Optimum crop stand is a precondition for higher productivity. We must find innovative ways to ensure better crop establishment of the major nonrice crops.

Nutrient deficiencies and improper use of fertilizers

We need to know the amount of nutrients removed by crops in different cropping systems so that soil fertility can be maintained with added fertilizers and organic matter. For this purpose, soil-testing facilities should be developed for easy access and use by the farming community. Recently, the Soil Resources Development Institute has shown that productivity gains can be achieved by using a soil-testing kit in intensively cropped areas.

Lack of irrigation

Among the nonrice. crops, only wheat and potato are irrigated. Other major nonrice crops, such as pulses and oilseeds, are mainly grown under nonirrigated conditions. One or two irrigations to these crops could greatly enhance their productivity. The main limitations are the difficulty in irrigating noncontiguous lands and high water service fees.

Shortage of high-quality seeds

Few improved varieties of nonrice crops have been released. For the diverse ecological conditions of Bangladesh, more improved varieties are needed so that farmers can plant varieties that suit local conditions. In the field, however, fanners face the problem of unavailability of improved varieties and their seeds. Seeds supplied by government agencies are inadequate to meet current demand, whereas seeds preserved by farmers lack the needed quality. Improved seed quality can increase productivity by 10-15%.

Unfavorable land tenure system

Many Bangladeshi farmers who grow nonrice crops have small landholdings and most of them are tenants. The unfavorable land tenure system is a chronic socioeconomic problem that negatively affects cropping intensity and productivity. Studies have shown that small tenant farmers are better adopters of high-yielding varieties and good crop management practices. These fanners are also interested in intensifying cropping to maximize production. Existing land tenure and sharecropping systems, however, do not allow them to freely use the land and discourage them from applying crop management practices.

Poor marketing system and unstable prices

The agricultural marketing system in Bangladesh is not organized well enough to aptly support producers interests. As a result, prices of agricultural produce-particularly those of nonrice crops-remain unstable. During the peak harvest time, the prices of agricultural produce often drop to levels that are even below the cost of production. Therefore, the nation needs agricultural marketing reforms that will offer farmers greater incentives to grow more nonrice crops.

Lack of credit

The existing agricultural credit system is mostly inadequate, particularly for small and marginal fanners who are interested in growing norice crops in addition to rice. Credit is availed of through cumbersome and lengthy procedures, and loan repayment terms are so stringent that farmers just pass up credit opportunities.

Measures for increasing productivity of nonrice crops

Solving the problems of low cropping intensity, inadequate crop production practices, and low crop productivity requires the concerted efforts of all agencies involved in the agricultural sector. Some measures can, however, be implemented immediately to improve the productivity of the major nonrice crops.

- Cropping patterns recommended by researchers should be promoted in suitable areas. Demonstration plots that can show the profitability of these cropping patterns should be established in areas with the same agroecological characteristics. Both research and extension agencies should be involved in this work so that rapid feedback can be obtained and the process fine-tuned accordingly.

- The use of soil test results for balanced fertilization may take a long time, In the interim period, to ensure that crops receive proper fertilization, the Fertilizer Guide put out by the Bangladesh Agricultural Research Council could be followed, and extension agencies could undertake pilot projects in this regard. Policies for fertilizer marketing and related extension services should be improved to encourage fanners to use fertilizer judiciously.
- Irrigation is essential for increasing the productivity of nonrice crops. The government agency responsible for supplying electrical power to deep tubewells (DTWs) should review its currently high "line charge," which discourages farmers from using them for nonrice crops. Further, policies on charges for electrical power for DTWs and fuel for shallow tubewells should be revised to incorporate incentives for fanners.
- The availability of better quality seeds of high-yielding varieties of nonrice crops is a prerequisite to high productivity. Groups of small farmers can be encouraged to grow better quality seeds, which the government can purchase at an incentive price. The private sector can also be asked to play a similar role. Significant developments in this regard have taken place in recent years.
- Intensive cultivation of nonrice crops cannot be expected if farmers fail to get reasonable prices for their produce. Marketing systems that will allow produce to reach consumers easily-and thereby reduce the middlemen's share and increase producers' profit-must be set up. Furthermore, low prices at peak harvest tines should be prevented. Improved transport and storage facilities and liberalization of policies related to establishing agricultural industries will go a long way toward motivating the private sector to take a more active role.
- Many farmers cannot grow nonrice crops because of unfavorable land tenure and sharecropping systems as well as the weak credit system. Major policy reforms are needed to give tenant fanners the right to use contracted farm land more freely. At the same time, special easy-to-access credit programs should be developed to encourage fanners to grow nonnce crops.

Conclusions

Food demand in Bangladesh will increase tremendously in the next few decades as the country's population continues to grow. At the same time, the expected economic growth will bring about diverse lifestyles and food habits, creating a larger demand for various nonrice crops. To meet this challenge, new technologies to improve productivity must be developed and disseminated to farmers. We also need to review frequently and update the technologies that farmers already use. To create a favorable environment for growing nonrice crops more intensively, a stronger linkage between research and extension is critical. Establishing policy reforms for marketing systems, land tenancy, and credit will further ensure sustainable production of the major nonrice crops.

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Citation: Bhuiyan SI, Karim ANMR, editors. 1998. Increasing rice production in Bangladesh: challenges and strategies. Manila (Philippines): International Rice Research Institute, and Dhaka (Bangladesh): Bangladesh Rice Research Institute.

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Agricultural development in West Bengal, India: policies and programs

N. K. Saha

In West Bengal, the most densely populated state in India, 75% of the population depends on agriculture for its livelihood. About 60% of the 5.46 million ha of the net cultivated area are cropped more than once every year, bringing cropping intensity to 160%. Rice covers two-thirds of the cropped area but accounts for 92% of the total food grain production. West Bengal achieved a commendable and sustained growth in agriculture over the last decade: food grain production reached a record 13.28 million t during 199495. This growth was brought about mainly by Increases in area and productivity of boro rice and nongrain food crops such as oilseed, potato, and vegetables. Food production enhancement programs were supported by appropriate policies of the local government; greater surface water availability for Irrigation was achieved through three major river valley projects. In addition, research and extension services helped launch innovative institutional development programs and tested mass communication mechanisms such as agricultural clinics, quizzes, folk tales, and dramatizations on agricultural themes. These, along with the land reform program and microlevel planning that involved local leaders, contributed to sustained agricultural growth.

West Bengal, wit 767 persons km^{-2}, is the most densely populated state in India. It has a geographical area of 8.9 million ha (2.7% of the nation's total area) and a population of 68.07 million (mare than 8% of the country's total population). About 75% of the population lives in 37,910 villages of the state and depends, directly or indirectly, on agriculture for its livelihood. Marginal and small farms dominate the agricultural sector; more than 91% of these fm-ms have scattered and fragmented holdings. Average holding size is 0.90 ha.

