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BRIDGING THE RICE YIELD GAP IN THE ASIA-PACIFIC REGION

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
REGIONAL OFFICE FOR ASIA AND THE PACIFIC
BANGKOK, THAILAND, OCTOBER 2000

BRIDGING THE RICE YIELD GAP IN THE ASIA-PACIFIC REGION

Edited by

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FOREWORD

Rice is the most important food crop of the Asia-Pacific Region, demand of which is growing faster than the population. Over 90 percent of the world's rice is produced and consumed in this Region. Moreover, this Region, where more than 56 percent of the world's population live, adds 51 million more rice consumers annually. As a result, the thin line of rice self-sufficiency experienced by many countries is disappearing fast, and more countries are importing rice. How the current annual production of 538 million tonnes of rice can be increased to over 700 million tonnes by the year 2025, using less land, labour, water and pesticides is a serious question.

Superior conventionally bred varieties, “super rice” (New Plant Type), hybrid rice, super hybrid rice and biotechnologically engineered rice, all point to increased yield potentials. Exploited appropriately, these can increase the biological potential to stabilize yield. However, the countries of the region are at various levels of development, especially with respect to transfer and use of technology and policy support, and no single formula can be applied across the board. However, the yield ceiling must be raised and stabilized, the declining yield trends reversed, and the yield gap narrowed, while still remaining sustainable and environmentally friendly. Problems in bridging the yield gap under the limitations of social, biological, cultural, environmental and abiotic constraints need close scrutiny. But, on a positive note, groups of farmers have been able to achieve yields close to the yield potential for their respective locations, reducing the existing yield gap. A clear understanding of factors contributing to this phenomenon could lead to the recovery of a significant part of the current yield potential and provide another avenue to increase production and farm incomes.

Against the above backdrop, FAO organized a Regional Expert Consultation on Bridging the Rice Yield Gap in the Asia and Pacific Region, at the FAO Regional Office for Asia and the Pacific, Bangkok, Thailand, from 5 to 7 October 1999. Experts from concerned countries participated in the workshop. They were able to identify critical issues needing attention. The report of the Consultation was published as FAO/RAP Publication No. 1999/41, in December 1999, highlighting the major recommendations. This publication collates further useful information in the form of Proceedings.

Appreciation is expressed to the participants for their presentation of papers and contribution to the discussions. In particular, sincere thanks must be accorded to Messrs. M.K. Papademetriou, F.J. Dent and E.M. Herath, for compiling and editing this valuable document. Also, the unfailing support of Mrs. Valai Visuthi, who provided assistance in formatting the manuscript, is greatly appreciated.

R.B. Singh
Assistant Director-General
and FAO Regional Representative
for Asia and the Pacific

INTRODUCTORY REMARKS

M.K. Papademetriou [*]

Allow me to welcome you to the FAO Regional Office and to this Expert Consultation. This Consultation has been organized by the FAO Regional Office for Asia and the Pacific, in collaboration with the Field Food Crops Group of the Plant Production and Protection Division, FAO, Rome. I am grateful to you for coming here to make your contribution to this Consultation, despite your busy work schedules back home.

As you know, rice is the most important food crop in the Region. In fact, in the majority of the Asian countries, food self-sufficiency and Food Security largely depend on rice self-sufficiency and rice security.

IRRI, FAO, other International Organizations, Agencies, Commissions, Institutions and Donor countries have been assisting the rice sector in the past, and all of them still continue to do so. Their active involvement and contribution to the development of this sector has to be acknowledged and commended.

There is no doubt that significant achievements have been made in increasing the rice crop yields during the past few decades. However, there are still serious gaps between potential and actual yields in many countries of the Region and, therefore, much more remains to be done in this direction. There is a need and scope to further increase the yields and narrow the gaps between potential and realized yields. This gathering is in support of realizing this goal.

Briefly, the objectives of the consultation are the following:

a) to review the situation regarding the gaps between potential and actual rice yields in the Asia-Pacific Region; and

b) to discuss a number of key issues relating to sustainable increased rice production and to develop proposals needed for further action.

To attain these objectives we have invited all of you here to share with us your knowledge and experience on the topics to be presented and discussed.

I wish you all productive discussions and good contacts among one another for the exchange of information and experience.

Thank you for your attention.

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WELCOME ADDRESS

Prem Nath [*]

It is a great pleasure and privilege for me to welcome you to the Expert Consultation on "Bridging the Rice Yield Gap in the Asia-Pacific Region". May I take this opportunity to extend to you warm greetings on behalf of Dr. Jacques Diouf, Director-General of FAO, my colleagues in the Regional Office and myself.

I am happy to see the positive response we have received from scientists working on rice in the Asia-Pacific Region. Considering the importance of this crop for the countries of the Region and the need for inter-country cooperation, we have decided to hold this Expert Consultation in order to elaborate on the issue of narrowing the yield gap. I hope this meeting will prove to be productive and beneficial for all the participating countries in their attempts towards alleviating rice shortages.

As you know rice is not only a major cereal crop in Asia but also a way of life. The region produces and consumes more than 90 percent of the world's rice. The crop contributes around 40 percent of the total calorie intake in some countries of the Region, and in a number of countries the contribution goes up to 70 percent. Increased productivity and sustained production of rice is critical for food and nutritional security in Asia. However, during the 1990's global rice production has grown at a much slower rate than population, eroding the gains made earlier in expanding the per capita availability of this dominant staple food crop in the region. The annual growth rate of rice production was about 4.35 percent during the 1960's, 2.59 percent in the 1970's, 3.24 percent in the 1980's, and 1.25 percent in the first half of the 1990's.

The Asia-Pacific Region, where more than 56 percent of the world's population live, adds 51 million more rice consumers annually. As a result, the thin line of rice self-sufficiency experienced is disappearing fast, and more countries are importing rice. How the current annual production of 540 million tonnes of rice will be increased to over 700 million tonnes by the year 2025, using less land, labour, water and pesticides is an enigma to national planners. The task of increasing the current production faces various difficulties, as the avenues of putting more land area under modern varieties and using more fertilisers for closing the yield gap, or bringing in additional area under rice or under irrigation are becoming limited. Irrigated rice occupies about 56 percent of the area and contributes 76 percent of the total production of rice. It would be difficult to increase its production due to water scarcity, alternative and competing uses of water, problems of soil salinity, and the high cost of irrigation development.

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Estimates of the Inter Centre Review instituted by the Consultative Group on International Agricultural Research (CGIAR) indicate, however, that about 70 percent of additional production will have to come from the irrigated rice ecosystem and almost 21 percent from rainfed lowland. To achieve this, it was estimated that the yield ceiling of irrigated rice in Asia, for example, would need to be increased from 10 tonnes/ha to around 13 tonnes/ha in 2030. Simultaneously the yield gap would have to be reduced from 48 percent to 35 percent to produce average yields of about 8.5 tonnes/ha. But now the increasing population and consumption, and decreasing land, labour, water and other components of the resource base are predicted to change the equation completely. It is estimated that by the year 2010, Asia may no longer have a net rice export situation. Rather, it is forecasted that by the year 2020, Asia may become a net importing continent.

Superior conventionally bred varieties, super rice, hybrid rice, super hybrid rice, and biotechnologically engineered rice are all pointers to the increased yield potential. Exploited appropriately, these can enhance biological potential and stabilise yields. However, the countries of the Region are at various levels of development, transfer and use of technology, and policy support, and no single formula can apply across the board. But the yield ceiling must be raised and stabilized, and the yield gap narrowed while still remaining sustainable and environment friendly. Problems in bridging the yield gap under the limitations of social, biological, cultural, environmental and abiotic constraints need close scrutiny. Breaking yield barriers and development of new kinds of rice varieties with superior nutritional attributes (higher protein, iron, zinc, vitamin A etc.), will be the next popular strategies to address.

Policies supporting investments to help farmers in improving their crop management practices and post-harvest handling will be critical, as also those that will promote efficient transmission of prices from the international market to the domestic retail markets and, finally, to the farmers.

Groups of Asian farmers have been able to achieve yields close to the yield potential for their respective locations, reducing the existing yield gap of 30-70 percent. A clearer understanding of factors contributing to this phenomenon could lead to the recovery of a significant part of the current yield potential and provide another avenue to increase production and farm incomes.

Distinguished participants, FAO looks forward to your advice and guidance concerning appropriate strategies for narrowing the rice yield gaps in order to alleviate or avoid shortages. I assure you of our support in your efforts towards this important issue. I look forward to the outcome of this Expert Consultation, and wish you success in your deliberations. I hope you have a very pleasant stay in Bangkok.

Thank you.

RICE PRODUCTION IN THE ASIA-PACIFIC REGION: ISSUES AND PERSPECTIVES

M.K. Papademetriou [*]

1. INTRODUCTION

Rice is the staple food of Asia and part of the Pacific. Over 90 percent of the world's rice is produced and consumed in the Asia-Pacific Region. With growing prosperity and urbanization, per capita rice consumption has started declining in the middle and high-income Asian countries like the Republic of Korea and Japan. But, nearly a fourth of the Asian population is still poor and has considerable unmet demand for rice. It is in these countries that rice consumption will grow faster. The Asian population is growing at 1.8 percent per year at present, and population may not stabilize before the middle of the next century. A population projection made for the year 2025 shows an average increase of 51 percent, and in certain cases up to 87 percent over the base year 1995. So far the annual growth rate for rice consumption in the Asia-Pacific Region over a period of 45 years (1950 to 1995) has kept pace with the demand, more through yield increase rather than area expansion. Improved varieties have made a significant impact (Khush, 1995) in an ever increasing order during this period. The world rice supply has more than doubled from 261 million tonnes in 1950 (with Asian production of 240 million tonnes) to 573 million tonnes in 1997 (including the region's production of 524 million tonnes). Production has more than doubled overtaking the population growth of nearly 1.6 times in Asia. A measure of this success is reflected by the fall in the price of rice in the world markets.

The Asia-Pacific Region, where more than 56 percent of the world's population live, adds 51 million more rice consumers annually. As a result of this the thin line of rice self-sufficiency experienced by many countries is disappearing fast. How the current 524 million tonnes of rice produced annually will be increased to 700 million tonnes by the year 2025 using less land, less people, less water and fewer pesticides, is a big question. The task of increasing substantially the current level of production will face additional difficulties as the avenues for putting more area under modern varieties and using more fertilizers for closing the yield gap, bringing in additional area under rice or under irrigation are becoming limited. The irrigated rice area currently occupies about 56 percent of the total area and contributes 76 percent of the total production. It would be hard to increase this area due to the problems of soil salinity, high cost of development, water scarcity, alternative and competing uses of water, and environmental concerns. Thus, increased productivity on a time scale has to make the major contribution across ecosystems by using more advanced technologies.

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2. CURRENT RICE SITUATION

2.1 Production-Consumption Scenario

Rice is the crop of the Asia-Pacific Region. The projected demand by the year 2025 is mind boggling (Hossain, 1995), as in major Asian countries rice consumption will increase faster than the population growth. In summary, in Asia, the rice consumption by the year 2025, over the base year 1995, will increase by more than 51 percent (Table 1). Another significant change will be the development of many mega cities of the size of 10-15 million people over and above the general urbanization of the populace. Thus, the number of consumers will grow and the number of producers will be reduced dramatically. The current demand of 524 million tonnes is expected to increase to over 700 million tonnes. Rice will continue to supply 50-80 percent of the daily calories, and thus the average growth rate in production has to keep pace with the growth rate of the population.

Table 1. Projections of Population in Major Rice Producing and Consuming Countries in Asia, 1995 to 2025

Country	Population (mill.) 1995	Annual Growth Rate (% per year)		Projected Population (mill.) in 2025	Percent Increase 1995-2025
		1995-2000	2020-2025		
China	1199	0.9	0.5	1471	23
India	934	1.7	1.0	1370	47
Indonesia	192	1.4	0.8	265	38
Bangladesh	121	1.8	1.1	182	50
Vietnam	74.1	2.0	1.2	117	58
Thailand	60.5	1.3	0.7	80.8	34
Myanmar	46.8	2.1	1.1	72.9	56
Japan	125	0.3	-0.3	124	-1
Philippines	69.2	2.2	1.2	115	66
Rep. of Korea	44.8	0.8	0.3	52.9	18
Pakistan	130	2.7	1.6	243	87
Asia (excluding China)	2244	1.8	1.1	3389	51

Source: World Bank Population Projections, 1994-95 Edition

During 1997 the Region produced 91.37 percent of the world's rice during the decade 1987-1997, with an average annual growth rate of 1.8 percent. In the last 3 decades, starting with the era of the green revolution triggered by IR 8, rice production in Asia increased by more than 100 percent outstripping the population growth of 80 percent. This increased the availability of rice and decreased the price, which fully justified the investments in research, thus creating a sense of social justice. Several countries like Cambodia, China, India, Indonesia and the Philippines achieved self-sufficiency, even though short-lived in some. Liberalization of economies, increasing consumer wealth and the proliferation of grey-channel trade ignited the demand for high quality rice imports. China's imports are increasing steadily (Anon. 1998). In addition to Thailand, countries like Australia, India, Myanmar, Pakistan, Sri Lanka and Vietnam became rice exporters. During the year 1995, together they exported 17.1 million tonnes of rice (FAO, 1997) which accounted for 73.4 percent of the total world export in rice. The rice export grew during the 1985-1995 period by an average annual growth rate of 6.1 percent (FAO, 1997). This has been possible even in the light of the fact that the major producers like China increased their imports by an annual growth rate of 2.4 percent during this period. However, the number of rice farmers has been declining faster in proportion to the development stage of the countries, (4.3 percent on average in the Asia-Pacific Region). In addition, growth rate in fertilizer usage has leveled off in general and use of modern varieties is also plateauing with major producers. There has been almost no growth (0.4 percent) in the rice area but the production (1.8 percent) has grown due to the growth in the productivity (1.4 percent on annual basis) during the period of 1987-1997. In some countries like Bangladesh, Bhutan, China, DPR Korea, Fiji, and the Republic of Korea, the rice area decreased during this period.

2.2 Rice Balance in the Region

Aggregate rice output growth rate for Asia increased from 2.2 percent per annum during 1950-1965 to 2.9 percent during the 1965-1980 period, outstripping the annual population growth of 2.23 percent. This growth declined to 2.6 percent during 1980-1990 and to 1.8 percent during the 1987-1997 period. Despite an anticipated decline in per capita rice consumption, aggregate demand for rice is expected to increase by about 50 percent during 1990-2025. As income grows, per capita rice consumption is expected to decline as consumers substitute rice with high-cost quality food containing more protein and vitamins such as processed preparations of rice, vegetables, bread, fish and meat. Japan and the Republic of Korea have already made this transition, and rest of the Asia will be making it in proportion to the pace of their economic growth. But these declines will be offset by the population growth (Table 1) and additional income (Table 2), increasing the net demand of rice to over 700 million tonnes by 2025. It is frightening to note that the rice production growth rate of 1975-85 (3.2 percent) which declined to 1.8 percent during 1987-97 (Table 3) is declining further. As a result in the next 10 to 20 years most Asian countries will find it hard to be self-sufficient and in fact, helped by trade liberalization under the General Agreement on Tariff and Trade (GATT), will likely become net rice importers. Several countries that are now self-sufficient in rice may find it more profitable to import rice in exchange for diverting production resources to more remunerative activities. But who will produce this rice is yet another issue to be understood and answered.

