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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

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Edited by

Minas K. Papademetriou
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TABLE OF CONTENTS

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.

* *Senior Plant Production and Protection Officer, FAO Regional Office for Asia and the Pacific, Bangkok, Thailand.*

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	?	?	$Endo^{+}$ fix^{+} NUE	3-5 years	High
Induced symbiosis (*Rhizobia, Frankia* etc.)	> 200 kg/ha	> 8 t/ha	Nod^{+} fix^{+} NUE	> 5 years	High
Nif gene transfer	> 200 kg/ha	> 8 t/ha	nif^{+} 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.

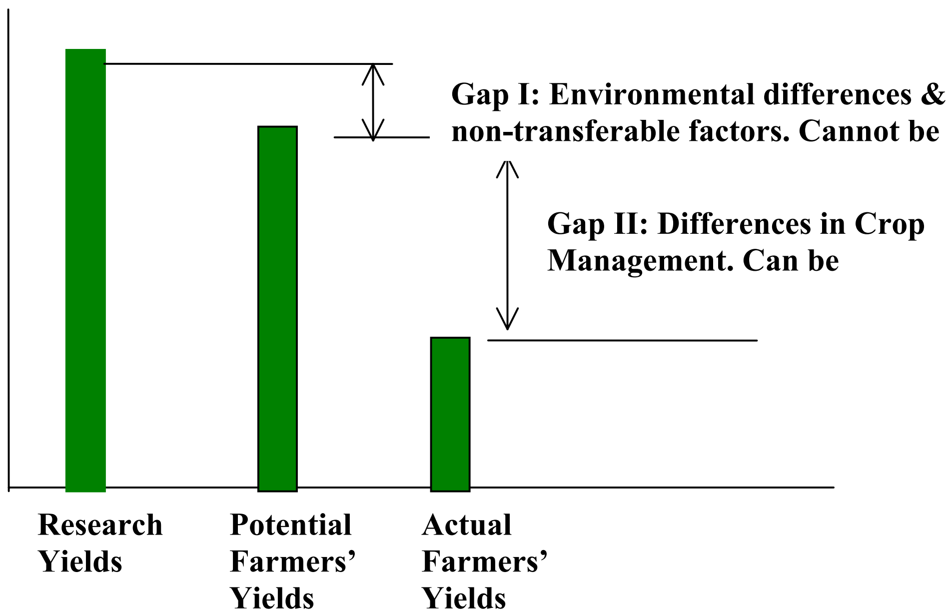

Figure 1. Components of Yield Gaps (Adopted from De Datta, 1981)

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.