West Bengal is divided into two broad agroecological zones and seven subregions based on soil characteristics, topography, rainfall, and temperature. The state has a net cultivated area of 5.5 million ha, 60% of which is used more than once. Cropping intensity is 160%.

The state has sustained an impressive growth in agricultural production over the last decade.

Crop profile

Rice, wheat, pulses, oilseed, potato, and jute are the major crops raised in. West Bengal. Rice covers nearly 67% of the cropped area and accounts for 92% of the total food grain production in the state. Rice is grown in diverse agroecological situations, from the saline coastal areas in the south to the terraced lands in the hills of the Himalayan range in the north at an altitude of 1300 in. Rice is also grown in the subhumid plateau in the southwest (annual precipitation of 1100 mm) to the humid alluvial plains in the northeast (annual rainfall of 3600 mm).

Rice is grown year-round in three rice seasons---aus, aman, and boro. The premonsoon rice, known as aus, accounts for 3--10% of the total rice area and is grown during April-July in the northern region and May-September in the southern region. The aus crop is a relatively drought-tolerant upland crop with low yields (1.5--2.0 t ha^{-1}). The aus area is declining with the expansion in irrigation facilities. The monsoon rice, known as aman, is grown during July-December and accounts for more than 75% of the total rice area. Mostly traditional varieties are grown under rainfed conditions in the medium-deep flooded land. The remaining rice area (15--18%) is covered by the dry-season rice known as boro.

The entire boro area is grown to modem varieties in irrigated conditions. In deepwater (DW) areas, traditional elongating rice varieties, known as DW aman rice, are grown. The growing season of boro rice overlaps that of aus rice. With expansion of irrigation facilities, farmers gradually released land previously devoted to aus and DW aman for boro cultivation. In the 33% of the state's cropped area where boro rice is not grown, wheat (3.7%), pulses (2.6%), oilseed (6.0%), jute (6.0%), potato (3.0%), vegetables (7.0%), fruits (1.5%), spices, and plant sources of condiments, drugs, and narcotics (3.2%) are cultivated.

Production scenario

West Bengal achieved an all-time record food grain production of 13.3 million t during 1994--95. The estimated food grain production during 1995--96 is around 13.5 million t. Trends in cultivated area, yield, and production of major crops from 1980-81 to 1994--95 (Tables 1--3) indicate a sharp rise in food grain production and a progressive agricultural growth over the last decade. This breakthrough in food grain production is mostly due to the substantial increase in area under boro rice and the productivity of both aus and aman rice. Production of oilseed and potato also increased because of expanded area and higher productivity4 A silent revolution has taken place in vegetable production with the expansion of area and higher yield through the use of hybrid seed. The state has been able to produce more than 9.5 million t of vegetables in an area of 0.87 million ha during 1994--95. Production of fruits has also increased---in 1994--95, production reached 1.83 million t from an area of 0.17 million ha.

Table 1. Area (million ha) under major crops In West Bengal, India.

Crop	1980-81	1984-85	1993-94	1994-95
Food grains	6.099	6.017	6.531	6.394
Rice	5.176	5.198	5.876	5.772
Aus rice	0.615	0.631	0.540	0.519
Aman rice	4.215	4.096	4.291	4.210
Boro rice	0.346	0.471	1.045	1.043
Wheat	0.283	0.336	0.307	0.326
Oilseed	0.317	0.389	0.532	0.531
Potato	0.116	0.149	0.231	0.232

Source: GWB (1996a).

Table 2. Yield (t ha^{-1}) of major crops In West Bengal, India.

Crop	1980-81	1984-85	1993-94	1994-95
Food grains	1.358	1.538	2.006	2.077
Rice (clean rice)	1.442	1.557	2.061	2.120
Aus rice	0.937	1.047	1.681	1.615
Aman rice	1.429	1.504	1.855	1.991
Boro rice	2.497	2.698	3.102	2.888
Wheat	1.672	2.418	2.060	2.286
Ollseed	0.474	0.607	0.781	0.780
Potato	17.057	21.071	22.396	23.961

Source: GWB (1996b).

Table 3. Production (million t) of major crops In West Bengal, India.

Crop	1980-81	1984-85	1993-94	1994-95
Food grains	8.282	9.257	13.101	13.279
Rice (clean rice)	7.465	8.093	12.111	12.236
Aus rice	0.576	0.661	0.908	0.838
Aman rice	6.024	6.162	7.961	8.385
Boro rice	0.865	1.270	3.242	3.113
Wheat	0.473	0.812	0.632	0.745
Oilseed	0.150	0.236	0.416	0.414
Potato	1.972	3.135	5.172	5.559

Source: GWB (1996a).

Table 4. Sources of growth (96 yr-1) in agricultural production In West Bengal, India.

Crop	1984-85 to 1994-95		
	Harvested area	Yield	Production
Food grains	0.70	3.56	4.11
Rice	1.28	3.45	4.77
Aus rice	-2.03	5.55	4.11
Aman rice	0.30	3.25	3.04
Baro rice	6.40	0.70	8.39
Wheat	-2.01	0.13	-2.13
Oiiseed	3.33	0.50	3.22
Potato	5.14	1.22	6.41

Source: GWR (1996c).

West Bengal has achieved a sustained and commendable growth in agriculture over the last decade (Table 4), mainly because of the increase in area of boro rice and nonfood grain crops such as oilseed, potato, and vegetables. Expansion of irrigation water systems through private investments in shallow tubewells and the increase in productivity of aman rice and nonfood grain crops with the use of improved production technologies have also contributed. Growth has accelerated as local government institutions in rural areas are strengthened.

Policies and programs

The transformation of the agricultural sector is related to the development strategy followed in the rural areas of the state. Because the scope for increasing arable land is limited, emphasis has been placed on the following aspects.

Increased productivity per unit land area

- Use of the, same land area more than once has been given priority through the creation of irrigation facilities from both surface water and groundwater sources and efficient water use. Surface water is obtained mainly from three major river valley irrigation projects (DVC, Kangsabati, and Mayurakshi) and partly from the Tista River Valley Project as well as through the use of water-harvesting devices such as microwatersheds/reexcavation of derelict tanks and ponds in rainfed areas. The groundwater sources are tapped by deep and shallow tubewells. A large-scale private investment in shallow tubewells has been made in recent years.
- Farmers have been motivated to adopt modem technology packages, including hybrid seeds, suited to specific agroclimatic conditions.

Institutional development In rural areas

A strong linkage has been established between research and extension systems trough location-specific adaptive trials of promising crop varieties in the zonal, subdivisional, and block levels. Feedback has been strengthened by regular monitoring.

Dissemination of the latest knowledge on crop production has been done through a well-knit extension backup, with a village-level agricultural technical assistant (Krishi Projukti Sahayak) assigned to every 1000-1200 farm families. Some innovative ideas have also been introduced in a few areas for quick and effective dissemination of modem agricultural technologies. A few examples follow.