Table 2. The Demand Response to Incomes and Prices for Rice
(Estimates for Selected Asian Countries)

Country	Percent Increase in Demand from 1% Increase in Income	Percent Increase in Demand from 1% Increase in Prices
China	0.09	-0.26
India	0.06	10.23
Indonesia	0.11	N/A.
Bangladesh	0.41	-0.20
Thailand	0.08	-0.93
Philippines	0.08	-0.93
Japan	-0.25	-0.17
Rep. of Korea	-0.11	N/A

Source: IRRI/IFPRI, 1995. Rice Supply and Demand Project

Table 3. Rice Production, Yield, Area and Growth Rates in Production (P), Yield (Y) and Area (A) in the Asia-Pacific Region (1987–1997)

Country	Production (P) (000 tonnes) in 1997	Area (A) (000 ha) in 1997	Yield (Y) (kg/ha) in 1997	Growth Rate (%) (1987-1997)		
				P	A	Y
Australia	1,352	164	8,244	6.2	4.5	1.6
Bangladesh	28,183	10,177	2,769	1.1	- 0.4	0.7
Bhutan	50	30	1,667	- 0.2	0.1	- 0.2
Cambodia	3,390	1,950	1,771	4.4	2.4	2.2
China	198,471	31,348	6,331	1.0	- 0.7	1.6
DPR Korea	2,347	611	3,841	- 5.1	- 1.7	- 3.3
Fiji	18	7	2,246	- 5.5	- 7.1	0.8
India	123,012	42,200	2,915	2.6	0.5	2.1
Indonesia	50,632	11,100	4,449	2.2	1.2	0.8
Iran	2,600	550	4,240	4.9	1.5	2.8
Japan	12,531	1,953	6,416	-	- 0.5	0.5
Laos	1,414	554	2,902	2.1	-	2.8
Malaysia	1,970	655	3,008	1.6	0.1	1.5
Myanmar	18,900	6,070	3,064	4.0	3.3	0.6
Nepal	3,711	1,511	2,455	1.3	0.5	0.9
Pakistan	6,546	2,316	2,827	3.3	1.2	2.1
Papua New Guinea	1	-	3,023	-	-	0.1
Philippines	11,269	3,842	2,933	2.7	1.8	1.0
Rep. of Korea	7,100	1,045	6,794	- 1.8	- 2.3	0.5
Sri Lanka	2,610	660	3,954	1.3	-	1.3
Thailand	21,280	9,932	2,143	1.3	0.2	1.1
Vietnam	26,397	7,021	3,760	5.5	2.4	3.1
Total	523,784	133,696	3,918	1.8	0.4	1.4
Rest of World	49,479	16,115	3,070	2.0	0.3	1.7
World	573,263	149,811	3,827	1.8	0.4	1.4

Source: FAO/RAP Publication: 1998/21

3. BALANCE SHEET OF PROBLEMS

The task of producing the additional rice to meet the expected demands of the year 2025 poses a major challenge. The danger is that stability in rice production is linked to social and political stability of the countries in the Asia-Pacific Region (Hossain, 1996). The scope of area expansion in some countries is offset by the reduction in rice lands in major rice producing countries. So far irrigated rice which occupies about 57 percent of the area and produces 76 percent of total rice has helped double the rice production. It will be easier to produce the necessary increases in productivity under irrigated conditions than under rainfed or other ecosystems. The question turns more problematic when we think that production increases have to be realized annually using less land, less people, less water and less pesticides. There are additional difficulties of putting more area under modern varieties and using more fertilizers for closing the yield gap, or bringing in additional area under rice or under irrigation. The irrigated rice area would be hard to increase as the problems of soil salinity, high cost of development, water scarcity, alternative and competing uses of water, environmental concerns of the emission of green house gases like methane (rice fields contribute 20 percent) and nitrous oxide (fertilizer contributes 19 percent). The difficulties are further amplified when potential consequences of increased cropping intensity are taken into account. Estimates of the Inter Centre Review instituted by the Consultative Group on International Agricultural Research (CGIAR) indicate that about 70 percent of additional production will have to come from the irrigated rice ecosystem and almost 21 percent from rainfed lowland. To achieve this, it was estimated that the yield ceiling of irrigated rice in Asia, for example, would need to be increased from its late 1980s level of about 10 tonnes/ha to around 13 tonnes/ha in 2030. Simultaneously the yield gap would have to be reduced from 48 to 35 percent to produce average yields of about 8.5 tonnes/ha or about double the current level. One of the several ways GATT will affect research will be through funding and comparative resource allocation. With the movement from subsistence to a market-oriented economy, rainfed rice production may bring additional changes in many countries which depend on this ecosystem heavily and have no resources to convert rainfed to irrigated systems (Pingali et al. 1997).

3.1 Germplasm Availability and Varietal Development

In the past agriculture, plant germplasm, and crop varieties were treated differently from the industry and industrial products with respect to Intellectual Property Rights (IPR). When the UPOV convention initiated a patenting right for the plant varieties and micro-organisms in 1961 (UPOV, 1991), only a few countries had become signatories. Most of the Asian countries that had not signed had sizeable public research investments for technology generation, which was seen as government support to feed the people. The IPR has its roots embedded in World Intellectual Property Organization (WIPO) established by a convention in 1967, enforced in 1970, and attached to the United Nations Organization (UNO) as a specialized agency in 1974 (WIPO, 1988; WIPO, 1990. It is generally argued that IPR and patenting will assure returns to research investment by providing product secrecy, and will attract private investment for agricultural research. In GATT, there is provision for patenting along the lines of IPR. Although, only a recommendation, it yet becomes binding for the signatory country to "provide some alternative means of protection for such plants". The GATT provisions state: "The only types of inventions that countries can exclude from patentability are those whose exploitation would prejudice public order or morality, those involving diagnostic, therapeutic or surgical methods for the treatment of humans or animals, and inventions of plants and animals or essential biological processes for their production". Countries taking advantage of this provision to preclude the grants of patents for new plants must, however, provide some alternative means of protection of such plants. In the absence of IPR and patenting, germplasm moved unrestrictedly and made contributions globally (Chaudhary, 1996), which can no longer be tolerated.

The historic discovery of the semi-dwarfing gene (sd1) of *De-Geo-Woo-Gen* variety in the district of Taichung in Taiwan ROC (province of China), revolutionized rice production in the world. Today varieties carrying this gene are cultivated in almost all the tropical rice growing countries. Can one imagine if the world has to pay Taiwan for this gene? Grassy stunt virus during the 1980's threatened the cultivation of rice grown without the use of costly and hazardous pesticides. A single accession of *Oryza nivara* had the requisite gene later named as *gsv*. Ever since, all the IR varieties starting from IR

28 incorporating this gene were developed and released. Dr. G. S. Khush (*personal communication*) mentions that at its peak a single variety IR 36 carrying *gsv* gene was planted in 11 million ha in the 1980's. IR 64, another variety carrying *gsv* gene is planted in about 8 million ha. There is no fair estimate available of the area under *gsv* gene but a rough guess is that in Asia alone it will be more than 100 million ha. One can very well imagine the production impact of a single freely available gene simply taken from a rice producing area in the eastern part of Uttar Pradesh in India. Can one imagine if this gene was patented by a private company? What if the world has to pay for this gene to the community from where the accession carrying this gene was collected?

3.2 Stagnation, Deceleration and Decline of Productivity

Yield decline is noticed when in order to get the same yield level, increased amounts of inputs are needed. This trend has been felt by farmers in irrigated rice systems, and reported by Cassman et al. (1997). Yield decline may occur when management practices are held constant on intensive irrigated rice systems, owing to changes in soil properties and improper nutrient balance. It also leads to a depletion of soil fertility when inputs do not replenish extracted nutrients. The need for designing regional programmes of action to enhance and sustain rice production and to attain durable food security and environmental protection in the Asia-Pacific Region was also recommended by an earlier FAO Expert Consultation (FAO, 1996). It was recommended that different countries should undertake systematic studies on the actual and potential downward yield trends (deceleration, stagnation, and decline), quantify these processes and delineate the affected areas as accurately as possible. These could find a place in the research agenda of the CGIAR institutions like IRRI, WARDA and other centres. The development of more location specific technologies for crop management, Integrated Pest Management, Integrated Nutrient Management, technology transfer to further reduce the yield gap, and manpower development in appropriate areas would have to be handled by NARS. The sharing, testing and utilization of technology and knowledge across national boundaries have to be facilitated by the CGIAR institutions and FAO through various networks supported by them (Tran, 1996). FAO's work on agro-ecological zones (AEZs) and the CGIAR's Eco-Regional approach have lots of common ground for this new paradigm in technology assessment and transfer.

3.3 Declining Production Resources

Rice land is shrinking owing to industrialization, urbanization, crop diversification and other economic factors. Under these pressures in China, the rice area declined from 37 million ha in 1976 to 31 million ha in 1996. A similar trend of negative growth is visible in many countries even over a relatively shorter period from 1986-1996 (Table 3). Similarly, the number of rice farmers is also declining fast in most countries. In the Republic of Korea during 1965-95, the numbers of rice farmers declined by 67.3 percent. It is estimated that by the year 2025, more than 50 percent of people will live in urban areas compared to 30 percent in 1990. Growing urbanization and industrialization will further reduce the agricultural labour, increase the labour wages and farm size, needing more mechanization.

The Green Revolution technologies used in irrigated and favourable rainfed lowlands, which stabilized rice production and reduced prices, are almost exhausted for any further productivity gains (Cassman, 1994). In fact, a net decline in the irrigated area may be expected if problems of salinization, waterlogging, and intensification-induced degradation of soil is not handled forthwith. It is predicted that quality and quantity of water for agriculture will be reduced. Water will become scarce and costly for agriculture (Gleick, 1993) and the next war may be fought over water. The water to rice ratio of 5,000 litres of water to 1 kg of rice has remained unchanged over the last 30 years, yet the availability has declined by 40 to 60 percent in Asia. In addition industrial and agricultural pollutants have degraded the water quality in most countries.

3.3.1 Declining factor productivity

A significant problem in Asia is the yield decline now noticeable in irrigated and rice-wheat rotation areas. Long-term experiments conducted at IRRI, the Philippines, have indicated that the factor productivity has gone down over the years. At the fixed level of fertilizer, the productivity has been going down, and to get the same yield a higher level of fertilizer has to be added. Cassman and Pingali (1995) concluded that decline in the productivity is due to the degradation of the paddy resource base. They analyzed that at any nitrogen level, the long term experiment plots at IRRI are giving significantly lower yields today than in the late 1960's or and early 1970's. The same may hold true for farmers' fields. Productivity of rice has been declining faster in mono-crop rice areas as well as under rice-wheat rotation (Cassman et al. 1997). Sizeable areas in Bangladesh, China, India, Myanmar, Nepal, Pakistan and some in Vietnam and Thailand are under rice-wheat rotation. Thus, this problem needs attention soon without any sense of short-term complacency.

3.3.2 Deteriorating soil health

The continuous cropping of rice, either singly or in combination, has brought about a decline in soil health through nutrient deficiencies, nutrient toxicity, salinity and overall physical deterioration of the soil (Cassman et al. 1997). Saline and alkaline soils cover millions of hectares in several South and South-East Asian countries. Also upland rice cultivation has promoted soil erosion in the fields and clogged irrigation and drainage canals down stream. The over use or improper use of irrigation without drainage encouraged waterlogging, resulting in salinity build-up and other mineral toxicities. Proper technology backed by policy support and political will is needed for addressing these issues.

3.3.3 Low Efficiency of Nitrogen Fertilizers

Urea is the predominant source of nitrogen (N) in the rice fields. But its actual use by the rice plant is not more than 30 percent meaning thereby that 70 percent of the applied nitrogen goes either into the air or into the water, endangering the environment and human health. Further research is needed to understand and avert this situation. Related to nitrogen use efficiency is the area of proper use of nitrogenous fertilizer. Use of the chlorophyll meter and leaf colour chart to improve the congruence of N supply and crop demand is a good tool, for example, to save on fertilizer and optimize factor productivity. However, this knowledge intensive technology has its own hidden costs.

3.3.4 Ever-changing balance of rice and pests

Pests (including insect-pests and diseases) of rice evolved under the influence of host genes are changing the rice-environment. Thus, scientists are in a continuous war with ever changing races, pathotypes and biotypes of rice pests. New and more potent genes, being added continuously using conventional or biotechnological tools, fight a losing battle. But these efforts are essential to add stability to production and avoid the recurrence of the great Bengal famine of the Indian sub-continent, or brown plant hopper catastrophe of Indonesia and the Philippines, or blast and cold damage experienced in the Republic of Korea and Japan during 1996.

3.3.5 Aging of rice farmers

The average age of rice farmers is increasing in almost every country in proportion to rate of its industrialization. The younger generation is moving away from agriculture in general, and backbreaking rice farming in particular. The result is that only the old generation is staying with the rice farming, which has manifold implications. This also raises a serious socio-political issue.

3.3.6 Increasing cost of production

By the adoption of modern rice varieties and technologies, the unit cost of production and global rice prices came down. But since the beginning of the 1990’s, unit production costs are beginning to rise and rice farmers are facing declining profits. A stagnant yield frontier and diminishing returns to further intensification are the primary reasons for the reversal in profitability. Contemporaneous changes in market factors – especially land, labour and water - are driving up input prices. Rapid withdrawal of labour from the agricultural sector, diversion of land for other agricultural and non-agricultural purposes, increased competition for water, and withdrawal of subsidies for inputs have contributed to the current situation and may worsen it in the future. Politically, sound lower rice prices are welcome but who is losing?

3.4 Rice Trade and Price Incentive

Although less than 5 percent of the rice production is traded in the international market, yet it influences the local rice prices. GATT has increased pressure to liberalize trade and to open up rice markets in the middle and high-income countries. It has also an indirect effect on research priority setting and rice production by introducing a market-oriented decision making process. Though a modest expansion in rice trade can be expected due to opening of the closed markets of Japan and Republic of, yet due to a special “rice clause” the Philippines and Indonesia negotiated for tariff reductions. The tariff reduction by USA and EU may lead to additional exports of specialty rice and global trade may increase in general. Subsidies at input level by individual countries may reduce production costs marginally. The movement from subsistence to market-oriented rainfed production may bring in additional changes (Pingali et al., 1997). Given the long-term impact of GATT on increasing competitiveness among ecosystems, irrigated ecosystem may get 50 percent of the research share. Issues of intensification versus diversification, yield enhancement versus quality improvement, knowledge-intensive technologies versus farmers time, private sector versus public funded research need further investigation and alignment to set research priorities (Pingali et al., 1997).

3.5 Post-Harvest Losses

It is extraordinary that the tremendous efforts being made to lift rice productivity through modifications and manipulations of the rice plant and its environment, are not matched by corresponding efforts to address the dramatic post-harvest losses of 13 to 34 percent (Chandler, 1979) that continue to occur through much of the rice growing world. Part of the productivity gains that have been laboriously achieved through decades of research and development are simply thrown away after harvest in many cases.

3.6 Weeds

Weeds reduce rice yield by competing for space, nutrients, light and water, and by serving as hosts for pests and diseases. Under farmers' conditions, weed control is not generally done properly or timely, resulting in severe yield reduction. In Asia, losses run up to 11.8 percent of potential production. Effective weed control requires knowledge of the names, distribution, ecology, and biology of weeds in the rice-growing regions. One or another form of weed control has been used during the last 10,000 years (De Datta, 1981), but no single weed-control measure gives continuous and best weed control in all the situations. Various weed control methods including complementary practices, hand weeding, mechanical weeding, chemical weeding, biological control, and integrated approaches are available (De Datta, 1981). As mentioned earlier, these methods need to be fine-tuned for specific regions, ecosystems, cropping systems, and economic groups.

It is worth mentioning also that red or wild rice has become a major problem of rice production in Malaysia, the Central Plain in Thailand and the Mekong Delta in Vietnam where direct seeding has been increasingly practiced.

3.7 Biotic and Abiotic Stresses

Rice has been under cultivation over thousands of years and in 115 countries. As a result, it has served as a host for a number of diseases and insect-pests, 54 in the temperate zone, and about 500 in tropical countries. Of the major diseases, 45 are fungal, 10 bacterial, 15 viral (Ou, 1985), and 75 are insect-pests and nematodes. Realizing the economic losses caused by them, efforts have been directed to understand the genetic basis of resistance and susceptibility. The studies directed to understand the host-plant interaction in rice have given rise to specialized breeding programs for resistance to diseases and insect-pests. Ten major bacterial diseases have been identified in rice (Ou, 1985). The major ones causing economic losses in any rice growing country are bacterial blight, bacterial leaf streak, and bacterial sheath rot. Many of the serious rice diseases are caused by fungi. Some of the diseases like blast, sheath blight, brown spot, narrow brown leaf spot, sheath rot and leaf scald are of economic significance in many rice growing countries of the world. Twelve virus diseases of rice have been identified but the important ones are tungro, grassy stunt, ragged stunt, orange leaf (in Asia), hoja blanca (America), stripe and dwarf virus (in temperate Asia). Brown plant hoppers, stem borers and gall midges are among the major insect-pests in rice production.

4. BRIGHTER RAYS OF HOPE

4.1 Raising the Yield Ceiling

The yield barrier of about 10 t/ha set by IR 8 (140 days) has been broken on a per day productivity front only by the shorter duration varieties (110 - 115 days). But to raise the yield ceiling by breaking the yield barrier set by IR 8, new approaches need to be implemented vigorously. These could be feasible by using the concepts of hybrid rice and the New Plant Type ("super rice"). However, the New Plant Type is not yet available to the farmers, and hybrid rice remains the only viable means to increase yield potential in rice at present.

4.1.1 New Plant Type rice

In narrowing the yield gap it is also necessary to raise the ceiling of yield potential for further increase in rice yield, where applicable. The yield potential of rice is 10 t/ha under tropical conditions and 13 t/ha under temperate conditions. The present technology of hybrid rice can increase the yield ceiling by 15-20 percent compared to the best commercial varieties. The New Plant Type of rice, which has been developed by IRRI, may raise the present yield potential by 25-30 percent (Khush, 1995). Rice biotechnology, which has recently made considerable progress, may also provide an opportunity to increase the rice yield in a more effective and sustainable manner.