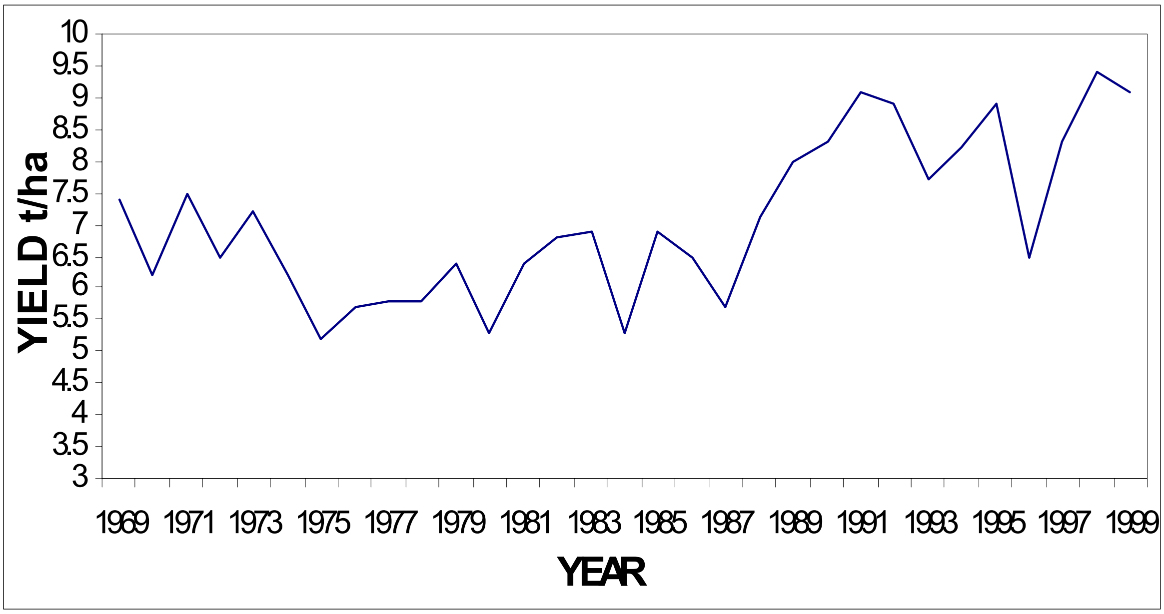

Figure 1. Average NSW rice yields from 1968 to 1999

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.

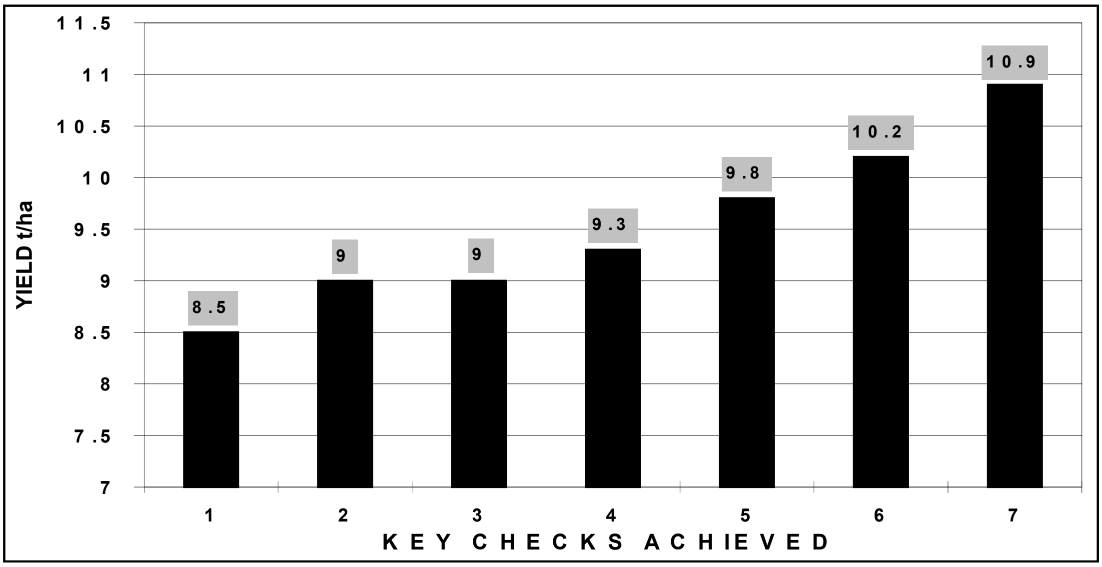

Figure 2. Yield response to checks adopted 1994 - 1999

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.