Agricultural clinic. With financial assistance from the Dutch Government, agricultural clinics have been set up at the village level by retired and experienced agricultural specialists in the terai region of West Bengal. Fanners attend these clinics to get advice on various aspects of crop production. This system is well accepted by fanners in the area.

Quizzes, folktales, and dramas with agricultural theme. Quizzes, folktales/songs, and dramatizations (*tarja/kabi*) on modem agricultural technologies in local dialects are organized frequently at the village level in collaboration with the *panchayats* to enrich fanners' knowledge on crop cultivation (GWB 1994). Farmers, both men and women, actively participate in such programs. Prizes are awarded to the best perforiners.

Land reform program. Effective steps have been taken to bring about a change in land ownership and tenancy system. Vested and ceiling-surplus land was distributed to the landless and poor peasants. Out of 0.51 million ha available as ceiling-surplus and vested agricultural land, 0.39 million ha have already been distributed to 2.27 million beneficiaries, the poor and landless members of society, up to September 1995. To promote productive activities, land reform beneficiaries and marginal and small farmers are given priority in the distribution of crucial inputs such as seed, fertilizer, irrigation, and credit. About 1.467 million sharecroppers had registered themselves under "Operation Barga" and obtained security of tenure during the same period (GWB 1996b).

Microlevel planning by local participation. All plans including the agricultural plan are formulated at the grass-roots level through a decentralized district-level planning process. The common people in the rural areas participate in decision making and the service delivery process trough the elected panchayats.

The entire development strategy is complemented by the spread of literacy in the state through free education and mass literacy campaigns.

All these have generated a sense of dynamism in the rural areas and led to accelerated growth in agriculture in West Bengal, India.

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Citation: Bhuiyan' SI, Karim ANMR, editors. 1998. Increasing rice production in Bangladesh: challenges and strategies. Manila (Philippines): International Rice Research Institute, and Dhaka (Ban~1adesh): Bangladesh Rice Research Institute.

Policies and programs driving Agricultural production in Indonesia

Sumarno

Indonesia has become self-sufficient in rice by harnessing its 10.7 million ha of irrigated, rainfed, tidal, and swamp lands. Recent trends, however, show a decrease in fertile irrigated land area, particularyly on Java and Bali islands, because land is being diverted for housing and industrilization. Faced with the challenge to produce more rice on diminishing land, the government formulated several policies and programs to intensify rice production. The president of Indonesia himself spearheaded a national rice production program. Organized by the central agricultural ministry and its affiliated directorates in cooperation with the provincial governments, the program aimed to optimize rice productivity by providing agricultural inputs, credit services, and technical supervision at the village level. It encouraged the use of a package of technologies suited to local conditions—i.e., improved varities, certified seeds, optimum fertilization, integrated pest management, improved water management, weed control, and better handling of harvest and postharvest operations. In addition, new farm lands and new irrigation facilities have been developed to support the program. To boost farmers' interest in increasing production, an incentive floor price for rice was maintained throughout the year. Rice production contests were organized regularly to encourage farmers to maximize productivity. By implementing these policies and programs, Indonesia ws achieving an average yield of 4.6 t ha^{-1} in 1996. An average rice production growth rate of 2.4% yr^{-1} has been maintained since 1970.

Indonesia requires about 26 million t of rice annually to feed its 200 million people. The area planted to rice is about 10.7 million ha, consisting of irrigated, rainfed, tidal, and swamp lands. Fertile irrigated farm land, especially that on Java and Bali islands, has been decreasing because land is being diverted for nonagricultral uses—houses, industrial and public facilities, roads, and offices. This posed a great challenge to the Ministry of Agriculture because self-sufficiency in rice must be achieved through an intensified rice production program.

Government policies for rice production

Political support

The rice production program is organized nationally with full support from the president. The Ministry of Agriculture organizes the production program and the director general of food crops, together with the secretary for the Agriculture Mass Guidance Agency, formulates the annual rice production plan for each province. The governor sees to it that the rice production plan of his province is fully implemented.

Intensification program

The program is designed to optimize rice productivity by providing agricultural inputs, credit, and technical supervision at the village level. A package of technology is formulated based on local agroecological characteristics, with emphasis on the use of improved varieties, certified seeds, an optimum fertilizer rate, integrated pest management (IPM), optimum irrigation water, weed control, and proper handling of harvest and postharvest operations. To ensure adequate guidance, farmers in agroecologically homogeneous production environments (blocks of 250-1000 ha) are organized into groups.

Crop diversification

Fanners are advised to diversify their cropping pattern to maximize cropping intensity. The lack of rainfall during the dry season is compensated for by water from groundwater wells, village water reservoirs, and pumped water from rivers and lakes. Emphasis was on the efficient use of irrigation water. Rotations of rice-rice-upland crop are recommended for most land areas.

Extension of farm land area

New farm land is being opened to grow more rice; targets are the converted secondary forest lands, swampy areas, or tidal-swamp areas. One million ha of rice fields were under development in 1997 in the South Kalimantan swamp area to balance the decreasing fertile farm land in Java and Bali.

Rehabilitation, and improvement of agricultural facilities

The program includes construction of new water darns and irrigation canals; improvement of village-level irrigated canals, water reservoirs, roads, etc; improvement of soil drainage systems; and rehabilitation of problem soils.

Floor price for rice

The floor price fir rice is adjusted each year. During the peak harvest, when the price of rice declines 'to a level below the floor price, the government buys rice from farmers at the floor price through the District Logistics Bureau.

Operational program

Formulation of recommended technology package

The Agency for Agricultural Research and Development, through the Central Research Institute for Food Crops and related research institutes, together with the Directorate General of Food Crops and the Agency for Agriculture Mass Guidance, formulate technology packages containing recommended varieties, IPM techniques, and fertilizer rates for use in rice production programs. At the provincial level, the Agricultural Technological Committee is entrusted to formulate the needed location-specific technologies.

Technical field supervision and extension

This program is conducted by field extension agents located in each village. Each extension agent covers an area of 250-1000 ha. The training and visit method is the basis for the extension program. The extension agents also assist farmer groups in obtaining farm credit.

Provision of agricultural credit

Low-interest loans are provided to farmers to cover the cost of seeds, fertilizers, and pesticides. The credit is channeled at the village level though the farmers' coopera-fives. The loan is provided by government banks and payment is due after the rice harvest.

Provision of farm Inputs at the village level

Seeds, fertilizers, and pesticides are made available at a fixed price at the village level, through farmers' cooperatives and private outlets. In distributing farm inputs, emphasis is placed on the following six principles: proper variety, proper place, proper time, proper quality, proper quantity, and affordable cost.

Provision for irrigation

Irrigation is provided by the Department of Public Works free of charge down to the village level. The same department also maintains the water dams and the primary and secondary canals. Maintenance of smaller canals is carried out by farmer groups.