To break the current yield potential barrier, IRRI scientists proposed New Plant Type (NPT) rice, referred to in the media as "Super Rice". The basic architecture of the plant has been redesigned to produce only productive tillers (4-5 per plant), to optimize the allocation of assimilates to the panicles (0.6 harvest index), to increase nutrient and water capture by roots (vigorous roots), and thicker culm to resist lodging under heavy fertilization. Reduced tillering is thought to facilitate synchronous flowering, uniform panicle size, and efficient use of horizontal space (Janoria, 1989). Low-tillering genotypes are reported to have a larger proportion of high-density grains. A single semi-dominant gene controlled the low tillering trait, and this gene has a pleiotropic effect on culm length, culm thickness, and panicle size. The future rice plant (NPT) is also expected to have larger panicle (200-250 grains) as compared to 100-120 of current varieties, sturdy stems to bear the weight of larger panicles and heavy grain weight, and give high (13-15 t/ha) yields (Khush, 1995). The NPT rice will be amenable to direct seeding and dense planting and, therefore, would increase land productivity significantly. While architecturally, the design is virtually complete, it has not been possible to realize the full potential (15 t/ha) of the New Plant Type. One of the principal limitations is the inability to fill all of the large number of 200-250 spikelets. Addressing this problem will require further intensive research into the physiology of photosynthesis, source - sink relationships, and translocation of the assimilates to the sink. Incorporation of better disease and insect-pest resistance and improvement of grain quality would be highly desirable, which are also being currently addressed.

4.1.2 Hybrid rice

Hybrid rice has become a reality over a period of 30 years. The rice area in China (Virmani, 1994; Yuan, 1996) under hybrid rice has reached more than 60 percent. Countries like India, Vietnam, Myanmar and the Philippines have a strong interest in this direction. The Government of India has set a target of putting 2 million ha under hybrid rice by the year 2000. All the rice hybrids grown in India, Vietnam, the Philippines, and most in China are *indica* hybrids. In the northern part of China, *japonica* hybrids are under cultivation. Now it is proven beyond doubt that *indica* x tropical *japonica* hybrids give higher yields than *indica* x *indica* hybrids. It is apparent that the next breakthrough in yield may be set in motion by the use of *indica* x tropical *japonica* and *indica* x NPT rice (Virmani, 1994). Currently the three-line system of hybrid rice production is being followed. But it is known that the two-line system, based on the Photosensitive Genetic Male Sterility System (PGMS) or the Thermosensitive Genetic Male Sterility System (TGMS) are more efficient and cost effective. NARS must re-orient their hybrid rice breeding programmes accordingly. The one-line system using the concept of apomixis is under active research at IRRI and NARS will benefit the moment any system becomes available.

4.1.3 Transgenic rice

Over the last two decades humanity has acquired biological knowledge that allows it to tamper with the very nature of creation. We are only at the beginning of a process that will transform our lives and societies to a much larger extent than all inventions of the last decades. Ownership, property rights, and patenting are terms now linked to living matter, and tools to create them. No global code of conduct is yet in sight. Biotechnological developments (James, 1997) are poised to complement and speed up the conventional rice improvement approaches in many areas (Khush, 1995), which could have immediate and long term impacts on breaking the yield ceiling, stabilizing the production and making rice nutritionally superior. In summary, the tools of genetic engineering will help to increase and stabilize rice yields under varied situations of its growing, and thereby reducing the yield gap. These tools could be used to introduce superior kinds of plant resistance through wide hybridization, anther culture, marker aided selection, and transformation. These tools, and tagging of quantitative trait loci would help enhance the yield potential. Rice transformation enables the introduction of single genes that can selectively perturb yield-determining factors. Approaches like differential regulation of a foreign gene in the new host for partitioning sucrose and starch in leaves, the antisense approach as used in potato, and transposable elements *Ac* and Ds from maize have opened up new vistas in breaking yield barriers (Bennett et al. 1994). Identifying the physiological factors causing differences in growth rate among rice genotypes seems fundamental to success in germplasm development for greater yield potential. Increasing the rate of biomass production, increasing the sink size, and decreasing the lodging susceptibility would enhance these efforts (Cassman, 1994).

4.1.4 Stable performing variety

Superior yielding varieties are available (Chaudhary, 1996), which can take farmers' yield to 8.0 tonnes/ha if grown properly. But their performance is variable due to higher proportion of Genotype X Environment (G X E) interaction. G X E interaction is a variety dependent trait (Kang, 1990; Gauch, 1992; Chaudhary, 1996). While the genetic reasons of stability in the performance may be difficult to understand, resistance to biotic and abiotic stresses, and insensitivity to crop management practices are the major reasons. There is a need to identify and release stable yielding varieties even on a specific area basis, as against relatively less stable but on a wide area basis. There are strong genotypic differences among varieties for this interaction, providing opportunities for selecting varieties which are more stable across environments and methods are available to estimate these (Kang, 1990; Gauch, 1992). Thus, two varieties with similar yield may have different degrees of stability. During the final selection process, before release, it is possible to select varieties which are more stable and thus giving stable performance even in poorer environments or management regimes.

4.2 Agronomic Manipulation

Other than using genetic means of raising yield ceiling, avenues of agronomic manipulation need to be explored. The success story of Bangladesh in becoming a self-sufficient country with stable yield by using Boro rice instead of deepwater rice is a case in point. This is a case of matching a technology in its proper perspectives.

4.2.1 Improving nitrogen (N) recovery efficiency, resourcing and management

Nitrogen being the major nutrient and in demand, it is applied in every crop season. Thus, efforts in improving the N recovery-efficiency will save quantity and cost, and reduce the cost of rice production. Avenues exist to enhance the recovery further, and also to augment its supply (Table 4).

Nitrogen is the nutrient that most frequently limits rice production. At current levels of N use efficiency, the rice world will require at least to double the 10 million tonnes of N fertilizer that are annually used for rice production. Global agriculture relies heavily on N fertilizers derived from petroleum, which in turn, is vulnerable to political and economic fluctuations in the oil market. N fertilizers, therefore, are expensive inputs, costing agriculture more than US$45 billion annually (Ladha et al., 1997).

Rice suffers from a mismatch of its N demand and N supplied as fertilizer, resulting in a 50-70 percent loss of applied N fertilizer. Two basic approaches may be used to solve this problem. One is to regulate the timing of N application based on needs of the rice plant, thus partly increasing the efficiency of the plant’s use of the applied N. The other is to increase the ability of the rice root system to fix its own N (Table 4). The latter approach is a long- term strategy, but it would have enormous environmental benefits while helping resource-poor farmers. Although N use has increased, still a large number of farmers use very little of it, primarily due to non-availability, lack of cash to buy it, and poor yield response or high risk. Furthermore, more than half of the applied N is lost due to de-nitrification, ammonia volatilization, leaching and runoff. It is in this context that biologically fixed N assumes importance. Furthermore, farmers more easily adopt a genotype or variety with useful traits than they do with crop and soil management practices that may be associated with additional costs.

Table 4. Conventional and Future Biological Nitrogen Fixation (BNF) Systems, their Potential and Feasibility

BNF System	**N supply Potential**	**Rice Yield Potential**	**Rice Trait/Genotype**	**Technology Availability**	**Feasibility and Adoption**
Conventional BNF systems					
Free-living / Associative	50-100 kg/ha	3-6 t/ha	ANFS NAE NUE	3-5 years	High
Green manure (*Azolla, Sesbania*)	100-200 kg/ha	5-8 t/ha	NAE NUE	Available	Low
Future BNF systems					
Endophytic	?	?	Endo^+ $\textit{fix}^+$ NUE	3-5 years	High
Induced symbiosis (*Rhizobia, Frankia* etc.)	> 200 kg/ha	> 8 t/ha	$\textit{Nod}^+$ $\textit{fix}^+$ NUE	> 5 years	High
Nif gene transfer	> 200 kg/ha	> 8 t/ha	nif^+ $\textit{fix}^+$ NUE	> 5 years	High

ANFS = associative N_2 fixation stimulation; **NAE** = nitrogen acquisition efficiency; ***nod*** = nodulability; **NUE** = nitrogen utilization efficiency; **Endo** = Endophytic; ***fix*** = N_2 fixation ability; ***nif*** = N_2 fixation gene

Recent advances in understanding symbiotic rhizobium-legume interaction at the molecular level, the discovery of endophytic interactions of N fixing organisms with non-legumes, and the ability to introduce genes into rice by transformation have stimulated researchers world-wide to harness opportunities for N fixation and improved N nutrition of rice. The development of symbiotic N_2 fixation between legumes and Rhizobia is a multi-step process in which genes from both host plant (nodulin genes) and *bacterium (nod, nif, exo, lps,* and *ndv* genes) play essential roles (Khush and Bennett, 1992). Small signal molecules pass between the two organisms, activating genes and eliciting developmental responses which culminate in the formation of a cluster of bacterial cells rich in nitrogenase and protected from external O_2 by a complex molecular barrier. Nodules take sucrose from phloem, convert it to succinate, and through bacterial respiration generate the ATP and reduced ferredoxin required for conversion of N_2 to ammonia. The plant component of the nodule takes up the ammonia and assimilates it into glutamine and asparagine in temperate legumes or into the ureids, allatonic acid and allantoin in tropical legumes. The assimilate is then taken to the rest of the plant via the xylem. The engineering of plants capable of fixing their own nitrogen is an extremely complex task, requiring the coordinated and regulated expression of 16 *nif* genes; 8 core genes (B, E, D, H, M, N, K, V), and 8 housekeeping genes (S, T, Q, U, W, X, Y, Z) assembled in an appropriate cellular location (Dixon et al., 1997). Additional genes to maintain nitrogenase in an active form may also be needed. Dixon et al. (1997) suggested that plastids may provide a favourable environment for *nif* gene expression and the damage of nitrogenase enzyme can be protected from oxygen by regulating that nif genes function only in the dark.

Once incorporated, these genes can become part of the seed-based input in rice with high potential of adoption. This becomes more significant when it is realized that every tonne of rice harvested contains about 12 kg N, half of which comes from soil N and biologically fixed N_2. The share of biologically fixed can be increased to suffice the entire need of rice plant. In that case the yield gap due to nitrogen may be reduced a to bare minimum. Currently, it appears a dream but is reasonable and realizable, as nodule formation is a reality (Reddy et al., 1998).

4.2.2 Integrated fertilizer use and balanced use of fertilizers

In addition to chemical fertilizer, there are avenues to augment it through organic manure, biological nitrogen fixation, and the adoption of Integrated Plant Nutrition Systems (IPNS). Recent efforts of IRRI in transferring the nodulating genes to rice roots is an innovative approach which may help rice plant fix atmospheric nitrogen for its own and future use. While this is recognized as a breakthrough using biotechnological tools, future research should be based on the current gains to create a nodulation rice plant in the near future. Until that is accomplished, the addition of a legume crop either in rice - wheat rotation or in a rice - rice system would be imperative.

Soil degradation and quality deterioration limit crop yields in many intensively cultivated farms in Asia. Changes in organic matter and soil nutrient supplying capacity, nutrient imbalance and multi-nutrient deficiency, waterlogging and iron toxicity, soil salinity and alkalinity, and development of hard pans at shallow depths are some of the major indicators of deteriorating soil quality. A lot of yield gaps can be attributed to knowledge gaps. Techniques (Balasubramanian et al., 1998; Cao et al., 1984) which can be used to handle the soil degradation, include the chlorophyll meter (SPAD) and leaf colour chart (LCC), N placement methods, use of modified coated urea materials, phyto-availability soil tests, nutrient-efficient rice varieties, periodic deep tillage to exploit the subsoil N reserve, catch crops to tap pre-rice accumulated soil nitrate, and use of biofertilizers.

Phosphorus, potassium, sulfur and zinc deficiencies in rice production have been increasingly observed in Asia. Therefore, more attention is needed in this direction. A balanced use of fertilizers is equally as important as other issues.

4.2.3 Water and irrigation

Water is essential to rice cultivation. Adequate water supply is one of the most important factors in rice production. In Asia, the rice crop suffers either from too little water (drought) or too much of it (flooding, submergence). Most studies on constraints to high rice yield indicate water as the main factor for yield gaps and yield variability from experiment stations to farms. A recent study conducted by the International Water Management Institute (IWMI), estimates that by the year 2020 a third of the Asian population will face water shortages. The next wars may be fought over water (Gleick, 1993). The growth rate in the development of irrigation has already declined (Barker et al. 1998). Even the existing irrigation systems are labeled as inefficient based on the irrigation efficiency calculated as the ratio of requirement to the percentage of water used. With the growing scarcity and competition for water there is an increased demand for research to identify potential areas for increasing the productivity of water in rice-based systems. The major challenge for research in the coming decade lies in identifying specific situations for the optimum combination of improved technologies and management practices that can raise water productivity at farm, system, or basin level.

Improved water use at the systems and farm levels are important considerations. Development of on farm water reservoirs for water harvesting, selection of drought tolerant varieties, land leveling, subsoil compaction, and need based irrigation scheduling may play a major role in increasing water use efficiency and decrease yield gaps.

4.2.4 Integrated crop management (prescription farming)

Based on the extensive and critical testing of rice varieties and the crop management technology, it is possible to develop a “prescription rice farming” for individual farmers and each situation. The concept was tested on a limited scale in Indonesia during 1996-1997.

It is essential, therefore, that crop management practices should not be applied in isolation but be holistically integrated in Integrated Crop Management Packages (ICMPs) with flexibility for adjustment to fit to prevailing environmental, socio-economic and market factors. The development of ICMPs, which are similar to the Australian Rice Check package, and their transfer could effectively assist farmers in many countries to narrow the yield gaps as well as to reduce rural poverty. The ideal ICMP, however, must aim to improve farmers’ knowledge not only on crop production and protection but also on the conservation of natural resources and market dynamics. This requires substantial improvement to the system of collection and dissemination of information on rice, its production factors, and its technologies as well as the modification of the extension systems in many countries.

4.3 Bridging the Yield Gap

A gap between the potential yield that can be achieved at farmers' field level and what they actually get is very wide (Table 5). Bridging this yield gap offers a very lucrative opportunity to produce additional rice even by using the available technologies.

4.4 Reversing Yield Decline

The yield decline appears real even at farm level. To reverse this trend, a strong research base is essential on an area specific basis, rather than on factors cutting across the continents. Setting up of a joint FAO/IRRI/NARS programme to identify causes, and arrest the decline was recommended by Cassman et al. (1997).

4.5 Policy Support to Increase Production

Government policies provide the environment to benefit from research investment, improve productivity, alleviate poverty, ensure systems' sustainability, protect the environment, and provide food security. It is therefore imperative that through appropriate policies, socio-economic adjustments should be effected in terms of input-output pricing, institutional support, and to redress the needs of rice farmers in order to complement the technological gains.

4.5.1 Credit

Drastic policy changes are needed in making credit facilities available to small and marginal farmers. The interests of these producers and rice policy makers are inter-linked.

Table 5. Rice Yield Gap (kg/ha) in Different Agro-Ecological Zones and Rice Eco-Systems in Asia (Evenson et al. 1996)

Country	AEZ/Ecosystem	Best Farm Average Yield	Actual Farm Average Yield	Gap
Southern India	Warm and semi tropics/irrigated	4562	4012	550
Eastern India	Warm and sub-humid tropics/irrigated, rainfed, lowland, flood-prone, upland	3802	2041	1761
Bangladesh	Warm humid tropics/irrigated, rainfed, lowland, flood-prone, upland	3937	3055	882
Northeastern China	Warm arid and semi-arid/irrigated	8654	5617	3037
Central China	Warm and sub-humid subtropics/irrigated, rainfed, lowland, upland	9080	5297	3783
Nepal	Warm and sub-humid subtropics/irrigated, rainfed, lowland, upland	3940	2267	1673
Northern China	Warm cool humid subtropics/irrigated	8361	5257	3104
Western China	Cool subtropics/irrigated	9207	5465	3742

4.5.2 Input availability

Fertilizers, especially nitrogen, play an important role in rice production and productivity. Farmers need adequate amounts of fertilizer at the right time for obtaining high yields in rice cultivation. The supply of fertilizers needs to be decentralized to village markets and the quality of fertilizers should be assured. Small farmers are usually unable to buy sufficient quantity on time for application; hence, the provision of village credit could greatly help them. The Bangladesh Grameen Bank is an interesting example of providing rural credit to landless and resource-poor farmers. The loan proposals are received by the bank only on a group basis (at least 5 persons), focusing on technology loan, housing loan, joint loan and general loan (Dadhich, 1995). The principle of the Grameen bank could be deployed in other developing countries, with some modification for adaptation to local conditions. The problems of credit and input supply cannot be quickly resolved unless there is strong government intervention. The issue of village credit and input supply is being tackled where FAO and Governments are implementing Special Programmes for Food Security (SPFS).

4.5.3 Institutions

Availability of agricultural credit, inputs (seeds, fertilizers, pesticides) supply, availability and quality of contract services and machinery for different farm operations, and repair and maintenance services in rural areas will influence the rate of adoption of knowledge intensive technology (Price and Balasubramanian, 1998). The government and private institutions associated with credit, input and pricing directly influence the adoption and level of the use, and thereby the yield level. The kind of production environment provided by these agencies must be harmonious as any one of these factors is capable of becoming a bottleneck factor.