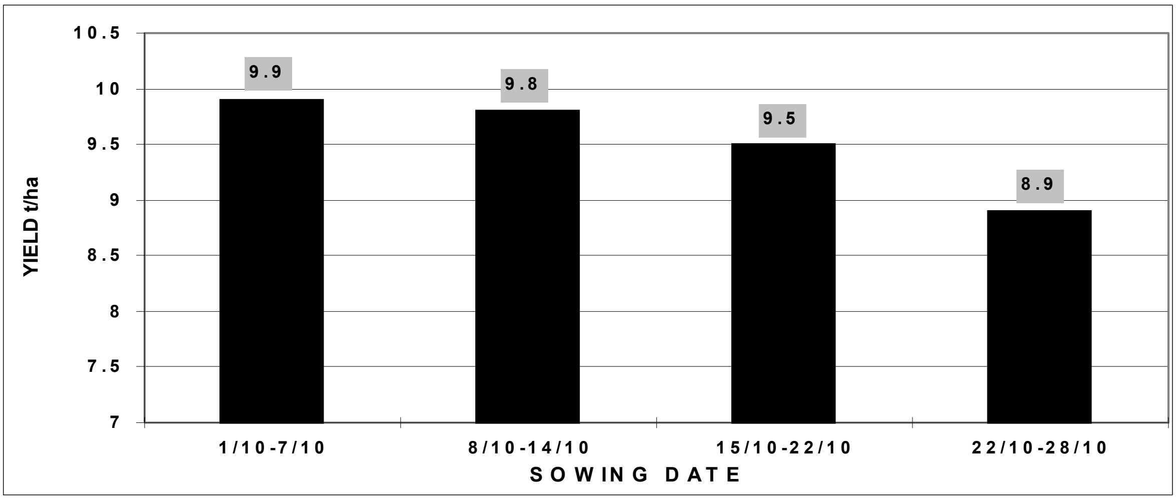

Figure 3. Effect of Sowing Date on Yield for MIA/CIA 1994-1999

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.

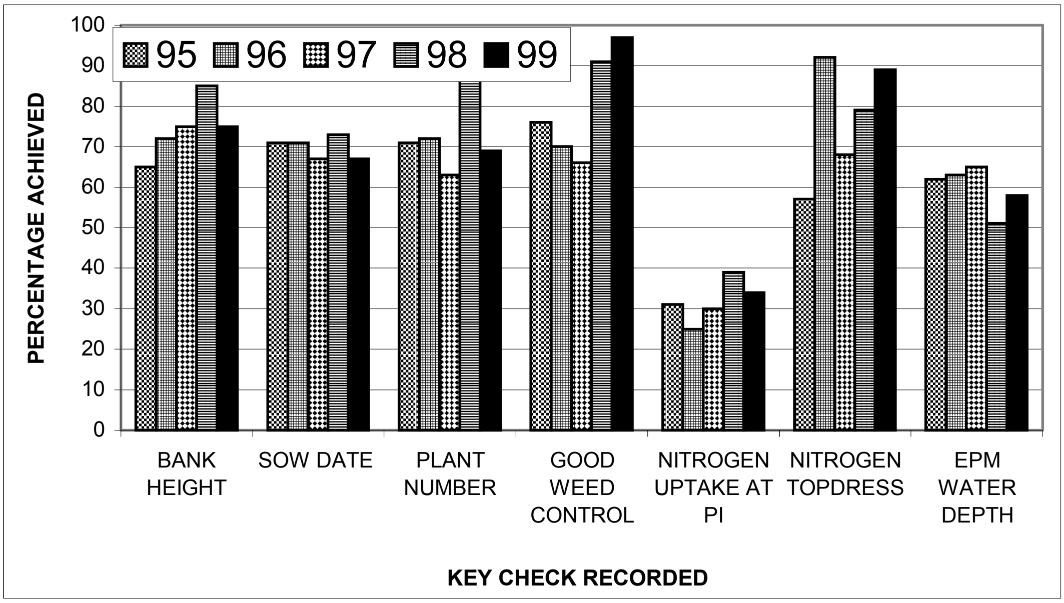

Figure 4. Adoption of key checks 1995-1999

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**	**Fresh weight** 2956 **g/m^2**	Yes	**3677 g/m^2**	**3220 g/m^2**	**43%**
and **1.4 - 2.0 N%**	**NIR** 1.56 **%N**	Yes	**1.67 %N**	**1.92 %N**	**67%**
to give **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**

NSW Agriculture

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

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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 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.

Table 2. Yield Potential of the Popular Rice Varieties Grown in Various Ecosystems (BRRI, 1989, BRRI, 1999).

Ecosystem	Ecotype	Variety	Potential Yield (t/ha)
Irrigated	Boro	BR1	5.50
		BR3	6.9
		BR8	6.0
		BR9	6.0
		BR14	7.9
		BR15	5.5
		BR16	6.0
		BRRI DHAN 28	7.5
		BRRI DHAN 29	9.1
		Purbachi	5.5
Rainfed Lowland	T. Aus	Purbachi	3.5
		BR1	4.0
		BR3	4.0
		BR14	5.0
	T. Aman	BR11	6.5
		BR22	5.0
		BR23	5.5
		BRRI DHAN 32	5.0
Rainfed Upland	B. Aus	Local varieties	2.1-2.8
Deepwater	Deepwater rice	Local varieties	2.8-3.2