Rental of farm equipment

In each subdistrict, rental arrangements for farm equipment are generally available. Equipment is owned by farmers' cooperatives, wealthy fanners, or private companies. The responsibility of operating the rented equipment remains with the owners.

Pest and disease surveillance

In each subdistrict, a rice pest and disease specialist is posted to monitor disease and pest populations and to recommend control measures. These field personnel are also responsible for implementing IPM programs.

Field training on IPM

Farmer groups regularly attend field training conducted by crop protection specialists.

Improved technology assessment

Assessment of improved technologies used by farmers is made in a block of 500 ha in several district representing the target areas of the rice production centers. New technologies include newly released varieties and improved production techniques. The assessment is supervised by researchers, extension agents, district agricultural services, and local field extensionists. The technology assessment block also serves as the training venue for farmers.

Production contest

Rice production contests are regularly organized. Farmers who achieve the highest productivity are declared national winners and are invited to the Presidential Palace. District and provincial awards are also given in each cropping season by the governor. The production contests have boosted the morale of Canners, field extensionists, agricultural service staff, and the provincial government.

Technical backstopping

A Technical Agricultural Committee is formed in each province through a decree from the Governor's Office. The committee consists of experts from research institines, universities, and agricultural service offices. It gives advice and technical recommendations to be implemented in rice production programs, conducts monitoring and assessment of the rate of adoption of new technologies, and suggests solutions to existing problems.

With these policies and programs, Indonesia has been able to maintain self sufficiency in rice. New technologies are being tested and adopted every year. National rice (dry paddy) productivity has increased from 2.5 t ha^{-1} in 1970 to 3.3 t hr^{-1} in 1980, 3.9 t ha^{-1} in 1985, and 4.6 t ha^{-1} in 1996. Yield has increased at an annual rate of 2.4% yr^{-1} since 1970.

The farmers who won the national contests sometimes obtained a yield of 10 t ha^{-1} (dry paddy), but average yield was still around 4.6 t ha^{-1}. In fertile lands in Java, Bali, and South Sulawesi, average rice yield has reached 5.6 t ha^{-1}.

For national food security, rice production will remain the first priority for agricultural development in the decades to come. As Indonesia's land resources are extreniely limited, concerted efforts have to be made to successfully carry out the rice production program.

Notes

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Citation: Bhuiyan SI, Karim ANMR, editors. 1998. Increasing rice production in Bangladesh: challenges and strategies. Manila (Philippines): International Rice Research Institute, and Dhaka (Bangladesh): Bangladesh Rice Research Institute.

Impact of research policies and support programs on rice production growth in Indonesia

Sumarno

In Indonesia, rice production and productivity have increased steadily during the last three decades. This has resulted in self-sufficiency in rice since 1984 despite the increase in population and reduction in area under rice cultivation. The driving force behind this phenomenon has been the application of improved technologies generated through research, technology transfer supported by field extension personnel, and government support to farmers in the form of soft loans to enable them to adopt the technologies. The separation of R&D and extension activities, however, was perceived to have created a gap between the generation of research outputs (technologies) and their extension to users. To speed up the process of farmer adoption, the usefulness of new technologies should be demonstrated on a large scale and should involve farmers, field extension people, local government personnel, extension administrators, and researchers. With this in mind, the Ministry of Agriculture, under the Agency for Agricultural Research, established in 1995 one Assessment Institute for Agricultural Technology (AIAI) in each of the 27 provinces, putting research and extension staff under one roof. The mandate of the AIATs was to develop adaptive technology packages (based on research findings of national crop research institutes) suitable to specific agroecological conditions in the target areas. Although this new model of technology adaptation and extension has not functioned long enough to be properly evaluated, initial results are encouraging.

Rice, the staple food of almost all of the 200 million people of Indonesia, is considered a strategic commodity. Food security means year-round availability at stable prices. To ensure this, the government assigned the National Bureau of Logistics to procure and distribute rice all over the country at the same price.

Although people in urban areas have started changing their food consumption patterns, most Indonesians still eat rice three times a day. The average yearly requirement is 130 kg capita^{-1}. Rice substitutes available in the market include wheat flour (consumed as bread, cake, biscuit, noodle), maize, sweet potato, cassava, sago palm, potato, yam, taro, sorghum, and plantain. But these foods are eaten as snacks and not as part of a regular meal.

Table 1. Area harvested and rice yield In Indonesia.

Year	Harvested area ('000 ha)		Yield (t ha^{-1})	
	Irrigated rice	Upland rice	Irrigated rice	Upland rice
1970	6679	1470	2.5	1.1
1975	7334	1161	2.8	1.3
1980	7824	1181	3.6	1.4
1985	8756	1147	4.2	1.8
1990	9500	1002	4.4	2.0
1995	9895	1150	4.5	2.2

Rice production is the main thrust of the Department of Agriculture (DOA) program, which aims to attain self-sufficiency in rice, increase farmers' welfare, and sustain productivity from available farm resources. Because of rapid industrialization and urbanization in recent years, substantial areas of fertile farm land in Java and Bali had been used for nonagricultural purposes. The DOA is hying to meet this challenge by applying improved rice production technology. Consequently, Indonesia–––previously one of the largest rice importers in the world––has been self-sufficient in rice production since 1984. The success of the rice production program is attributed to the synergistic efforts of government agencies, the private sector, and the farmers. Table 1 presents historical data on rice area and yield during the 1970-95 period.

Rice production systems

Rice is grown throughout the year in various agroecological zones in Indonesia. The major planting seasons and peak harvest times depend largely on rainfall, land type, and availability of irrigation water. Cropped area is largest during the rainy season from October to April and is at a minimum daring the peak of the dry season from July to September. Year-round rice cultivation has both advantages and disadvantages. The advantages are an assured rice supply throughout the year, a shorter storage period, a stable price, and availability of freshly harvested rice grains in the market. The disadvantages are the high risk of crop damage from insect pests and diseases, and drought stress for the dry-season crop when irrigation water is not sufficient.

Farmers in Indonesia practice five different methods of rice production.

Wet nursery, transplanting flooded rice

This method, which is the most commonly practiced one in Indonesia, includes a wet nursery, puddled soil, and transplanting of 20-25-d-old seedlings. The crop is flooded either continuously or intermittently, and the soil is dried up before harvest. It takes 130-135 d from sowing to harvesting.

Dry soil nursery, transplanting flooded rice

This method is applied in rainfed wetlands where water has not accumulated sufficienfly at the beginning of the rainy season but is sufficient to begin land preparation and to seed the nursery. The soil is puddled and seedlings are transplanted when enough. rainwater accumulates.

Dry land preparation and direct seeding, followed by flooding of 30-d-old crop

This method is applied in areas where rainfall is erratic and unpredictable at the beginning of the rainy season. Land preparation is done during the dry season, When the first rain comes, farmers start seeding directly with regular plant spacing. Mter about 1 mo, the field is flooded using the accumulated rainwater, The hard work and problems associated with land preparation during the dry season and heavy weeding at the early rice growth stage have discouraged many farmers from using this method, This is the best way of growing rice under such limited rainfall conditions.