4.6 Quality Seed

Use of quality seed is the first and foremost way of realizing the yield potential of the recommended technology. High quality pure seed ensures proper germination, crop stands, freedom from weeds and seed borne pests and diseases. It is recognized in general, that quality seed ensures 10 to 15 percent higher yields under the same set of crop management practices. In the case of superior quality rice, it even ensures higher price and profit. Unfortunately, in most countries sufficient quantities of certified seed are not available from all the seed sources put together. As a result more than 80 percent of the area is cultivated using farmers' own seed. Thus, there are several issues associated with the use of good quality seed. While the private seed producers need to be encouraged to produce more seed of the released varieties and hybrids, governments have to come up with proper legislation where the seed industry can prosper. Even an ambitious programme cannot stop the use of self-grown seeds (now that CGIAR system and most countries have rejected Terminator Technology) by the farmers, thus knowledge can play its part.

4.7 Post-Harvest Loss Reduction

Introduction of more efficient technologies for handling, drying, storage and milling rice at the village level is essential to reduce post-production losses (PPL). The present impressions are that post-production is labour intensive, as the operations involve harvesting hand-reaping, field sun-drying before threshing, threshing by trampling, and wind winnowing. This results in poor quality milled rice including grain discoloration. The physical losses are more in wet season harvests, with problems in drying, and the use of antiquated mills. Basic beliefs are that people in communities whose livelihood is affected are likely to provide their own motivation for change to ensure increased benefit for themselves. It is also believed that the local farmers and entrepreneurs are, therefore, to be given the opportunity to define their post-production needs and to be consulted in the selection of appropriate technologies. But one must also bear in mind that community organizations are required to make concerted efforts in the introduction of new technologies.

4.8 Research and Knowledge Transfer

The support of research and extension can ensure the effective bridging of yield gap of rice. Farmers' adoption of the above-mentioned improved technologies depends on the capability of national agricultural research centres and extension services, which need more government resource allocation and training. The research scientists should understand well the farmers' constraints to high rice productivity and provide them with appropriate technological packages for specific locations to bridge the gap under participatory approaches (IRRI, 1998; Price and Balasubramanian, 1998). The extension service should ensure that farmers use correctly and systematically recommended technological packages (ICMPs) in the rice fields, through effective training and demonstrations. For example, only relevant application of nitrogen fertilizers from seeding to heading, in terms of quantity and timing, will make significant contributions to narrow the yield gap of rice while avoiding unnecessary losses of nitrogen, which increase the cost of production and pollute the environment. The transfer of knowledge based on scientific principles aimed at altering farming practices requires a good fit between the knowledge system of the farmers and that of scientists (Price and Balasubramanian, 1998). If new components were added to the knowledge system and if these were couched in familiar terms, there would be latitude for experimentation at the local level that could eventually develop into a functional fit. The current "blanket recommendation approach" gives farmers information without understanding it, and provides information but not the knowledge.

5. CONCLUSIONS

- Rice is the life-blood of the Asia-Pacific Region where 56 percent of humanity lives, producing and consuming more than 90 percent of the world's rice. The demand for rice is expected to grow faster than the production in most countries. How the current level of annual production of 524 million tonnes could be increased to 700 million tonnes by the year 2025 using less land, less water, less manpower and fewer agro-chemicals is a big question. Alternative ways to meet the challenge by horizontal and vertical growth have their own prospects and limitations. Based on this scenario, the bridging of the yield gap for producing more rice appears to be promising.

- Development of more location specific technology for crop management as well as technology transfer and adoption, coupled with manpower development in appropriate areas, has to be handled by the countries themselves. The sharing, testing and utilization of technology and knowledge across the national boundaries have to be facilitated by Regional and International bodies through various networks supported by them.

- The Integrated Crop Management approaches, including available location-specific technologies coupled with active institutional support from governments, particularly for input and village credit supplies as well as stronger research and extension linkages, can expedite the bridging of yield gaps and thus the increase in production. Location specific packages of technologies moving towards "prescription farming" could be made available and popularized. However, there is a need for better understanding of the yield gaps and national policies on this issue.

- The yield deceleration, stagnation and decline observed in high-yield environments must be arrested, first by systematic studies to understand the causes and then by the development of new varieties and crop management practices. As the phenomenon affects the most productive ecosystem - the irrigated rice, and the permanent asset - the soil, it is of great concern in which Eco-Regional Initiatives and AEZs networks may help.

- Technical knowledge is an important factor in determining the adoption of improved crop management practices and increased yields. Transfer of knowledge intensive technologies has to receive priority. The bridging of knowledge gaps can bridge yield gaps. New paradigms need to be added to transfer and use newer seed and knowledge based technologies under new policy environments.

- Yield variability is driven primarily by variability in the natural environment, and the challenge to research workers is to confront such variability in productivity by genetic and input manipulations. On the genetic side, there is ample evidence that considerable progress has been made (and can be further expanded) in exploiting natural tolerance to both biotic and abiotic stresses, which are polygenically controlled. But the diversion of resources towards risk reduction in phenotypic expression must be traded off against more direct progress in terms of mean yield performance. Thus, one has to consider the trade-off between high yield and yield stability. Development of varieties with high stability may therefore be considered.

- The efforts to break the rice yield ceiling (NPT rice, hybrid rice, and agronomic manipulation) need to be geared-up to attain higher yields. The technology must be made available through IRRI and FAO operated networks for testing and deployment by NARS. However, hybrid rice is the only technology available at present for raising the ceiling of rice yield potential.

- Technologies to decrease the cost of production and increase profitability must be considered very seriously at the same time. Issues in poverty alleviation, social justice and diversification in agriculture are inter-linked and should be handled at that level. The Asia-Pacific Region has the resilience to meet its future demand and remain a net exporter of rice, provided concerted efforts are continued with greater vigor and thrust.

- The trade globalization provided by GATT, WTO and COMESA, and geographic comparative advantages of producing a crop, can provide major incentive for farmers to strive hard and bridge the yield gap. The Region may also focus on other continents to answer questions. Africa can be a promising “Future-Food-Basket” for Asia, but concrete policy framework and support background under the South-South Co-operation and NAM must be added. The combined strength and synergistic links between Asia and Africa can work wonders. This can be a boost and provide a solid platform for a shared prosperity for both continents.

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REFLECTIONS ON YIELD GAPS IN RICE PRODUCTION: HOW TO NARROW THE GAPS

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1. INTRODUCTION

Rice is the world's most important food. More than half of the world's population depends on rice for food calories and protein, especially in developing countries. By the year 2025, the world will need about 760 million tons of paddy, or 35 percent more than the rice production in 1996, in order to meet the growing demand. However, arable lands are mostly exploited, especially in Asia, where 90 percent of the world's rice is produced and consumed.

Rice production had steadily increased during the Green Revolution, but recently its growth has been substantially slowed down. Moreover, crop intensification during the Green Revolution has exerted tremendous pressures on natural resources and the environment. On the other hand, under the globalization of the world economy, rice producers are exposed to competition not only among themselves but also with the producers of other crops. The future increased rice production, therefore, requires improvement in productivity and efficiency. Innovative technologies such as hybrid rice, New Plant Types, and possibly transgenic rice can play an important role in raising the yield ceiling in rice production, thus increasing its productivity. Also, in many countries, the gaps between yields obtained at research stations and farmers' fields still exist. Narrowing of these gaps could improve not only the productivity but also the efficiency of rice production.

Some specialists, however, have expressed their concern about the economic gains of narrowing the yield gaps. They considered that economically there is very limited scope for further increasing rice yield by closing the gaps. Other specialists believe that the yield gaps are economically exploitable for increasing rice yield. In a number of countries, regardless of the initially high yield, national yields still significantly increased during the last 30 years thanks to integrated national efforts in promoting rice development programmes. In addition, it is well known that yields are different among farmers in the same location. Good farmers usually reap more benefits from improved technologies than mediocre farmers at the same place. The challenge for policy makers, scientists and developers is how these gaps can be effectively and economically narrowed at the rice grower level.

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2. EVOLUTION OF RICE YIELDS AND PRODUCTIVITY

2.1 World

The annual growth rates of the world's population and rice production, harvested area, and yield are shown in Table 1. The year 1961 was selected as base year for the analysis of the evolution of rice production since it was the earliest year when statistics on rice production were available in FAO databases (FAO, 1998).

**Table 1: Annual Growth Rates (percent) of World Population and Rice Production,
Harvested Area, and Yield.**

Period	Population	Rice Production	Rice Harvested Area	Rice Yield
1960's (starting 1961)	2.17	3.48	1.54	2.51
1970's (1970-79)	2.03	2.71	0.80	1.76
1980's (1981-89)	1.86	3.14	0.23	2.80
1990's (ending 1996)	1.55	1.31	0.23	1.10

Note: Data on population, rice production, harvested area, and yield in FAOSTAT (1998) were transformed into 3-year-moving-average (3YMA) values. Growth rate was calculated based on the following formula:

GR (percent) = ((B-A)/A) x 100)/N

Where: GR = Annual Growth Rate
A = 3YMA values of the starting year of a period
B = 3YMA value of the ending year of a period
N = Number of years in a period

Table 1 shows that world rice production has continuously increased since 1961, but at varying growth rates. The annual growth rate was about 3.5 percent during the 1960's, 2.7 percent in the 1970's, 3.1 percent in the 1980's, and 1.3 percent in the first half of the 1990's. A comparison between the growth rates of rice production and those of population since 1961 shows that for the first time since 1990, rice production has grown slower than population.

During the 1960's the high annual growth rate of rice production was due to both a high yield growth and a moderate growth in rice area, whereas the rapid rice production growth during the 1980's was due principally to improvement in rice productivity. The growth rate of rice yield was 2.5 percent per year during the 1960's, 1.8 percent in the 1970's, 2.8 percent in the 1980's and only 1.1 percent in the first half of the 1990's; while the annual growth rate of harvested rice area decreased from 1.6 percent during the 1960's to 0.2 percent in the 1980's (Table 1). The trend of evolution in growth of rice harvested areas indicates that future increase in rice production will come mainly from improvement in productivity, unless major development activities are undertaken to bring more land under rice cultivation.

The very low annual growth rate of rice yield observed since 1990, therefore, is cause for concern and it has been the topic of numerous reviews (Pingali and Rosegrant, 1994; Cassman and Pingali, 1995; and Pingali, et al*.,* 1997). Regardless of food consumption trends, the slowdown in growth of rice yield is particularly serious considering the continuing population growth. The reversal of this trend and the bridging of yield gaps require urgent and concerted efforts of all concerned parties and political support from both national and international authorities.

2.2 Asia

Asia accounts for over 90 percent of world rice production. Therefore, the evolution of rice production, area, and yield in Asia are similar to those which were observed at global level, but more pronounced. The annual growth rate of rice production in Asia was about 4.4 percent during the 1960's, decreased to about 2.6 percent during the 1970's, then increased to about 3.2 percent during the 1980's. During the first half the 1990's rice production grew only at 1.3 percent per year (Table 2). Rice production in the Region, grew faster than population during the 1960s, 1970s and 1980s but slower than population during the 1990s. The growth rate of rice production was about half of that of the population since 1990.

Table 2. Annual Growth Rates (percent) of Population and Rice Production, Harvested Area, and Yield in Asia.

Period	Population	Rice Production	Rice Harvested Area	Rice Yield
1960's (starting 1961)	2.64	4.35	1.34	2.70
1970's	2.28	2.59	0.60	1.88
1980's	2.05	3.24	0.31	2.86
1990's (ending 1996)	2.05	1.25	0.10	1.06
Note: Please refer to note in Table 1, with regard to formula for calculating the growth rates.				

Increase in rice production has been mainly due to improvement in the productivity per hectare. The harvested rice area has increased at a decreasing rate since 1961: from about 1.3 percent per year during the 1960's to only 0.3 percent in the 1980's and 0.1 percent since 1990. On the other hand, the annual growth rate of rice yield was 2.7 percent during the 1960's, 1.9 percent in the 1970's, 2.8 percent in the 1980's, and only 1.1 percent since 1990 (Table 2).

It does not seem logical that the annual growth rate of rice yield observed during the 1970's (1.9 percent per year) was lower than that which was observed during the 1960's (2.7 percent per year), considering the fact that IR 8 was released for cultivation in 1966 and in China commercial hybrid rice cultivation started in 1976. This fact, however, is very valuable experience for all concerned with improvement in rice production as it indicates that the adoption of new rice varieties alone does not necessarily result in higher rice yield. It also shows that it may take one decade or more from the successful development of new rice varieties/types before gains in productivity at farmer level are obtainable. The variety IR 8 and its parental variety Peta does not differ in yield very much if fertilizers and other improved cultural practices are not used. In Indonesia, although HYVs had been widely adopted in the early 1970's, rapid increases in rice yield were obtained only after the implementation of coordinated extension and development programmes named INSUS from 1975 -1985 and SUPRA INSUS since 1985 (Dudung, 1990).

The increase in the annual growth rate of rice yield from 1.9 percent during the 1970's to about 2.8 percent during the 1980's could be attributable to the wide adoption of a new generation of rice varieties (Table 3); the improvement of farmers' crop management practices; and the increased use of irrigation, fertilizer and other agro-chemicals in rice production. It may also be due to the adoption of policies, which are favourable to rice production in a number of countries. Vietnam, for example, became a major rice exporter only in late 1980s after favourable policies were adopted.

Table 3. Estimated Areas Planted to HYVs and Hybrid Rice (percent of total rice areas) in Major Rice-Producing Countries in Asia in 1989

Country	1989		1997***	
	HYVs*	Hybrid Rice**	HYVs	Hybrid Rice
Bangladesh	40.7	-	65	-
India	62	-	62	Neg
Indonesia	73	-	85	-
Myanmar	51.9	-	51.9	-
Philippines	88.5	-	93	-
Vietnam		-	85	Neg
China	-	50	45	50

* IRRI (1995) World Rice Statistics,

** Yuan (1996),

*** FAO estimates (Neg = Hybrid rice was planted to about 60,000 ha in India and about 120,000 ha in Vietnam)

Several factors may be responsible for the drastic drop in growth rate of rice yield since 1990 and they need to be examined in detail in order to be able to reverse the current trends of rice yield and rice production and to achieve food security for the Region's population as well as the conservation of natural resources and bring about socio-economic stability in the Region.

Future increase in rice production in Asia will continue to depend on improvement in the productivity of irrigated rice, which in 1995 occupied about 57 percent of the Region's rice harvested area, as it is in this ecology where the application of hybrid rice and other genetic improvements of rice plants are most feasible. In the long term, increases in rice production in the Region requires the improvement in productivity of rice in the rainfed ecologies as the land and water resources in irrigated ecologies are coming increasingly under competition from other crops, urbanization, industrialization and environmental protection.

2.3 South America

Rice production in South America has grown at about 3.7 percent per annum or faster, except during the 1980’s when it grew at only 1.6 percent per year. The growth rate of rice production in the Region was more than twice that of the population since 1990. The high growth rate of rice production during the 1960’s and 1970’s was due mainly to the expansion of rice area. The annual growth rates of harvested area during these periods were respectively 4.6 and 3.2 percent per year. However, improvement in the productivity of rice production was the main force behind the increase in rice production during the 1980’s and 1990’s. Rice yield increased at a rate of 4 percent per year during the 1980’s and of 3.5 percent per year since 1990 (Table 4).

Table 4. Annual Growth Rates (percent) of Population and Rice Production, Harvested Area, and Yield in South America.

Period	Population	Rice Production	Rice Harvested Area	Rice Yield
1960’s (starting 1961)	2.69	3.68	4.63	-0.67
1970’s	2.90	3.95	3.18	0.96
1980’s	1.91	1.57	-2.01	3.98
1990’s (ending 1996)	1.88	3.97	0.33	3.54

Note: Please refer to note in Table 1, with regard to formula for calculating the growth rates.

The high growth rate of yield in South America during the 1980’s can be mainly attributed to a significant reduction in the area devoted to low yielding upland rice in Central America and central Brazil. The rapid spread of high yielding varieties (HYVs) and the recent expansion of irrigated rice areas in southern Brazil, Argentina, and Uruguay are other factors contributing to the high annual growth rates of rice yield during the 1980’s and the first half of the 1990’s. On the other hand, upland rice production in South America has become increasingly less sustainable due to its low productivity.

The Southern Horn of Latin America, such as southern Brazil, Uruguay, Paraguay and Argentina, which has a Mediterranean climate, still has yields of 5-6 t/ha. This yield is lower than the potential yield of 10t/ha and the yield gap reaches 3-4 t/ha.

2.4 Africa

The annual growth rate of rice production in Africa was about 4.9 percent during the 1960’s. It decreased to about 1.6 percent during the 1970’s then increased to about 5.2 percent during the 1980’s. Rice production in the Region has slowed down since 1990, but the current growth rate (3.4 percent per year) is still respectable and higher than the population growth rate (Table 5). The increase in production, however, has not been able to satisfy the increased demand, resulting in increased importation of rice into Sub-Saharan Africa.

Most of the production increase can be attributed to the expansion in rice area. The growth rate of harvested rice area has always been above 2.1 percent per year while that of yield was below 1.1 percent per year, except during the 1980's when it was 1.8 percent per year. Rice production is totally under irrigation in North Africa. Yields in Egypt are among the world's highest, increasing by nearly 50 percent in the last decade. In contrast, in Sub-Saharan Africa, upland rice production is dominant and average yields in most countries are still less than 2.5 tonnes/ha. Upland rice production in Sub-Saharan Africa is generally practised under shifting cultivation. There is much concern over shifting upland cultivation in Africa, due to widespread ecological damage such as soil erosion, deforestation and losses in soil fertility.

Table 5. Annual Growth Rates (percent) of Population and Rice Production, Harvested Area, and Yield in Africa

Period	Population	Rice Production	Rice Harvested Area	Rice Yield
1960's (starting 1961)	3.01	4.94	3.67	0.95
1970's	3.05	1.58	2.37	-0.59
1980's	3.25	5.16	2.85	1.84
1990's (ending 1996)	2.88	3.38	2.09	1.02

Note: Please refer to note in Table 1, with regard to formula for calculating the growth rates.

The stagnation in yield potential of HYVs is of major concern to sustainable rice production in Egypt while socio-economic factors limit rice yield in irrigated schemes in Sub-Saharan Africa. However, there are still considerable land and water resources in the Region for future increase in rice production to meet consumer demand. In Sub-Saharan Africa, most of the inland swamps and hydromorphic lands are still untapped. In addition, in many irrigated rice schemes, rice yield is decreasing after a few years of exploitation, mainly due to the level of management and operation of large irrigation projects as well as farmers' poor crop management practices (Table 6). The reversing of this trend and increased sustainable rice production and productivity are two major concerns in the Region.

Table 6. Rice Area, Yield and Production at the Mbarali Rice Farm in Tanzania, 1980/81-1988/89

Year	Area (ha)	Yield (t/ha)	Production (t)
1980/81	2,647	8.15	21,573
1981/82	2,897	7.90	22,886
1982/83	2,844	7.50	21,330
1983/84	2,881	7.00	20,167
1984/85	2,893	5.50	15,911
1985/86	2,690	4.00	10,625
1986/87	2,680	3.90	10,180
1987/88	2,786	3.50	8,915
1988/89	2,253	4.00	9,012
Potentials	**2,800**	**6.0-7.1**	**16,800-20,000**

Source: URT, Food Strategy Unit, 1989

3. ANALYSIS OF CURRENT YIELD GAPS

3.1 Definitions of Yield Gaps

The national rice yield is an average of yields of rice planted across agro-ecologies and locations in a country. Therefore, exploitable yield gap cannot be defined as the difference between the national yield and that of research stations. National yields may be used as indicators for monitoring the evolution of rice productivity in a country. In general, the analysis of the evolution of rice yield in the world shows that national average yields have increased, suggesting that yield gaps have narrowed, although at a slow rate.

Rice cultivation extends from 50^o N to 35^o S and generally yields of rice planted in tropical climates or in areas between the Tropic of Cancer and the Tropic of Capricorn are lower than those for rice planted in temperate and/or Mediterranean climates. The high solar radiation, long summer days and low night temperature in countries under temperate and Mediterranean climates are favourable for high yields of rice. The highest rice yield recorded under tropical conditions was 10.3 tonnes/ha obtained from IR 8 planted at the experimental farm of IRRI, Philippines in the 1965 dry season (De Datta, 1981). The *japonica* rice variety Koshihikari planted in Yanco, NSW, Australia, was reported to give 13 tonnes/ha (Horie et al, 1994). It is, however, very rare not only for farmers but also for researchers to obtain these exceptionally high yields.

Rice is cultivated under a wide range of agro-ecologies. Irrigated rice yields substantially improved during the Green Revolution, while in other ecologies, with the possible exception of the favourable rainfed lowland ecology, rice yields have not been substantially improved, due to a host of biotic and abiotic stresses. However, yields of irrigated rice in many developing countries are only around 4-5 t/ha. Substantial and exploitable yield gaps, therefore, are generally found only in irrigated and to a lesser extent in favourable rainfed ecologies. In the Philippines, it was reported that water control, seasonal factors (solar radiation) and economic factors are the yield constraints which respectively account for the difference between actual and potential yields of 35, 20 and 15 percent (De Datta, 1981).

The gaps between research yields and actual farmers' yields in a particular location and season, therefore, are better indicators of yield gaps.

The yield gaps have at least two components. The first component is mainly due to factors which are generally not transferable such as the environmental conditions and some built-in component technologies available at research stations. This component of the gaps (or Gap I in Figure 1), therefore, cannot be narrowed or is not exploitable.

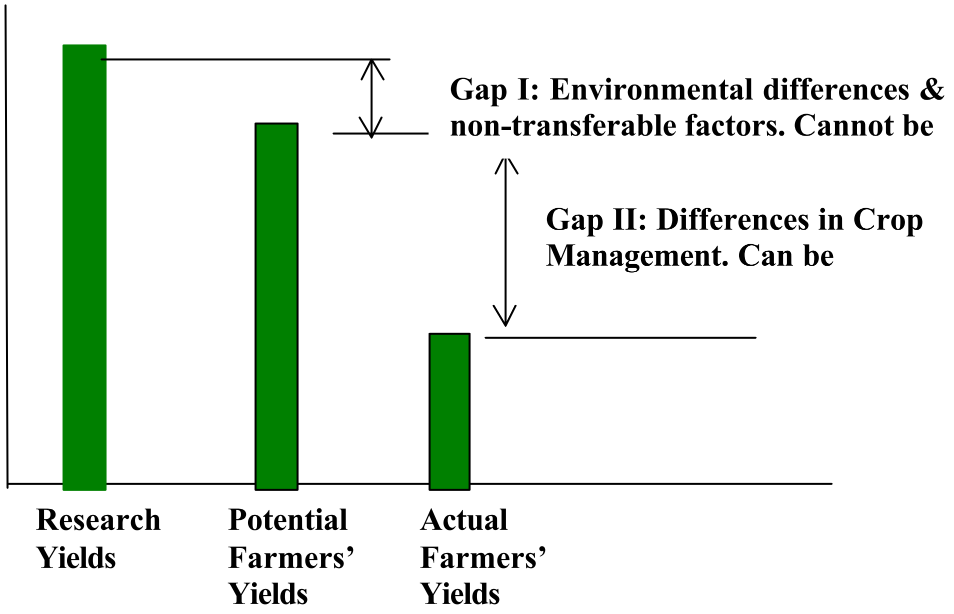

Figure 1. Components of Yield Gaps (Adopted from De Datta, 1981)

The second component of yield gaps or Gap II in Figure 1, however, is mainly due to differences in management practices. This Gap II exists as farmers use sub-optimal doses of inputs and cultural practices. Herdt (1996) provided a similar description of the yield gaps and components. Gap II is manageable and can be narrowed by deploying more efforts in research and extension services as well as Governments' appropriate intervention particularly on the institutional issues.

3.2 Views on the Potential of Narrowing Yield Gaps

Due to its complexity, there are different views with regard to the possibility of narrowing yield gaps as tools for increasing rice production.

Less Exploitable Yield Gaps: Pingali et al., (1997) argued that the yield gaps in favourable rice ecologies are not significant for exploitation for increasing rice yield and production. Under this situation further increase in yield is possible only with the deployment of new technologies, such as hybrid rice. Agronomic yield potential determined on experimental stations is the maximum achievable yield with no physical, biological and economic constraints to rice production (Gap I). Once these constraints are accounted for, the exploitable gap of rice is small and, in many cases, non-existent.

Therefore, narrowing of the exploitable yield gap in Asia is of little profit, particularly in irrigated rice. The authors reported a reduction of the yield gaps in farms with favourable conditions in Nueva Ecija and Laguna, Philippines from nearly 2 t/ha to less than half a ton after a decade. They also reported that yield gaps in the remaining two-thirds of the same rice areas, remained around 2 t/ha, and were even widening. Thus, the narrowing of yield gaps is not profitable for farmers in these environments.

Exploitable Yield Gaps: Authors of this school of thought believe that large yield gaps of rice still exist in both favourable and less favourable conditions in many countries and they could still be exploitable for further improvement in productivity. This is due to poor crop management and problems of institutional support, especially input and farm credit supplies, in many developing countries. Table 7 shows that the estimated yield gaps in irrigated rice yield production vary from 0.8 t/ha in Bangladesh to 2.3 t/ha in India.

Table 7. Comparative National Average Yields, Irrigated Rice Yields, and Experimental Station Rice Yields, Asian Countries, 1991.

Countries	National Average Rice Yield (t/ha)	Irrigated Rice Yield (t/ha)	Average Potential Rice Yield (t/ha)
Bangladesh	2.6	4.6	5.4
China	5.7	5.9	7.6
India	2.6	3.6	5.9
Indonesia	4.4	5.3	6.4
Nepal	2.5	4.2	5.0
Myanmar	2.7	4.2	5.1
Philippines	2.8	3.4	6.3
Thailand	2.0	4.0	5.3
Vietnam	3.1	4.3	6.1

Sources: IRRI (1993)
Average potential yield data cited from Dey and Hossain (1995)

National average yields of rice in many developing countries in 1995 were still low and national yields in about 78 countries were less than the world average yield of 3.77 t/ha (Table 8), hence yield gaps obviously exist in many of them.

Table 8. Some Statistical Data on Rice Yields in 1995

Item	Value
World average yield	3,771 kg/ha
Number of records on national yield	118
Number of records on national yield whose values are less than 1,000 kg/ha	2
Number of records on national yield whose values are equal to or less than 2,000 kg/ha	37
Number of records on national yield whose values are less than world average yield	78

Adapted from FAOSTAT, 1998

However, yield gaps at a specific location in each growing season still need further studies. Yield differences between farmers in the same areas are frequently observed because of their different levels of crop management and environmental variations. Progressive farmers usually obtain higher yields and more profits than ordinary farmers.

3.3 Factors Causing Yield Gaps

Based on the data from experiments on yield constraints, fertilizer application rate and timing have been found to be the most limiting factors for high yields in dry seasons. In the wet seasons, insect control and fertilizer management have been found to be about equal in importance in contributing to high rice yields (IRRI, 1979). At farmer level, the management of inputs - fertilizer, insect control, weed control and seedling age - contributed little to explain the difference between the low- and the high- yield crops. However, the environmental parameters and a combination of weather-related factors and insects and diseases accounted for some 80 percent of the yield difference. In the dry season, the level of managed inputs used and their interaction with environmental factors accounted for 50-60 percent of yield differences among farmers (Herdt and Mandac, 1980). The observations at farmer level suggests that potentially exploitable yield gaps are more prevalent under favourable environmental conditions.

Yield gaps may be caused by technical deficiencies but also by economic considerations. For example, farmers who seek maximum profit may not apply fertilizer doses to obtain maximum production. The effort on narrowing the yield gap without considering the economic aspect may have a counter-productive effect. Closing the yield gap may actually decrease farmers’ income, particularly if rice prices are low. The ratio between price of rice and price of fertilizer could influence the rate of fertilizer applied by farmers and thus rice yield. Consequently, institutional factors, which increase the price of rice/price of fertilizer, could positively contribute to gap narrowing (De Datta, 1981).

In Southern India, the maximum rice yields obtained in experimental stations under irrigated conditions varied from 6.0 t/ha in Kerela to 8.6 t/ha in Tamil Nadu and Andhra Pradesh. The average yields in farmers’ fields are less than half of these amounts (Ramasamy, 1996). Table 9 summarizes the estimates on yield losses provided by 120 rice scientists and an equal number of extension personnel in Southern India.

Table 9 indicates that yield gaps are actually present, due to factors such as:

- **Physical factors:** problem soils, poor water management, drought, flash floods and temperature stresses.
- **Biophysical factors:** varieties, seeds, weeds, insect, diseases and other pests, due to inadequate crop management. Post-harvest losses, which vary from 10 to 30 percent, also contribute partly to yield gaps.
- **Socio-economic factors:** labour shortage, cost-benefit, farmers' knowledge, skills and welfare conditions.
- **Institutional factors:** Governments' policies, rice price, agricultural credit and input supply, land tenure, agricultural research and extension.

At farm level in many developing countries, socio-economic and institutional factors are often inhibiting the efforts to narrow the yield gap. Most modern rice technologies are resource- or input-intensive and put the small-scale farmers at a disadvantage.

Table 9. Factors Contributing to Yield Losses (kg/ha of paddy) in Rice Production in South India

	A. Pradesh	T. Nadu	Karnataka	Kerala	South India
Scarcity of irrigation water	23	37	24	28	26
Drought	18	23	18	0	18
Cold temperature at anthesis	0	6	14	0	4
Lodging	28	28	17	28	26
Low light intensity	0	3	11	0	3
Soil salinity	23	22	22	27	23
Low fertility	17	29	18	18	20
Zinc deficiency	15	25	23	0	18
Acid soils	0	9	10	27	6
Alkalinity	0	9	10	27	6
Iron toxicity	0	6	0	0	2
Weeds	25	30	25	10	25
Imbalanced use of fertilizer	19	41	26	0	24
Aged seedlings	7	7	0	0	5
Varietal problems	0	0	26	28	7
Socio-economic circumstances	39	64	111	142	66

Adopted from Ramasamy, 1996

3.4 Selected Cases of Yield Gap Narrowing

Rice yields generally have been steadily increasing during the last three decades. The yield increases in China, Indonesia, and Vietnam in Asia and Egypt, Australia and USA, however, are very spectacular and the yield increases appear to be mainly due to concerted national efforts in narrowing the yield gaps. In the late 1960's, rice yields in Vietnam and Indonesia were only about 1.8 to 1.9 t/ha; in China they were about 3.1 t/ha; in Egypt and USA 4.9-5.0 t/ha; and in Australia 7.3 t/ha (Table 10). Indonesia and Vietnam, therefore, represented countries where rice yields were still low; China represented countries where yields were medium; Egypt and USA represented countries where yields were high; and Australia where yields were extremely high. Rice yields during the 1995 to 1997 period were about 3.7, 4.4, 6.1, 6.7, 8.2 and 8.2 t/ha, respectively, in Vietnam, Indonesia, China, USA, Egypt and Australia. Consequently yield increases were about 0.9, 1.8, 1.9, 2.6, 3.1, and 3.3 t/ha, respectively, in Australia, USA, Vietnam, Indonesia, China, and Egypt. The yield increase in Australia indicates that even with very high yield (7.3 t/ha) further yield increase is possible through narrowing the yield gap. This observation is further strengthened with the impressive yield increases obtained in Egypt and China.

Table 10. Yield and Yield Growth Rate in Selected Countries, 1966-1997

Country	Growth Rate of Rice yield (percent)*			Average Yield (t/ha)**		Estimated N Rate (kg/ha)***	
	1967-77	1977-87	1987-97	1966-68	1995-97	1980	After 1990
China	1.81	4.47	1.72	3.12	6.17	-	145 (1994)
Indonesia	4.91	4.32	1.03	1.89	4.42	68	90 (1993)
Vietnam	0.97	4.22	3.56	1.81	3.73	-	90 (1997)
Egypt	0.54	1.26	4.46	4.95	8.25	83	120 (1997)
USA	0.2	2.32	0.92	4.96	6.74	-	-
Australia	-2.41	1.69	3.06	7.33	8.23	-	32 (1996)

* Please refer to Table 1 for information on farmula for calculation of the Growth Rate

** Source: FAOSTAT, 1998.

*** Estimated based on FAO/IFA/IFDC (1999) Database on fertilizer use by crop; for Vietnam based on Le (1998)

The factors responsible for the rapid increases in rice yield in the these countries are:

China: Rice production in China has steadily increased even though the rice area harvested has declined. This was possible due to substantial increases in rice yield which could be attributed to both the development and use of hybrid rice since 1974 (Yuan, 1996) and the improvement in crop management including increased fertilizer use (Singh, 1992). Rapid expansion of hybrid rice area took place in China after 1976. The area planted to hybrid rice attained about 15 million ha in the late 1980's. During 1950-1979, crop management was improved with the transfer of integrated crop management packages such as "Seven Techniques", which encompass improved varieties, growing strong/healthy seedlings, intensive cultivation, proper plant population, balanced fertilizer application, rational irrigation, and control of pests and diseases. After 1980, the crop management package was improved with the emphasis on improved land development, fertilization, cultivation and cropping systems, and use of improved seeds as well as integration of socio-economic factors such as prices. The annual growth rates for rice yield were only 1.8 percent during 1967-77 but increased to 4.9 percent during 1977-87. The stagnation of yield of 3-line hybrid rice varieties may be responsible for the decline in yield growth to about 1.7 percent during 1987-97.