Planting of deepwater rice on tidal-swamp area

Transplanting may be done twice to make adjustments for water depth (if needed).

Planting of upland rice

At the beginning of the rainy season, lice seeds are usually planted by dibbling in the dry uplands, which are commonly undulating land or newly replanted state forests. Diseases, particularly blast, are more severe in upland rice. Upland rice is cultivated annually on 1 million ha; average yield is 2.5 t ha^{-1}.

Cropping intensity in the fully irrigated lands is generally high (300-400%), consisting of rice-rice-upland crop, rice-rice-rice, or rice-rice-horticultural crop. In areas where irrigation water is limited, rice-soybean-mungbean or rice-soybean-maize is common.

Adoption of technology by farmers steadily increased yield from 2.5 t ha^{-1} in 1970 to 3.6 t ha^{-1} in 1980, 4.4 t ha^{-1} in 1990, and 4.5 t ha^{-1} in 1995. The average yieid from the more fertile farmland in Java and Bali was 5.6 t ha-' in 1.995. Despite the adoption of the recommended technologies by most rice tanners, the rice crop is continuously exposed to both biotic and abiotic stresses.

The major biotic stresses are insect pests (stem borers, gall midge, stink bugs, brown planthoppers, rats, and birds), diseases (grassy stunt virus, tungro virus, and bacterial leaf blight), and weeds. The abiotic stresses are drought due to erratic rainfall; flooding caused by heavy rainfall; soil toxicity, unbalanced use of nutrients, and salinity; zinc deficiency in poorly drained soils; low organic matter content in soil and low soil fertility; and heavy smog and low temperature on highly elevated farms.

Research accomplishments

To back up the rice production programs, research and development (R&D) is carried out by universities and the research institutes under the Agency for Agricultural Research and Development (AARD) of the Department of Agriculture. The following institutes are engaged in rice research:

- Central Research Institute for Agriculture (the Rice Research Institute at Sukamandi is the lead institution)
- Central Research Institute for Soil and Agroclimate in Bogor
- Central Agroeconomic Research Institute
- Assessment Institute for Agricultural, Technology (one office located in each of the 27 provinces)
- The universities

The research institutes have contributed significantly to rice production by developing improved varieties and techniques for pest and disease management; fertilizer, soil, and water management; crop management; weed control; and improved harvest and postharvest operations.

Since the implementation of the rice production intensification program in the late 1960s, improved varieties have been planted on around 80% of the total rice area. Planting of early maturing, high-yielding varieties has doubled and, in some cases, tripled rice productivity and shortened crop duration, enabling fanners to grow three crops a year and thereby increase their incomes. The switch from late-maturing, low-yielding local varieties to improved ones has also resulted in an abundant supply of rice at affordable prices. People in remote villages who used to eat less nutritious staple food (cassava, sago palm, sorghum) have made rice their staple food.

Other accomplishments include the following:

- Developed and released high-yielding pest- and disease-resistant varieties;
- Recommended varietal rotations, using a set of varieties with different resistance genes for pests and diseases, to reduce the risk of a larger scale pest attack;
- Formulated techniques for integrated pest management (IPM),
- Increased fertilizer efficiency through the use of pelleted urea, deep placement of fertilizer, and micronutrient fertilization (Zn, S) in specific agroecologies;
- Increased water use efficiency through intermittent irrigation schedules;
- Developed practical techniques for organic fertilization using azolla, decomposed rice straw, and others;
- Developed techniques for manipulating plant row spacing to take advantage of border row effects;
- Developed techniques for weed control using a combination of mechanical weeding and timely herbicide application;
- Developed methods for rice-fish culture to increase land productivity, reduce pest and weed infestation, and increase farmers' income; and
- Developed techniques for improving efficiency in harvesting and postharvest processing by using the toothed sickle, motorized threshers, and dryer

Researchers at the national and provincial levels are directly involved in formulating of the recommended technology packages for the Mass Guidance Program. They are also assigned as members of a technical team who regularly monitor and evaluate rice production in farmers' fields at the provincial level. This way, they can anticipate field problems and give appropriate instructions.

Technology assessment and transfer

Separate R&D and extension offices had resulted in a gap between research and extension; consequently, research results were not readily communicated by extension agents to end-users. To correct this problem, the minister for agriculture created in early 1995 a new institute within AARD-the Assessment Institute for Agricultural Technology (AIAT), with one office established in each of the 27 provinces throughout Indonesia. AIAT housed researchers and extensionists under one roof and this setup enabled the development of adaptive technological packages based on specific agroecological conditions and the transfer of technology from local extension agents to farmers. AIAT tailors technology components produced by the national crop research institutes for adoption or modification based on local needs.

To illustrate, the AIAT program implemented in 1995-97 produced results that became the basis for fine-tuning the recommended technology packages. In 16 provinces of the country, an improved technology package was assessed in terms of productivity, socioeconomic value, and farmers' acceptance. The new technology package contains the following components:

- newly released high-yielding variety,
- proper land preparation,
- supplementing soils with low organic matter content by applying 5-10 t of manure or decomposed organic materials,
- fertilization rate based on soil analysis,
- healthy (pest- and disease-free) seedlings for transplanting,
- proper weed control,
- judicious application of IPM techniques based on pest monitoring,
- water management practices for high water use efficiency, and
- improved harvest and postharvest handling to minimize losses.

The technology package is evaluated on 500 ha of farmers' fields, with intensive guidance and supervision provided by researchers and extension agents from AIAT in cooperation with local field extension personnel, the district agricultural service, and the local government unit.

In each province, 4-12 assessment units, each measuring 500 ha are established. Within each assessment unit, 50 ha is allotted for evaluating the direct-seeding method using a manually pulled planter. In 1995, a newly released variety, Memberano, was used; in 1996-97, the new variety Maros was planted.

Table 2. Economic analyses of three rice production methods, average over 12 locations in 8 production cent!rs, East Java, 1995-96 rainy season.

Item	Method		
	Direct seeding	Improved technology on transplanting	Farmers' methods
Cost of inputs ($ ha^{-1})	111	100	98
Cost of labor ($ ha^{-1})	376	365	338
Total cost ($ ha^{-1})	478	465	436
Rice production (t ha^{-1})[a]	6.5	6.0	5.4
Revenue ($ ha^{-1})	1484	1370	1233
Net income ($ ha^{-1})	997	905	797
Revenue/cost	3.0	2.9	2.9
Cost of production ($ t^{-1})	74.9	77.5	80.7

[a]Selling price was US$228 t^{-1} dry paddy, which was the current price. US$1. = Rp 2,300.