Indonesia: The national rice yield increased considerably by about 4.9 percent per year during 1967-77 and 4.3 percent during 1977-87. The increase in rice production has enabled the country to attain self-sufficiency in rice. The country benefited from the Green Revolution during the period from 1977 to 1987 while the Government's INSUS/SUPRA INSUS Rice Intensification Programmes have been effectively implemented since 1975. The successful IPM programme has also contributed to this high yield.

Vietnam: Vietnam had been a rice importing country and started exporting rice only in the late 1980's, thanks to its adoption of new agricultural policies. The national rice yield grew only about 1.0 percent per year from 1967 to 1977, although about 850,000 ha of IRRI's high yielding varieties were grown in South Vietnam in 1974. This was probably due to inadequate fertilizer use in this period. The annual growth rates of rice yield increased to about 4.2 percent annually during 1977-87 and about 3.6 percent annually during 1987-97 period. Increase in fertilizer application has played an important role in these increases in rice yields and narrowing of yield gaps. The use of fertilizers, especially urea, increased from 45 kg/ha in 1988 to 200 kg/ha in 1997 (Le, 1998).

Egypt: Egyptian rice yield increased from 5.8t/ha in 1987 to 8.5 t/ha in 1997, one of the highest yields in the world. The adoption of new HYVs (such as Giza 175, Giza 176, Giza 181, Giza 177, Giza 178, Sakha 101 and Sakha 102); the intensive demonstrations and training on crop management; and monitoring production constraints which were carried out under national coordinated programmes, namely Markbouk 4 and others (Badawi, 1998), have led to the successful narrowing of yield gaps.

Australia: The national rice yield declined by about 2.4 percent per year during 1967-77, moderately increased during the 1977-87 period, but then grew rapidly during the 1987-97 period. The Integrated Rice Crop Management Package called "Ricecheck" was developed in the mid-1980s and transfered to farmers since 1986 (Lacy, 1994). Cropping systems using legume-based pastures (*Trifolium subterraneum*) in rotation with the rice crop were another factor responsible for the impressive increase in rice yield. The main features of Ricecheck are shown in Annex 1. The increase in rice yield has made rice production in Australia a profitable business for farmers and enabled the country to earn substantial foreign exchange from exports.

U.S.A.: The annual growth rate of rice yield was high (2.3 percent) in 1977-87 but rather low (0.9 percent) in the last decade. Among the rice growing States, California has made considerable progress in yield increase, reaching around 9 t/ha, thanks to improvements in weed control, laser-based land preparation and modern rice varieties.

It is worthwhile to note that national yields in some Mediterranean countries, mainly Italy, Spain, France and Turkey, were stagnant at around 6 t/ha for many years, while the rice yield in Egypt reached 8.5 t/ha last year. The difference in national yield between these countries and Egypt in the Mediterranean Region is difficult to explain. Greece has also made great progress in narrowing yield gaps, with its national yield reaching 7.6 t/ha in 1996.

4. CHALLENGES IN NARROWING THE YIELD GAP

The narrowing of the yield gap of rice, as shown in the above cases, requires integrated and holistic approaches, including appropriate concept, policy intervention, understanding of farmers' actual constraints to high yield, deploying of new technologies and promotion of integrated crop management, adequate supplies of inputs and farm credit, and strengthening of research and extension and the linkages among the factors. If one of these components is missing or weak the yield gap in a particular rice production area cannot effectively be narrowed (Tran, 1997).

4.1 Concept

Narrowing the yield gaps aims not only to increase rice yield and production but also to improve the efficiency of land and labour use, to reduce the cost of production and to increase sustainability. Exploitable yield gaps of rice are often caused by various factors including physical, biological, socio-economic and institutional constraints, which can be effectively improved through participatory and holistic approach in action and attention of Goverments. An integrated programme approach is obligatorily required. The narrowing of the yield gap is not static but dynamic with the technological development in rice production, as the gaps tend to enlarge with the improvement of yield potential of rice varieties.

4.2. Policy Intervention

Rice policy should be well defined and formulated in a country, especially where major structural reforms were introduced. Most Sub-Saharan African and several Asian countries have experienced these reforms. Governments should address and find solutions for socio-economic and political questions before narrowing the agronomic gap between farmers' fields and research stations (Hanson et al., 1982). The goodwill of Governments is also essential to initiate a yield gap narrowing programme and to make effective coordination and intervention, with the aim of providing appropriate solutions to actual problems. Sensitization of policy makers and Government officers is a very important activity in bridging yield gaps of rice. The pilot approach should be considered in selection of zone/s for intervention.

4.3. Survey and Classification of Yield Gaps

The first step to narrow the yield gap is to identify actual and potential constraints to rice production in a particular area. The major constraints to high yield may vary from one place to another and should be well understood. A group of agronomists, economists and statisticians should carry out this preliminary survey. Based on the results of the survey, for practical purposes, yield gaps should be classified into:

- *Case 1: Unexploitable:* Gaps due mainly to non-transferable factors (or Gap I in Figure 1).
- *Case 2- Less exploitable gaps:* These gaps can be closed, but with less economic gains, due to the yield ceiling and law of diminishing returns in a production function. This type of gap can be found when rice yields are equal or more than 6 t/ha under a tropical climate and 8 t/ha or more under a Mediterranean climate.
- *Case 3- Exploitable gaps:* Gaps are due mainly to sub-optimal crop management practices (or Gap II) in Figure 1. This type of yield gap occurs when:

    - for irrigated rice under a tropical climate, yields are below 6 t/ha
    - for irrigated rice under a Mediterranean climate, yields are less than 8 t/ha
    - for favourable rainfed lowland rice, yields are less than 4 t/ha
    - The introduction of emerging technologies, such as hybrid rice, New Plant Type is needed to increase yield ceilings in the first *two cases*, while the promotion of integrated crop management along with the improvement of socio-economic and institutional issues are relevant for narrowing of the *exploitable gaps* in *case 3*.

In practice, yield gaps may also be classified according to constraints:

- *Agronomic gaps:* due mainly to biological and partly physical constraints
- *Socio-economic gaps:* due mainly to socio-economic constraints
- *Institutional gaps:* due manily to institutional constraints
- *Mixed gaps*: due to a combination of the above constraints. In this case and in the previous two cases, the socio-economic and institutional constraints should be solved before the agronomic gaps can be narrowed using improved technological packages.

4.4. Promotion of Integrated Crop Management

Integrated crop management can narrow agronomic yield gaps and at the same time help farmers to reduce wasteful resource utilization due to poor management of inputs, natural resources and other cultural practices and increase rice yield and farmers' incomes. Precision crop management practices can be realized with the use of advanced technologies. Precise application of fertilizers, for example, can be done with the use of computer-aided systems. However, most of the resource-poor farmers cannot afford such systems. The technique of using the chlorophyll meter and leaf colour chart for field-specific N management, which has been tested by IRRI, could be suitable for these farmers.

Narrowing the yield gaps by improvement of crop management practices of small farmers in developing countries is often not an easy task. Although there are several improved crop management practices, their dissemination has proven to be more complicated than that of seed-based technologies. Crop management practices are seldom static and often must be adjusted to environmental factors, knowledge and market forces. Interactions between crop varieties and environmental conditions and crop management practices are well known. Also, factors such as inputs and output prices and employment opportunities affect farmers' decision on the level of inputs to be applied and the time spent in crop management. The influence of market factors on farmers' decision with regard to crop management practices will be increased, as the market will be more and more open under the General Agreement on Tariffs and Trade (GATT).

It is essential, therefore, that crop management practices should not be applied in isolation but be holistically integrated in Integrated Crop Management Packages (ICMPs) with flexibility for adjustment to fit to prevailing environmental, socio-economic and market factors. The development of ICMPs, which are similar to the Australian Ricecheck package, and their transfer could effectively assist farmers in many countries to narrow the yield gaps as well as to reduce rural poverty. The ideal ICMP, however, must aim to improve farmers' knowledge not only on crop production and protection but also on the conservation of natural resources and market dynamics. This requires substantial improvement to the system of collection and dissemination of information on rice, its production factors, and its technologies as well as the modification of the extension systems in many countries.

Suitable improved varieties and improved cultural practices including integrated pest management and integrated plant nutrition management are, of course, the main components of ICMPs. A number of innovative technologies identified by CREMNET (Crop and Resource Management Network), IRRI, may provide effective tools to partly narrow yield gaps in rice production for small farmers in developing countries. CREMNET works on the chlorophyll meter technique, leaf colour chart for field-specific N management, urea tablet deep placement, direct wet-seeding method, stripper-harvest, low-cost in-stored dryer, etc. (IRRI, 1997) and is appropriate for inclusion in integrated crop management packages to narrow gaps in rice production in developing countries.

4.5. Deployment of New Technologies

Yield can be raised either by lifting the actual yield closer to the ceiling by improving crop management or by raising the ceiling itself. It is probable that the theoretical maximum rice yield is not very much different from the maximum yield of wheat of 20 t/ha per crop (Hanson et al 1982). The highest yields obtained at research level are only about 17 tons/ha per crop for hybrid rice, 15 t/ha for *japonica* high yielding varieties planted under a sub-tropical climate, and 10 t/ha for *indica* high yielding varieties planted under a tropical climate (Fig. 2). Hybrid rice is presently available for increasing the yield ceiling by 15-20 percent. The New Plant Type of rice, which has been developed by IRRI, may raise the present yield potential by 25-30 percent (Khush, 1995). Rice biotechnology, which has recently made considerable progress, may also provide an opportunity to increase rice yield in a more effective and sustainable manner.

20,000 kg/ha	Hanson et al (1982) reported that the theoretical maximum yield for wheat is 20,000 kg/ha	
17, 113 kg/ha	Yuan (1998) reported this yield of a 2-line hybrid variety Pei'ai 64S/Teqing planted on 0.10 ha at Yongsheng, Yunnan, China in 1992	The Climate at Yunnan, China is Sub-Tropical
14,700 kg/ha	Horie et al. (1994) reported this yield of a *japonica* variety YRL sown in an experiment on 21 October 1991 and harvested on 24 April 1992 in Riverina, Australia. The crop received 320 kg N/ha.	The Climate at Riverina, Australia is Sub-Tropical
11,070 kg/ha	Badawi (1998) reported this average yield of a *japonica* variety Giza 178 from 17 demonstration fields planted in the Lower Nile River Valley, Egypt in 1997	The Climate at Lower Nile River Valley is Sub-tropical
10,300 kg/ha	De Datta (1981) reported this yield of an *indica* line IR 8-288-3 planted during the dry season of 1996 at the experimental farm of the International Rice Research Institute at Los Banos, Laguna, Philippines. IR8-288-3 was later named as IR 8 by IRRI	The Climate at Los Banos, Laguna, Philippines is Tropical

Figure 2. Yield ladders at research level (Adapted from Hanson et al., 1982).

4.6. Adequate Input and Farm Credit Supplies

Fertilizers, especially nitrogen, play an important role in rice production and productivity. Farmers need adequate amounts of fertilizer at the right time for obtaining high yield in rice cultivation. The supply of fertilizers needs to be decentralized to village markets and the quality of fertilizers should be assured. Small farmers are usually unable to buy sufficient quantities on time for application; hence the provision of village credit could greatly help them. The Bangladesh Grameen Bank is an interesting example of providing rural credit to landless and resource-poor farmers for developing countries. The loan proposals are received by the bank only on a group basis (at least 5 persons), focusing on technology loan, housing loan, joint loan and general loan (Dadhich, 1995). The principle of the Grameen bank could be deployed in other developing countries, of course with some modification for adaptable local conditions. The problems of credit and input supplies cannot be quickly resolved unless there is strong Government intervention. The issues of village credit and input supplies are being tackled where FAO and Governments are implementing Special Programmes for Food Security.

4.7. Research and Extension

The support of research and extension ensures the effective bridging of a yield gap of rice. Farmers’ adoption of the above-mentioned improved technologies depends on the capability of national agricultural research centres and extension services, which need more Government resources allocation and training.

Research should understand well farmers' constraints to high rice productivity and provide them with appropriate technological packages for specific locations to bridge the gap under participatory approaches. The extension service should ensure that farmers use correctly and systematically recommended technological packages (ICMPs) in the rice fields, through effective training and demonstrations. For example, only relevant application of nitrogen fertilizers from seeding to heading, in terms of quantity and timing, will make significant contributions to narrow the yield gap of rice while avoiding unnecessary losses of nitrogen, which increase cost of production and pollute the environment.

5. CONCLUSIONS

Sustainable increased rice production in the near future requires substantial improvement in productivity and efficiency. Rice yield and production have considerably been increased during the last 30 years. In a number of countries, yields of rice in favourable ecologies have reached the research yield potential of the present generation of high yielding varieties. The use of innovative genetic improvement including hybrid rice, New Plant Type and possibly transgenic rice can increase the yield ceiling, where yield gaps are nearly closed. These increases not only enhance rice productivity but also efficiency in production systems, resulting in high economic outputs as well as high income for farmers.

On the other hand, in many countries, the gaps between yields at research stations and in farmers fields are still substantially large due to a combination of lack of initiatives, resources and goodwill to narrow them. In these countries, the integrated crop management approaches including available location-specific technologies coupled with active institutional support from Governments, particularly for input and village credit supplies, stronger research and extension linkages, can expedite the bridging of yield gaps; thus, improving the productivity and efficiency of rice production.

The causes of yield gaps of rice differ widely from season to season, country to country and/or even from location to location within a country or region and province. It is essential, therefore, to promote closer collaboration between research, extension, local authorities, non-governmental organizations (NGOs) and private sectors in order to identify specific constraints to high yield and adopt appropriate technologies and solutions, and take concerted actions to bridge yield gaps of rice, through participatory approaches. This will depend mainly on the will of Governments to support, coordinate and monitor such integrated and holistic programmes. International support to Government initiatives in this direction could speed up sustainable increased rice production and the conservation of natural resources and the environment for future generations.

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ANNEX 1

The Eight Key Factors or Checks in “Ricecheck”

■ an Integrated Crop Management Package for Rice Production Technology transfer to farmers in New South Wales, Australia.

☛ **1.** Develop a good field layout with a landformed, even grade between well constructed banks of a minimum height of 40 cm (measured at the lowest point).

☛ **2.** Use the recommended sowing dates.

☛ **3.** Obtain good or economic weed control.

☛ **4.** Establish a seedling population of 150 to 300 plants/square meter.

☛ **5.** Achieve an optimum crop growth level at panicle initiation of 500-1100 shoots/square meter and tissue nitrogen content (as measured by near-infra red NIR) of 1.2 percent to 2.2 percent depending on variety.

☛ **6.** Topdress nitrogen based on shoot count & NIR tissue analysis using the NIR tissue test.

☛ **7.** Achieve an early pollen microspore water depth of 20 to 25 cm on the high side of each bay for rice varieties Amaroo, Bogan, Jarrah, Illabong, YRL34 and for rice varieties Doongara and 25cm for Pelde, YRF9 and Goolarah.

☛ **8.** Harvest as soon as possible after physiological maturity when the grain first reaches 22 percent moisture.

BRIDGING THE RICE YIELD GAP IN AUSTRALIA

J. Lacy,[1] W. Clampett [2] and J. Nagy[3]

1. INTRODUCTION

The Rice Industry in Australia produces 1.3 million tonnes from an area of 150, 000 hectares, of which 85 percent is exported. One crop of *japonica* rice is grown per year under temperate climatic conditions. All rice is irrigated as the growing season rainfall of 180 to 220 mm is very low. The rice is milled and marketed by the Ricegrowers' Cooperative Limited, which is a farmer owned cooperative.

In 1986 the New South Wales (NSW) Department of Agriculture developed the objective crop management and collaborative learning extension programme "Ricecheck" aimed at improving farmer yields. Together with the development of semi-dwarf varieties, Ricecheck has resulted in a significant increase in farmer yields. In the 20 years prior to Ricecheck there was little yield improvement.

Ricecheck has led to great changes in rice management. One of the great changes is that farmers monitor and check crops to see how their crops compare to the measures for high yields. Before Ricecheck farmers rarely ventured into rice crops. Ricecheck is an ongoing extension programme. Components of the programme are the Ricecheck Recommendations for improving yields and grain quality, the Crop Evaluation Database and Farmer Discussion Groups. Ricecheck has created a learning culture. Ricecheck has also led to closer links between farmers, researchers, extension and commercial agronomists and the rice industry.

2. STATUS OF RICE CULTIVATION

2.1 Area, Production and Yield Trends

Most of Australia's rice is grown in southern New South Wales. The production is 1.3 million tonnes from an area of 150,000 hectares. Yields have been increasing. Average yield for the last 5 years (1995- 99) was 8.4t/ha compared to 6.8t/ha for the 1985-89 period. During this period the first semi-dwarf rice variety M7 was released in 1983, while the current main variety Amaroo was released in 1987.

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2.2 Production Constraints

The biggest production constraint is the supply of irrigation water. Rainfall runoff collected in dams in the catchments is subject to large seasonal variation. Irrigation water is released from dams on the Murrumbidgee and Murray Rivers and fed by channel gravity systems to farms. Farming industries are increasingly competing for water with the needs for the environment and maintenance of clean river flows. Another constraint is cold temperature at the early pollen microspore stage, which is a limiting factor in 6 to 8 years out of 10. Minimum temperatures in January average 16^o C. The rise of water tables to within 1 to 2 metres of the ground surface with potential for increased salting is another production constraint.

2.3 Yield Potential of Released Varieties

The yield potential of existing *japonica* varieties is 15t/ha although a few research plots yield above 14t/ha. Temperate climatic conditions allow only one crop per year which is sown in October (mid Spring) and harvested in March (mid Autumn).

2.4 Evidence of Yield Gaps

Farmer yields range from 8 to 12 t/ha with few if any farmers able to repeat 12t/ha yields every year. There is little difference between the best research plot yields and best farmer yields.

3. PROGRAMME FOR NARROWING THE YIELD GAP

3.1 Historical Perspective

In 1985 the Rice Research Committee convened a meeting to address the lack of progress in increasing yields. There had been little yield improvement in the previous 20 years (Figure 1). The cost-price squeeze was the trigger for the meeting with costs rising and incomes stagnant. Farmer yields tended to fluctuate widely. Most farmers could obtain high yields of 10t/ha in odd years but could not consistently reproduce 10t/ha yields. There was recognition that there were big gaps between research and farmer yields and between “top” and “bottom” farmers. There was a perception that the transfer of technology diffusion model was failing to deliver improved yields. There was a need for a new approach or model.

The new approach was based on finding the answers for the high yields in high yielding farmer paddocks rather than from research plots. It is called the Check Approach (Lacy 1998). It was based on what was really happening in farmer paddocks rather than on what was thought to be happening. The new approach was already having success for increasing irrigated wheat yields (Lacy 1991). The Rice Research Committee provided funding for the use of the approach for rice with the commencement of Ricecheck in 1986.

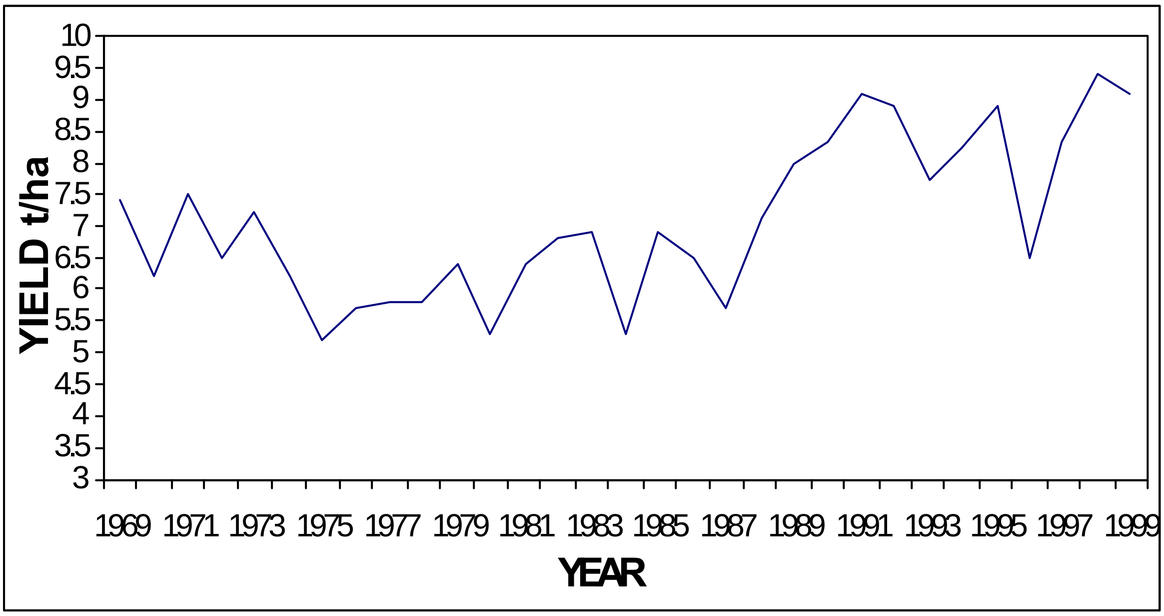

Figure 1. Average NSW rice yields from 1968 to 1999

3.2 Activities and Results of programmes to Narrow Gaps during the Last Two Decades

3.2.1 Ricecheck

Ricecheck, the crop management and collaborative learning system based on crop checking, has been used in the New South Wales rice industry to improve yields and grain quality. The checking and measuring of high yielding farmer crops identified 7 key recommendations or checks linked to high yields. Most farmers were not adopting these key checks hence yields were not increasing.

The most important feature of Ricecheck is to encourage farmers to monitor and check their crops to see how the crops compare to the 7 key checks. When Ricecheck commenced in 1986 the yield goal for the medium grain semi-dwarf varieties was 10t/ha. The number of key checks has recently increased to 9. The checks are described simply and objectively. This reduces information overload and aids communication and understanding of the total package. Another check targets improved quality. Farmers strive to adopt the key checks in order to increase yields. As part of the learning process farmers are encouraged to record their management of the checks by completing crop record sheets. The current key checks are:

- Develop a good layout with a landformed, even grade between banks and well- constructed banks of a minimum height of 40 cm.
- Sow on time during the ideal window for each variety.
- Achieve 200-300 plants/m^2 established in standing water to ensure uniform establishment over 100 percent of the crop area.
- Apply only registered or approved pesticides to control weeds and insect pests to prevent economic yield loss.

- Apply sufficient nitrogen to achieve the target range nitrogen uptake at panicle initiation (P.I.) so that the P.I. topdressing requirement does not exceed 60 kg N/ha.
- Topdress nitrogen based on fresh weight and NIR analysis using the NIR Tissue Test.
- Apply 10-25 kg P/ha pre-flood where the Colwell phosphorus is below 20 ppm.
- Achieve P.I. before 10 January.
- Achieve a minimum water depth of 20 to 25cm during the early pollen microspore stage.

The most important feature of Ricecheck is to encourage farmers to monitor and check their crops. This is achieved through a number of learning steps. These are:

Observing
↓
Measuring
↓
Recording
↓
Interpreting
↓
Acting

The aim is to educate farmers to improve their learning and performance at each step as well as moving from step to step over time. To assist paddock measuring and recording simple measuring aids and records are provided e.g. rice rings. The benefit of recording crop data is that crop growth and management can be related to the yield and grain quality check benchmarks.

3.2.2 Database analysis

Between 500 to 600 paddock records are received from farmers each year on 2 record sheets. The first sheet serves two purposes. It satisfies the needs for the objective NIR Nitrogen Topdressing Tissue Test and also satisfies the Ricecheck need for information on sowing and establishment up to panicle initiation. A second data sheet “Crop Evaluation P.I. to Harvest Data” records yield and other key check information. Records are entered into a Visual dBase for Windows software programme which uses the same template each year so that new data can be automatically added. The total number of crops on the Ricecheck Crop Evaluation Database (Lacy, Clampett and Nagy 1999) is currently 3822 crops for the 1994 to 1999 harvest years. A Report Smith™ software programme is used to produce 5 types of reports of farmer results.

The farmer data is analyzed to show comparisons of management practices between crops and indicate how high yields were achieved. The records allow farmer management practices to be compared to the Ricecheck key checks or recommendations and to determine the adoption of the recommendations. Farmers receive individual Ricecheck Crop Evaluation Reports, which compares their management to high yields and shows how they can improve. Another benefit of the records is that poorly adopted recommendations or checks can be quickly identified providing timely signals to extension, research and the rice industry as a whole on issues requiring further investigation.

3.2.3 Discussion groups

Farmer discussion groups have played a key part in the delivery *of* Ricecheck. About 45 discussion groups are run by 7 extension agronomists. The momentum for the success of Ricecheck and the discussion groups is from the focus on the key checks. At the group meetings farmers are encouraged to collaborate and learn from each other and give feedback on the check recommendations. This also allows them to influence changes to the Ricecheck management package and develop ownership of the programme. Between 3 to 5 rounds of meetings are held over the rice-growing season.

3.2.4 Yield evaluation results

Key checks and yield

Ricecheck is based on the principle that as the adoption of the 7 Key Checks increase, yields increase. Figure 2 shows the relation between the number of Key Checks achieved and yield for the main medium grain variety Amaroo from 1994 to 1999 based on 1,834 crop records. The results confirm that adopting more checks results in higher yield.

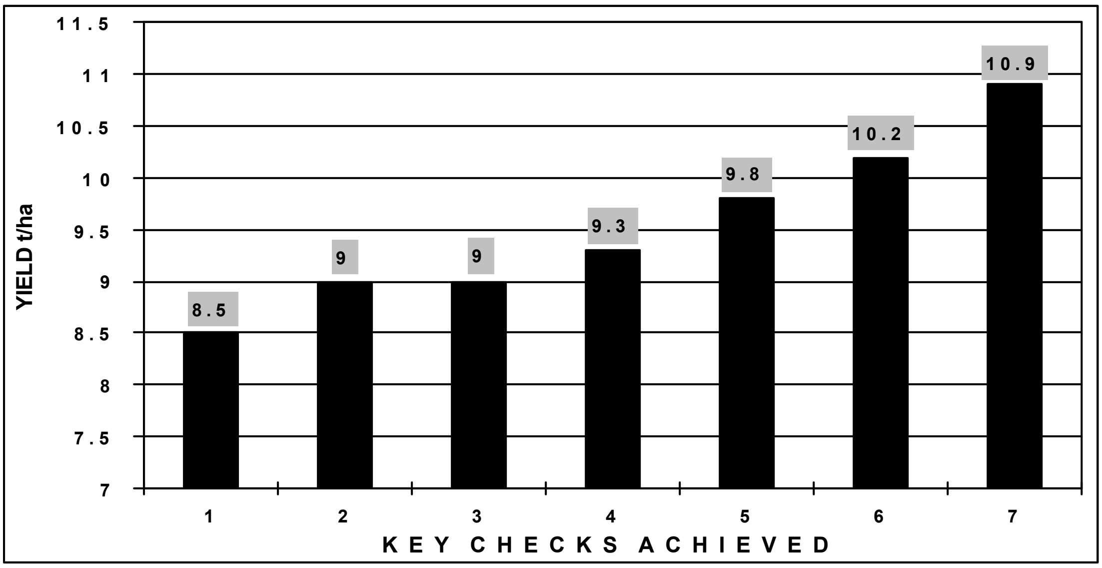

Figure 2. Yield response to checks adopted 1994 - 1999

Top and average yields

The database report "Statistics on high and low yielding crops" shows the check performance for high, average and low yields for any variety. This is important for the development of the Ricecheck recommendations. The check performance for high yields can be compared to the existing recommendations. This provides the opportunity to modify existing check recommendations to enable improvements to management and targeting of higher yields.

Check data comparing average Amaroo variety yields with the top 10 percent yields are shown in Table 1 for the 1994 to 1999 harvests. The results show that the top yielding crops have better adoption of each of the 7 Key Checks. The top crops were sown a little earlier, achieved better plant numbers with fewer weak areas, had higher bank heights, better weed control and higher nitrogen levels.

Table 1. Comparison of Average Amaroo yields with top 10% yields 1994 - 1999

Check	Yield		% Adoption	
	Average	12 t/ha	Average	12t/ha
Banks	42	44	69	78
Sow date	15 Oct	11 Oct	74	87
Plant numbers	174	192	74	88
Weak areas	5%	1%	89	99
Plants + weak area			68	86
Weeds 0 – 0.5t/ha			18	55
Fresh weight	3103	3280	54	54
NIR	1.61	1.62	44	57
N Uptake	114	123	32	37
P.I. N	39	53	83	75
Total N	112	131		
% N pre-flood	62	54		
P	6	7	29	39
EPM	20	20	56	71
Laser			81	91
Av. yield t/ha	8.8	12.6		

Single check yield comparisons

The database option "Analysis of Interactions" has the ability to compare any one of 60 major factors with yield and produce graphs of the results. Figure 3 is an example of one of the graphs comparing yield with sowing date for the Murrumbidgee Irrigation Area (MIA). The use of graphs at farmer meetings is an excellent tool for promoting discussion and farmer learning and motivating farmers to improve practices.

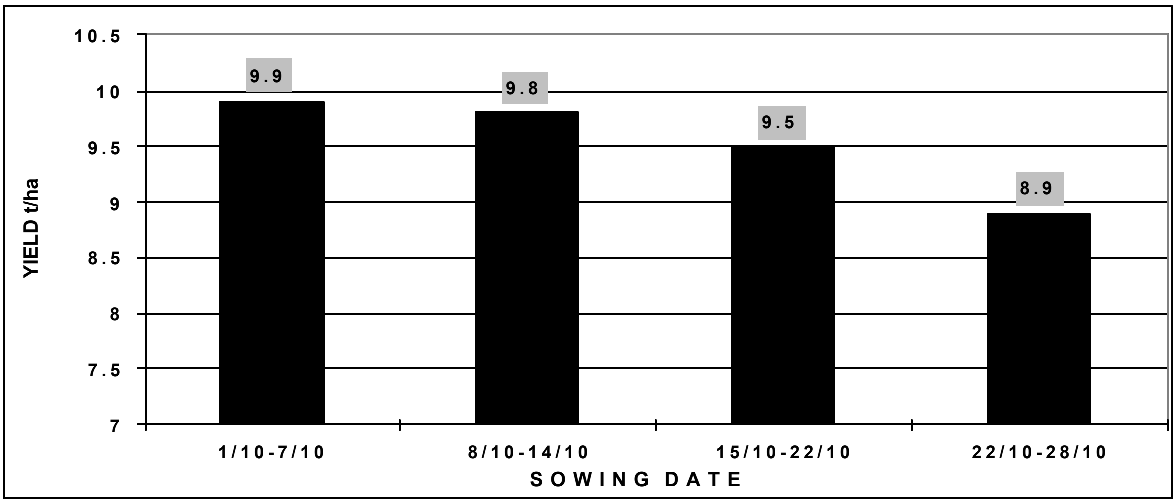

Figure 3. Effect of Sowing Date on Yield for MIA/CIA 1994-1999

3.2.5 Adoption of the checks

One of the aims of Ricecheck is to improve the adoption of the Key Checks since the higher the adoption the higher the yields. Figure 4 shows the trends in adoption for the variety Amaroo over the period 1994 to 1999. Overall adoption of the checks is good with the exception of the nitrogen uptake at P.I. and early pollen microspore water depth checks. On an individual year basis the 1998 harvest year had the best adoption for five of the checks. The checks where adoption has generally improved over the past 5 years are bank height, establishment plant number, weed control and recommended nitrogen topdressing rate. Bank heights have increased as farmers realize the importance of deep water at the early pollen microspore stage. Sowing rates have significantly increased to help improve establishment. More farmers are using the recommendations from the NIR Tissue Test to improve decisions for nitrogen topdressing.

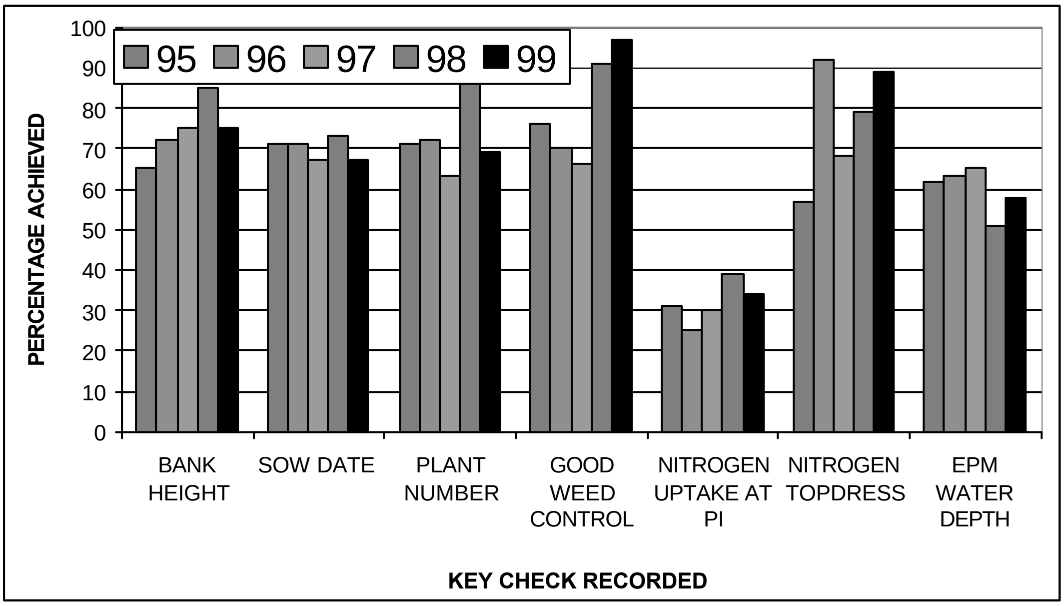

Figure 4. Adoption of key checks 1995-1999

Adoption of the nitrogen uptake at P.I. check though poor has slightly improved. Sowing date has remained static. Late announcements of water allocations often prevent farmers sowing in the recommended check window. Weed control has been improving which is surprising given the increasing problems with resistance to bensulfuron methyl. The adoption of deep water at the cold sensitive early pollen microspore (EPM) stage has tended to fall. This is the result of two factors. High temperatures at the P.I. to EPM stage prevented farmers raising water levels and uncertain water allocations, particularly in the Murray Valley in the last 2 years, has resulted in many farmers running much lower water levels than normal.