Averaged over 12 locations (assessment was conducted in eight subdistricts in East Java), yield obtained from direct seeding was the highest, 6.5 t ha^{-1}. The remaining 450 ha of the technology assessment block produced an average yield of 6.0 t ha^{-1} and the neighboring farms had 5.4 t ha^{-1}. The experiment indicated that the package of improved technologies increased rice productivity and farmers' net income. Direct seeding reduced labor use to only 4 labor-d ha^{-1} compared with 40 labor-d ha^{-1} for transplanting. The direct-seeded rice crop was harvested 10 d earlier than transplanted rice. The cost of producing direct-seeded or transplanted rice with improved technology was similar to that using the farmers' method. The reduced labor cost for planting in direct-seeded rice was offset by the increased labor needed for weeding. But when preemergence herbicides were applied before direct seeding, the need for labor to control weeds was reduced. Table 2 presents the economic analyses of the three cultivation methods.

Technology assessment using a large-scale production area has several advantages over the commonly used small-plot trials:

- Technology can be assessed agronomically, socioeconomically, and for general farmer acceptance.
- Stability as well as variation in performance can be evaluated.
- Direct feedback from farmers can be obtained.
- Adoption of technology, especially for the newly released variety, can be accelerated because many farmers can observe its performance and its seeds are readily available.
- Field days and farm visits can be organized and communication linkages between farmers and field extension staff can be established with participation of local government officials, extension specialists, and researchers.
- Field extension people, field inspectors, and agricultural service people can be motivated to play a more active role in the rice production program.

Conclusions

The success of any rice production program can be ensured through a synergistic work relationship between policymakers, agricultural service people, extension agents, researchers, the private sector, and farmers.

Technology generated from research activities could be readily tested in the field if both researchers and extension agents are directly involved with the Agricultural Technology Formulation Committee.

Improved technologies developed by research institutes can be quickly adopted by users when they are applied on a large scale, with supervision from researchers and extension specialists and in cooperation with farmers.

Notes

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Citation: Bhuiyan SI, Karim ANMR, editors. 1998. Increasing rice production in Bangladesh: challenges and strategies. Manila (Philippines): International Rice Research Institute, and Dhaka (Bangladesh): Bangladesh Rice Research Institute.

Policies and programs driving agricultural production in Vietnam

Vo Tong Xuan and Le Minh Tung

In 1988, Vietnam made some drastic changes in its agricultural policy to overcome the stagnation and decline in productivity in the preceding years that were governed by a centrally planned economy and characterized by food shortages and widespread hunger. The main feature of the new policy, which was known locally as Doi moi, was the establishment of a market economy, which replaced the state control over rice trade, supply of inputs, and prices. The new policy aimed to achieve food security, growth of the whole economy, improved health and nutrition, and protection of the environment and natural resources. It empowered the farm household to become an independent economic unit, having the right to freely plan and perform its business and benefit from its results. Simultaneously, the state reformed the agricultural cooperatives that it controlled. A second round of reform in 1993 gave farmers long-term (practically permanent) land ownership rights, reduced land taxes, and made cooperatives responsible for agricultural extension, marketing, and credit services, and for mobilization of farmer savings for local investments. The state's investment priorities were in agricultural infrastructure, credit to households, human capital, and crop diver sification. Investments in agricultural research and extension were increased. A special aspect in research was the constant strengthening of ties with IRRI for technology transfer and training of local scientists. IRRI-developed varieties (Vietnam released 65 of them) now cover 75% of the country's total rice area. These resulted in an increase in total rice production in Vietnam from 19 million tin 1989 to more than 28 million t in 1996, which transformed the country into a food-surplus economy. Vietnam exported more than 3 million t of rice in 1996.

Vietnam is now committed to a transition from a centrally planned economy to a market economy, which requires not only new policies but also new technologies and institutions. Vietnam is predominantly an agricultural country and has abundant agricultural resources. About two-thirds of its total population of 75 million depends directly on agriculture for its livelihood. The country's economy is based mainly on agriculture, with rice as its number one crop. During the past few years, Vietnam had put great emphasis on agricultural development, aiming to improve people's living conditions, especially those of farmers. This is an important strategy to achieve food security and to promote exports that contribute to foreign exchange earnings.

Vietnam's agricultural production increased for a few years after 1978, became stagnant in 1986, and declined in 1987. Rice production increased from 11.8 million tin 1978 to 17.0 million tin 1986, while population increased at around 1 million yr^{-1}. During this period, the state controlled rice trading, the supply of inputs, and prices. These policies resulted in serious food shortages, and a majority of the population lived at a subsistence level. Hunger and poverty plagued the country.

In late 1988, the government realized that there was no other choice but to liberalize the economy by adopting the market system. A new policy (*doi moi*) was designed to renovate the entire agricultural system and to stimulate the 10 million farm households to harness the potential of the land and other resources and thereby boost production. Vietnam's new agricultural policy has multiple purposes: achievement of food security, growth of the whole economy, improvement of health and nutrition, and protection of the environment and natural resources. By following this path, agricultural production (especially rice) increased considerably in the post-1988 period. The national average rice yield increased from 2.0 t ha-1 during 1976-80 to 3.3 t ha' during 1989-93 and surpassed 3.5 t ha-1 in 1996. The total annual rough rice production increased from 19 million t in 1989 to more than 28 million t in 1996. Thus, Vietnam moved from being a country with a chronic food deficit to one wit enough food for its population. The enhanced food security and surplus food allowed an export of more than 3 million t of rice in 1996. Over this period, the rural economy grew and poverty alleviation programs started to have an impact.

Policy on farm economy and land reform

In the centrally planned economy during the pre-1988 years, agriculture was controlled tightly by the state-owned and collective economic sector and the role of the individual farm household economic sector was not properly recognized. In 1988, the state recognized every farm household as an independent, self-directed economic unit, having the right to plan its own production strategy and enjoy the fruits of its labor.

The state also changed the way it manages state enterprises. It improved the performance of agricultural cooperatives, encouraged the development of the private sector, and created a favorable environment for the growth of all economic sectors. With a new land law approved by the National Assembly in 1993, land has been allocated to farmers on a long-term basis. Fanners gained the right to manage their lands and were 5couraged to reclaim additional abandoned lands. In this way, the state was able to mobilize 10 million farmer households to produce more wealth for themselves and society. To help fanners harness more resources to develop their own production system, the state enacted a new law that reduced the agricultural land utilization tax by 40%.

The state has also redefined the role of agricultural cooperatives. With the return of land to individual farm households, cooperatives were given a new role---that of providing agricultural services such as extension, marketing, and credit, which are not readily provided by the private sector. The cooperatives are also the legal institutions responsible for implementing rural credit programs and mobilizing farmer savings for local investments.

Price policy

Getting the right prices for their produce is the most important incentive to farmers. The state eliminated the mechanism of "commodity checks and bafflers" and adopted a new mechanism of agricultural product distribution that allows free movement for selling products and buying inputs at the best prices. This means that prices are agreed upon by both the seller and the buyer.