3.2.5 Evaluation of farmer crops

Ricecheck is a collaborative learning system. An important aspect of adult learning is participation and feedback. As part of the learning process farmers like to compare themselves with others. The Ricecheck Crop Evaluation Report provides feedback to each participating farmer as to how their crop compared to the Ricecheck Key Checks and to other farmers. The Reports are produced by the computer programme for each growing district for each variety and for each farmer crop. The Reports are sent to farmers after harvest and after entry of all data sheet records and yield analysis. Appendix 1 shows an example of a Ricecheck Crop Evaluation Report 1999 for one crop from the Eastern Murray Valley for the medium grain variety Amaroo. In the Report the crop data is compared to the achievement of the Key Checks, to the average yields and the highest 10 percent yields. The Report shows the crop achieved 7 of the 7 Key Checks.

4. ISSUES AND CHALLENGES IN NARROWING THE RICE YIELD GAP

Figure 2 showed that the more checks adopted, the higher the yield. The Crop Evaluation Database results show that there is an average of 60 to 70 percent adoption of the key checks. This is creditable but the challenge is to improve this level of adoption to close the yield gap. The relative importance of the checks changes each year so it is important for farmers to try and adopt all checks. Often farmers may adopt most of the checks and only miss out on one or two. However, if the one or two non-adopted checks in any year are crucial to yields there can be a significant yield penalty. Invariably the top farmers get more of the checks right more of the time than the average farmers. Any small lift in the performance of the average yielding farmers could make a big difference to the yield gap. Extension programmes need to highlight this and to motivate farmers to improve.

There is poor adoption of the nitrogen uptake at P.I. check and lower adoption of the early pollen microspore (EPM) water depth check. These are barriers to increasing yields. A recent survey of EPM water depths supports the Ricecheck results. Years with significant cold at EPM result in significant yield differences between the top and average farmers. There is a need to investigate the barriers to farmers adopting both checks.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Ricecheck has provided the framework for collaboration between farmers, researchers and extension officers. As a method of on-farm research it recognises that farmer learning and knowledge is just as important as research and extension knowledge.

Before Ricecheck, farmers used to pinpoint single factors as the main determinant of yield. Extension programmes focussed on single technologies. Ricecheck as a systems approach has demonstrated that there are many factors to get right for yields to increase.

Importantly Ricecheck has changed the culture and management of ricegrowing from managing from a distance, to walking in and checking the crop. Farmers learn by critically observing and measuring their crops. The Ricecheck Database reports and the individual Ricecheck Crop Evaluation Reports allow farmers to compare their management with high yields, and also assists learning and the bridging of the yield gap. The discussion groups have provided an ideal learning environment for extension delivery.

An independent evaluation of Ricecheck in 1997 based on random interviews with 124 farmers found that 83 percent of the farmers said Ricecheck was useful in producing higher yields. With the rating of the extension components discussion groups rated highly at 76 percent, the Crop Evaluation Reports next highest at 63 percent and Ricecheck Recommendation booklet at 54 percent.

Ricecheck will continue to develop and change to meet the demands of farmers and the rice industry.

5.2 Recommendations

- The close collaboration and teamwork between farmers, researchers, extension and commercial agronomists and industry needs to continue.

- The Ricecheck Recommendations need to be revised and improved each year through the incorporation of any new research results or new results from the Ricecheck Crop Evaluation Database.

- The discussion groups should be maintained using facilitation methods to keep meetings dynamic and to motivate both the top and average farmers.

- More farmers need to be encouraged to record crops because of the improved knowledge gained from the Crop Evaluation Reports.

- The Ricecheck Crop Evaluation Database includes a number of very high yielding 12t/ha and over crops which need to be analyzed to identify new key checks which can be incorporated into the Ricecheck recommendations and hence lift yield potential.

- There is a need to add crop grain quality to the database which will allow feedback and crop comparisons on grain quality and provide linkage to crop management. Quality assurance is becoming a significant issue relating to food safety and market access.

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`Ricecheck` CROP EVALUATION REPORT 1999-AMAROO MVE
Report from the R&D Project "Performance Evaluation of Commercial Rice Crops"

GROWER NAME:		
Address:		**Farm Number:**
Variety:	**Field Name:**	**RCL Sample Number:**

NB The results in this Report are based on information provided by Ricegrowers. The accuracy is that of the data provided.

`Ricecheck` **MANAGEMENT AREA**	**YOUR RESULTS** **CROP DATA**	**Achievement of each *Key Check***	**Average Results**	**Results for Highest 10% yield**	**% of all growers achieving *Key Checks***
YIELD TARGET -minimum of **10 tonne/hectare**	**Yield** 11.6 **t/ha**	Yes	**10.0** **t/ha**	**12** **t/ha**	**52%**
FIELD LAYOUT ***Key Check 1*** **-** "well constructed banks of a minimum height of **40cms**"	**Bank Height** 42 **cm**	Yes	**44 cm**	**43 cm**	**72%**
SOWING TIME ***Key check 2*** **-** "aim to sow between	**Sowing Date** 14/10/1998	Yes	**15 Oct**	**11 Oct**	**57%**
CROP ESTABLISHMENT ***Key Check 3*** **-** "aim to establish **150 - 300 plants/m^2**	**Seedling Number** 225 **m^2**	Yes	**188**	**183**	**82%**
with **less than 5% weak areas"**	**Weak area** 0 **%**	Yes	**1%**	**0%**	**98%**
CROP PROTECTION ***Key check 4*** **-** "prevent economic yield loss from weeds"	**Good Weed Control** Nil	Yes	**98%**	**100%**	**98%**
CROP NUTRITION *Key Check 5* - **Pre-flood Nitrogen** "apply sufficient nitrogen to achieve **2500-3700 g/m^2 fresh weight** and	**Fresh weight** 2956 **g/m^2**	Yes	**3677** **g/m^2**	**3220** **g/m^2**	**43%**
1.4 - 2.0 N% **to give**	**NIR** 1.56 **%N**	Yes	**1.67** **%N**	**1.92** **%N**	**67%**
90-130kgN/ha Uptake at P.I."	**N Uptake** 114 **Kg N/ha**	Yes	**136** **Kg N/ha**	**142** **Kg N/ha**	**27%**
Key Check 6 **- P.I. Nitrogen** "at P.I. topdress with nitrogen according to the NIR Tissue Test Recommendation"	**Deviation from NIR Test Recommendation** -2 **KgN /ha**	Yes	**7** **Kg N/ha**	**-1** **Kg N/ha**	**57%**
WATER MANAGEMENT ***Key check 7*** **-** "achieve a water depth of **20 - 25cm** during Early Pollen Microspore"	**E.P.M. Water Depth** **20 cm**	Yes	**19 cm**	**20 cm**	**55%**

You achieved 7 of the 7 recorded key checks (out of a total of 7) and the **RIRDC Rice Research & Development Committee**

BRIDGING THE RICE YIELD GAP IN BANGLADESH

Sheikh A. Sattar [*]

1. INTRODUCTION

The almost uneven topography and humid tropical climate of the country with abundant monsoon rain offers a unique environment for the rice plant in Bangladesh. As such, rice is the staple food of the people of this country and is part of their culture. Once this land was capable of meeting the food demand but with passage of time the cultivated land started diminishing with the rapid growth of population. Feeding of these new mouths with rice became a heavy burden with the present level of food production and thus there was a necessity for food imports. To minimize food import emphasis was given to the research and development of rice since the birth of Bangladesh.

In spite of doubling rice production in the country since the introduction of modern varieties in the early seventies, Bangladesh has experienced a continued annual shortage of nearly 1.5 million tonnes of food grains (Karim, 1999). This shortage of food production will continue to increase even if the present level of population growth is maintained. In other words, rice production has to be increased by at least 60 percent to maintain the present level of rice requirements by the year 2020 (Bhuiyan & Karim, 1999). Increasing rice production further is a gigantic task since there is no scope for horizontal expansion of the rice area due to the gradual diminishing of cultivated land as a result of diverting its uses for houses, roads, industries and urbanization. Therefore, options available for increasing rice production are a) a breakthrough in the present yield potential of the varieties, b) full exploitation of the present yield potential of the existing modern varieties; and c) utilization of unfavourable but potential ecosystems for rice and or other systems of food production. This paper will elaborate on the possibility and means of exploiting yield potential of the existing modern varieties of rice and problems thereof.

2. STATUS OF RICE CULTIVATION IN DIFFERENT ECOSYSTEMS

In Bangladesh the rice-growing environment has been classified into three major ecosystems based on physiography and land types. These ecosystems are a) irrigated, b) rainfed, and c) floating or deepwater. The rainfed ecosystem has been further classified as rainfed lowland and rainfed upland. Thus, all rice varieties cultivated in the country are grouped into five distinct ecotypes such as a) Boro, b) Transplanted Aus (T. Aus), c) Transplanted Aman (T. Aman), d) Upland Aus (direct-seeded Aus), and e) Deepwater rice (Floating rice). Boro rice is grown completely under the irrigated ecosystem during the dry period (November to July) while T. Aman (during July to December), T. Aus (during April to August) and Upland rice (during March to July) are grown under the rainfed ecosystem. Of the total 13.8 million ha of cultivable land in the country (UNDP/FAO, 1988), 10.27 million ha (74.4 percent) are devoted to rice cultivation covering the above four ecosystems (BBS, 1993 & 1997; Hamid 1991). Besides these, special types of ecosystems like

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tidal wetland covering about 425 thousand ha and about 3.05 million ha of coastal saline soils are also included into the 10.27 million ha of rice land.

2.1 Area, Production and Yield Trend

The area, production and yield of rice in different ecosystems during 1998 can be seen in Table 1. Rice is cultivated on about 10.27 million ha including about 3.47 million ha of tidal wetlands (both saline and non saline). Modern varieties (MV) of rice cover about 31.4 percent of the total Aus area (lowland and upland) contributing 47 percent to the total Aus rice production, 51 percent of T. Aman area sharing about 59 percent of total Aman rice production and 92.4 percent of Boro area contributing 96 percent to the total Boro rice production.

There has been a very slight positive change in the growth of area, particularly of Boro and T. Aman rice while areas under Aus and Deepwater rice are almost stagnant or are decreasing. This stagnation/decrease of Aus and Deepwater rice areas can be attributed to a) the low productivity of this rice due to unfavourable and unpredictable climate, and b) to lack of suitable varieties for upland and deepwater rice ecosystems. Thus, with the development of irrigation facilities, farmers are losing interest in growing low yielding Aus and relatively shallow flooded Deepwater rice releasing this extra land for more productive Aman and/or Boro rice. While the yield remains almost stagnant, the total production of T. Aman and Boro rice is increasing mainly due to the increase in area.

Table 1. Area, Rough Rice Production and Yield under Various Ecosystems in 1998.

Ecosystem	Ecotype	Variety	Area (million ha)	Production (million tonnes)	Yield (t/ha)
Irrigated	Boro	Local	0.22	0.52	1.54
		Modern	2.67	12.03	4.51
Rainfed Lowland	T. Aman[*]	Local	2.45	5.51	1.72
		Modern	2.55	8.05	3.14
	T. Aus	Modern	0.49	1.35	2.76
Rainfed Upland	DSR Aus	Local	1.07	1.55	1.45
Floating	Deepwater rice	Local	0.81	1.46	1.80
Tidal Wetland					
Non-saline	Boro/T. Aman	HYV/Local	(0.425)		
Saline	T. Aman	Local	(3.053)		
Total			10.26	30.47	

* Including tidal wetlands

2.2 Production Constraints in Different Ecologies

2.2.1 Irrigated ecosystem

Irrigated rice is grown after the harvest of T. Aman rice or after harvesting a non-rice crop like potato, mustard or quick growing vegetables. Low temperature during the early vegetative stage of the crop prolongs growth duration and thus most of the existing modern varieties mature within 165 to 180 days. This requires use of a high level of inputs like irrigation, fertilizer and plant protection measures.

Of all the constraints of Boro rice cultivation, the most pressing one is the availability of irrigation water followed by farmers incapability of using the required amount of fertilizer in a balanced dose. Farmers of some regions delay planting in order to shorten growth duration vis-à-vis the production cost, particularly of irrigation. This delayed planting, however, reduces yield significantly. Recently BRRI released relatively shorter duration Boro varieties. But some farmers without being fully aware of the appropriate technologies for such varieties often stick to their traditional practices of early transplanting, subjecting the crop to cold injury during the flowering stage and thus realize poor harvests.

2.2.2 Rainfed lowland ecosystem

The rainfed lowland rice - T. Aus, the wet season first crop, is grown when sufficient rainfall occurs during April to August. This is the period experiencing higher temperatures with minimum diurnal fluctuation, moderate humidity during the reproductive stage, but with occasional scanty rainfall during the early vegetative growth period. Such a climate is very much conductive to higher vegetative growth of the crop with the lowest partitioning coefficient and development of pests and diseases. Rice varieties grown are all insensitive to photoperiod and mature within 115 to 130 days. Therefore, climatic limitation is the most important constraint for this rice.

The wet season second crop grown in the rainfed lowland ecosystem is known as T. Aman, cultivated during July to December, the full monsoon period. The crop experiences high rainfall and temperature during the vegetative stage and low temperature often associated with drought during the reproductive stage. Though the occurrence of severe drought is found to be about once in five years, and annual drought of various intensities affects about 2.3 million ha of T. Aman rice (Karim, 1999). In the medium flooded area, harvesting of Aman rice, that is not or is less sensitive to photoperiod, often becomes difficult due to standing water at the harvesting time. To face this problem, varieties strongly sensitive to photoperiod were grown in the past which mature after the field dries up. Since the Aman crop experiences two extreme climates at two ends, planting time is very important for this rice but often farmers cannot follow the appropriate planting schedule due to various socio-economic factors and thus planting gets delayed. This late planting causes yield decline. To save the crop from low temperature stress at the reproductive stage and also to establish a wheat crop timely after the harvest of Aman, shorter duration varieties with less or no sensitivity to photoperiod have been evolved recently for cultivation in shallow flooded areas.

2.2.3 Tidal wetlands

This ecosystem includes both saline and non-saline ecologies. Mostly T. Aman rice is grown in the non-saline area, and MVs cover only 15 percent of the area (Nasiruddin, 1999). There is little scope for further expansion of MVs unless varieties with relatively higher growth rate in the nursery bed, sturdy culm and profuse root system are evolved.

2.2.4 Rainfed upland ecology

The yield potential of this crop is the lowest due mostly to the unfavourable weather. The second important constraint is the lack of high yielding varieties. Unpredictable distribution of rainfall hinders timeliness of some management practices, particularly fertilizer management. Thirdly, the climatic conditions are very much conducive for rapid growth of weeds and pest and disease infestation. Sometimes, incessant drizzling for days just after the emergence of both rice and weeds, makes weeding difficult resulting in complete failure of the crop.

2.2.5 Deepwater

This is a very long duration crop sown in March/April and harvested in November/December. This rice requires a special habitat of prolonged flooding. The varieties are strongly sensitive to photoperiod and low tillering, producing a very high amount of biomass but with the least harvest index. The most important constraints of this rice are lack of varieties with high yield potential, unpredictable flooding, and low response to fertilizers.

Besides the constraints discussed above, floods are a common natural phenomenon and affect almost all rice crops in an area of about 2.6 million ha in a normal year (Karim, 1999). In the flood-prone areas, matured Boro and the ripening Aus crops are affected causing either partial to complete decomposition of grains or viviparous germination of the seed. T. Aman crop is also affected by flash floods in the early vegetative stage and by late floods during the maximum tillering to panicle initiation stages. The extent of crop damage depends on the duration and level of flooding and the stage of the crops.

2.3 Yield Potential of Released Varieties

BRRI has so far evolved 38 modern varieties of rice for cultivation in different ecosystems except for the deepwater environment. Table 2 gives the names of the most popular modern varieties with their potential yields under actual field conditions. Yield potential of the irrigated rice is the highest due to the most favourable weather conditions. The recently developed variety, BRRI Dhan 29, often gives grain yield as high as 9-10 t/ha under the irrigated ecosystem. Some other popular Boro varieties have yield potential of about 8 t/ha. Yield potential of the most popular T. Aman varieties, on an average ranges from 5.0 to 6.5 t/ha, and in some cases (like yield potential of varieties such as BR11) was found to be 7.4 t/ha. However, physiological potential yield of most of these varieties has not been worked out as yet.