The state has also implemented policies to stabilize prices of agricultural products and material inputs to maintain a balance that is acceptable to both producers and consumers. A national reserve fund was established as an instrument to regulate demand-supply relations in the market. A price stabilization fund was also established to subsidize some essential agricultural products and input materials in favor of the farmers.

Three important relative price relationships are in place:

- The price of a product for farmers relative to consumers.
- The price of a product relative to other products and inputs. For example, a farm-gate barter price ratio should be maintained between rice and urea to provide incentives to farmers to apply appropriate levels of fertilizers. The effective barer ratio between 1 kg urea and 1 kg of rice is usually 2:1.
- The domestic product price relative to the border or world market price. The state still intervenes in the domestic rice price because of the instability of the world rice price. For example, in 1991, Vietnam adopted a variable export tax on rice, which ranged from 3% to 10%, depending on the level of the world rice price. Raising the export tax when there is a sharp rise in world prices would stabilize domestic prices. This policy reflects an appropriate balance between concern for revenues and stability, and incentives for farmers.

The price policy of Vietnam has been greatly affected by many constraints, such as budget limitations, lack, of foreign market, and lack of transportation facilities, Because of budget constraints, Vietnam cannot use farm price supports as a stabilizing measure to deal with the falling world price, or to subsidize fertilizer prices to promote greater use.

The role of the government is therefore to provide investments with the help of foreign financial sources, to give technical support to lower production and marketmg costs, and to diversify farming systems.

Policy on investment priorities

Infrastructure

With liberalization of the agricultural economy, the state increased investments for rural infrastructure--irrigation, transportation, telecommunication, electricity, marketing, etc.

Credit for farm households

The state adopted a policy on rural credit for farm households and reduced the interest rates. This enabled farmers to gain additional capital and to reduce their borrowing from non-institutional, high-interest sources. The state also improved its capacity to manage both public and private financial institutions, including cooperatives and credit unions. In the process, it was able to mobilize private savings for investment.

Human capital

Increased investment in human resource development, particularly in education, was considered a good way to take advantage of growth opportunities.

Diversification

Though Vietnam has the potential to further increase rice production, experience in other Asian countries suggested that a move toward diversification is a better option. So far, several joint ventures with foreign firms having advanced technologies and marketing know-how in export commodities (such as seafood and vegetables) have been approved and put in operation.

Research and extension policy

The state has enacted policies on the development of science and technology and has increased investment for agricultural research and extension. Many technological advances, particularly those in rice production, have become popular among farmers in recent years.

Vietnam has continued to strengthen its links with the international agricultural research centers, especially with the International Rice Research Institute (IRRI), to facilitate technology transfer from abroad to improve local research capacity and to provide greater international support to various regions in the country. Many national programs have successfully adapted technologies developed at the international centers.

For many years, IRRI has assisted Vietnam by providing a great variety of rice germplasm materials. So far, IRRI has released more than 65 breeding lines in the country. IRRI varieties now cover more than 75% of the total rice area. This has resulted in a major breakthrough in agricultural production.

Vietnam and IRRI have maintained close collaboration on germplasm conservation, sustainable rice farming systems, economic research, and publication and training since 1964. More than 370 Vietnamese scientists, who have been trained at IRRI under its degree and nondegree programs, are now using their knowledge to help farmers apply new rice production technologies.

Perhaps one of the reasons for the success of the Vietnam-IRRI cooperation is the strong program in technology transfer. For nearly 20 yr, many Vietnamese scientists, many of whom are connected with Cantho University, have practiced the participatory rural appraisal approach to determine constraints in fanners' fields. They have tried to solve farmers' problems by cooperating wit the local administration and with other scientists in the country.

Vietnamese leaders have also played an important role in the agricultural transformation. When Vietnamese leaden talk about development, they talk about rice. When they talk about rice, they talk about new varieties from IRRI. This political support to agricultural development has accelerated the planting of IRRI varieties throughout the country.

Notes

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Citation: Bhuiyaii SI, Karim ANMR, editors. 1998. Increasing rice production in Bangladesh: challenges and strategies. Manila (Philippines): International Rice Research Institute, and Dhaka (Bangladesh): Bangladesh Rice Research Institute.

Farmers' participation stimulates rice production in Vietnam

Vo Tong Xuan and Le Minh Jung

Farmers' participation in the economic, social, cultural, and political processes that affect their lives is necessary for sustainable development in rural society, in recent years, Vietnam has, during the process of transformation from a centrally controlled economy to a market economy, tried to internalize this principle. The first round of economic liberalization that took place in 1988 was accompanied by every household having the right to plan and operate its own production and business and reduced power of state-controlled cooperatives. Individual farmers were granted land use rights up to a maximum of 15 yr. These actions helped to raise farm output substantially. However, in the interest of long-term investments in the land by farmers, the 1993-enacted law granted land use rights for 20 yr for crop lands and 50 yr for forests. It also allowed land rights to be mortgaged, inherited, transferred, and rented. The goveminent increased and facilitated farmers' direct access to agricultural credit (under the centrally controlled system, credit went to cooperatives) and developed group credit facilities at low interest rates. Massive investments were made in improving the rural infrastructure, including roads and irrigation facilities, in which farmers participated through a voluntary labor contribution. As members of water users' groups, farmers take responsibility for operating and maintaining field-level irrigation facilities. They also pay the cost of their upkeep. This process has increased farmers' craving for better and newer agricultural technologies, which is constantly putting pressure on those responsible for technology generation and dissemination. These developments contributed significantly to increasing land use intensity and crop production and to reducing poverty in rural society.

People's participation is becoming the central issue in our time. Today, people desire to participate in the events and processes that shape their lives. Farmers' participation in the economic, social, cultural, and political processes that affect their lives can make a difference in rural society. The important thing is to see to it that farmers have constant access to the center of decision-making and power. Agricultural growth can offer great opportunities for farmers, especially poor farmers, but it will have a sustainable impact only when tanners have access to land, credit, public infrastructure, and services. Because farmers' participation is an essential element of rural growth and human development, Vietnam has adopted policies to this end.

Vietnam largely depends on its rural economy, with two-thirds of the labor force deriving its livelihood from agriculture. Farmers themselves are one of the most important national resources for agriculture. More than 90% are literate; they are diligent, dynamic, and creative. They have a long agricultural tradition and are able to learn new technologies quickly. Rice production is a traditional occupation of Vietnamese farmers and over tine it has remained the most important enterprise in rural society. Priority is therefore always givento rice production, with incentives to mobilize the potential capacity of 10 million farm households to produce more wealth for themselves and society.

The transition from a centrally controlled economy to a market economy

Since 1988, Vietnam has shifted from a centrally controlled economy to a market economy. There is a direct Link between the change in economic policy and the improvement in efficiency and growth. Under the liberalized economic environment, every rural household has to make efficient use of its resources. But when financial and technological, means are limited, their decision choices are rather narrow.

Because farmers know well their available resources such as land, rainfall, irrigation systems, varieties, etc., they know how important the proper dose or timing of fertilizer or pesticide applications is. While risk-averse, they nevertheless are typically more efficient individually than as collective units in allocating resources. If these families gain access to more resources, they are apt to use them wisely. In trying to earn as much as possible for their own families, individual farm households increase the productivity of any underemployed labor, any piece of idle land, and any capital available to them. This helps to increase output, unlike in a more collective system.

Under a market economy, it is not only the efficiency of resource use that is improved; the actual level of private investment is also likely to rise. When there is inflation and limited private opportunities, especially in rural areas, many farmers will hold "unproductive" assets such as gold, the house, or larger than normal stocks of food. These provide some secunty against bad weather or sickness, but are not useful in production. As a more stable macroeconomic environment emerges and private investment opportunities grow, much of the "unproductive" wealth will be converted into actual investment. Thus the stock of wealth can be used to create capital goods either directly within the family or as a loan to others. This is another reason why growth is higher in well-run market-led economics.

There are limitations, however, to what can be accomplished simply by liberalizing the economic climate. Vietnam has recognized that further gains in agricultural outputs can occur only with increased investment and changes in other policies that provide incentives and means for fanners to increase their production.

Increasing access to land

In the centrally planned economy, when the agriculture of Vietnam was based mainly on the state and collective economic sector, the role of the farm household economic sector was not properly recognized. The cooperatives functioned as large farms where farmers were employees. The farmers had limited incentives to work efficiently.

Since 1988, Vietnam has considered every farm household to be an independent, self-directed economic unit that has the right to plan and perform its own production and business. More autonomy was given to farmers and less authority was vested in the cooperatives.

The state allowed tanners to have land-use rights for as long as 10-15 yr. It also changed the relationship between individual fanners and cooperatives, with fanners deciding on what to produce and where to sell their products. Consequently, total farm production rose sharply and rice output increased from 17 million tin 1982 to 22 million tin 1993.

The land law of 1993 clearly states that, for annual crops, land-use rights should be for 20 yr; for forests, land-use rights for 50 yr could be granted. The law allows these land-use rights to be mortgaged, inherited, transferred, and rented out. This is a major step forward. When farmers were given long-term control of the land, their outputs increased. Farmers invest when they know they can reap the fruits of their efforts.

But many problems remain only partially addressed in the 1993 land law. For example, cooperatives still effectively control land and water resources. Also, cooperatives tend to control farmers' behavior Reform in this area has yet to be successfully undertaken to create sufficient confidence in farmers' land-use rights.

Increasing access to credit

Credit can help farmers to create and accumulate assets and to cushion their livelihood in hard times. Farmers need credit for farm inputs. The Agriculture Bank in Vietnam has expanded many programs to make small loans directly to about 50% of all farmers. Previously, loans had gone mainly to cooperatives that distributed inputs.

Group lending is one approach used to reach poor people without any collateral. Farmers themselves are organized into small, self-selected groups for seeking credit. Typically, under such a scheme, one member's failure to repay jeopardizes the group's access to future credit. Joint liability within a group of borrowers reduces the risk of default and makes it cheaper to reach dispersed clients.

Three lessons have emerged from the Vietnam experience with credit: first, the credit should be rural, not just agricultural. When land is limited, most families do both farm and nonfarm work to survive and to earn a higher and more stable income. Second, the credit should be made available at market interest rates, rather than at subsidized or very low rates. If loan rates are low, deposit rates also tend to be low and savings in bank accounts are very limited; as a result, there is not nuch money to borrow. In addition, low interest rates and credit regulations distort the allocation of resources and encourage corruption, damage the financial sector, and fall to expand credit to the poor. Third, farmers tend to repay loans most readily when they know they are likely to get more credit if they do repay the loans. Credit should be easily available to those who are likely to repay and should not be limited by red tape or restricted to a few.

Increasing access to rural infrastructure

Rural infrastructure refers to roads, bridges, irrigation, drainage, electricity, telephone, and others. Greater priority should be given to roads in general and road repair in particular. Activities such as rural credit or extension will not work well if farmers remain isolated from one another or from the market.

As the road situation improved, attention turned to improving irrigation and drainage facilities, especially in the delta areas. For example, in the Mekong Delta, which occupies 44% of Vietnam's rice lands, progress in rural areas was realized partly through massive investments made in developing and maintaining canals and embankments for flood control, drainage, and irrigation. The government shouldered the construction cost of the main and secondary canals, but that of tertiary canals and dikes surrounding fields was borne by farmers, usually in the form of a voluntary labor contribution. The farmers also paid the cost of operating arid maintaining irrigation fields. The investment in water resource development has converted the rice ecosystem from deep-water to irrigated lowlands; as a result, the area under deep-water rice declined proportionately. The cropping system changed from an upland crop and/or floating rice to two irrigated lowland rice crops using high-yielding vaneties. This conversion has contributed considerably to the growth in Vietnam's rice production in recent years.

Farmers have joined water user groups to improve the maintenance and distribution of their irrigation schemes. User groups allocate water and also share construction and maintenance responsibilities. The introduction of water user groups almost doubled the efficiency of water use and, consequently, poorer fanners are now better served by the irrigation systems.

Increasing access to technology

Before the agricultural reform in 1988, technological improvements in agriculture were transferred to cooperatives though the administrative system. Leaders of cooperatives and their technical assistants were the direct recipients of technology. Farmers received only limited fundamental training and had little incentive to obtain new technology in any other way. This process worked slowly.

Alter the reform, when fanners were given land-use rights to specific plots, they began to pay more attention to acquiring new technologies. Many began to actively search for better technologies once they realized that they would benefit directly from any increase in net revenue. Every year, farmers go to the nearest research station or university and ask for new rice varieties or other technologies. Vietnamese farmers always want something new. They want to replace the variety they have been growing for two or three crop seasons to cope with the evolution of insects, pests, and diseases. Farmers are now demanding varieties with higher yield, higher insect resistance, and better grain quality for export.

The local government helps farmers obtain information on new technology and the rice market through many programs, such as extension and rural development.

Vietnam has an energetic and entrepreneurial rural population. Past investments in human capital, particularly in education, place Vietnam in a good position to take advantage of growth opportunities when they become available.

Achieving a pattern of agricultural development that snccessfully reduces pow erty requires policies that provide opportunities to tanners, especially poor farmers, and enable them to participate in the growth process. Experiences in Vietnam indicate that sustained growth and poverty reduction require specific policies to improve tanners' participation by increasing their access to land, credit, public infrastmcture and services, and technology. This also requires moderate taxation on agriculture, relatively undistorted product and factor markets, public provision of infrastructure, and social enviromnents that make technological changes accessible to small farmers.

Notes

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ISBN 971-22-0128-7
Printed by BRAC Printers Bangladesh