2.4 Yield Gap in Different Ecosystems

Although rice varieties with yield potential of about 8.6 t/ha of rough rice under most favourable environment are available, the researchers have been able to achieve, on an average, only 6.5 t/ha in the Boro, 6.0 t/ha in the Aman, and 4.0 t/ha in the Aus seasons (Figure 1). Such yield gaps are attributed mostly to the annual variations in weather conditions and ability of the variety to withstand a certain amount of pests and diseases pressure which varies from season to season and also from year to year. Surveys conducted in eight northern districts on farmer's perception of rice yield and the associated management practices indicate that under real farming conditions this gap is much more wider. The yield gap between experiment stations and the farmers' fields varies from 1.02 to 2.53 t/ha in Boro with an average of 1.63 t/ha, 1.56 to 3.39 t/ha with an average of 2.32 t/ha in Aman, and from 1.24 to 2.62 t/ha in Aus with an average of 1.69 t/ha (Table 3). Physical and socio-economic factors responsible for this large yield gap are a) low levels of management, b) lack of price stability, c) loss of farmers' interest in investment due to unbalanced land tenure system, and d) other socio-economic factors.

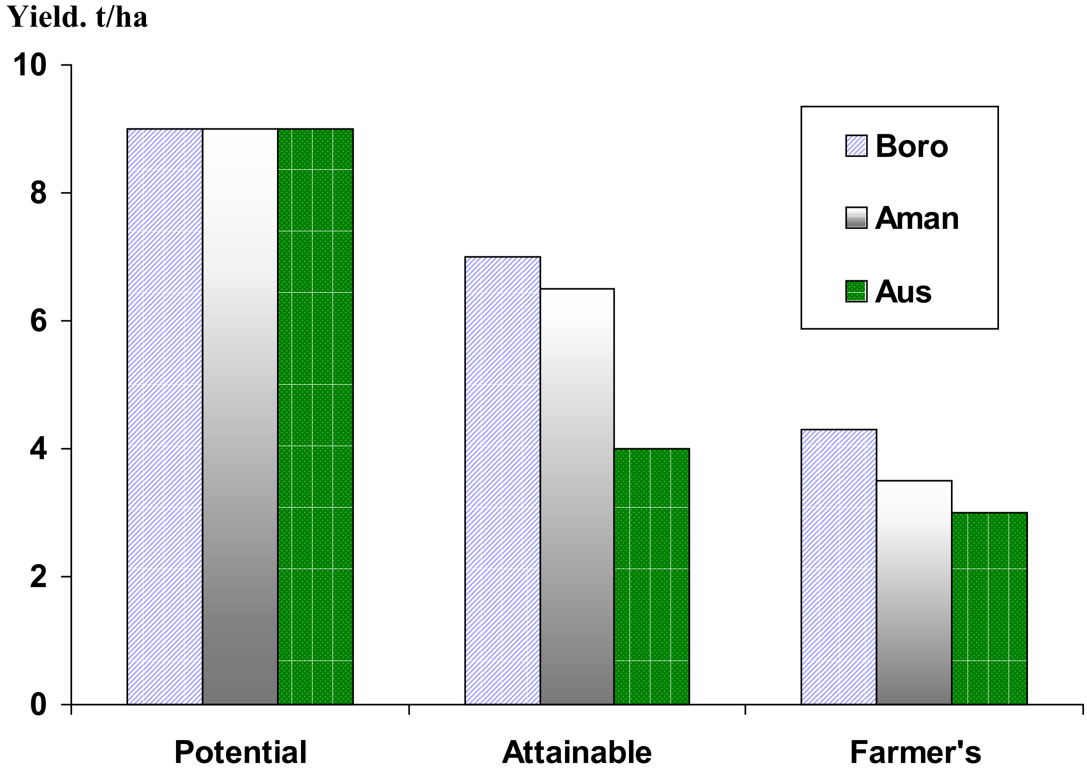

Fig 1. Yield Gap in Different Ecotypes.

Table 3. Rough Rice Yield (t/ha) achieved in experiment stations and national average yield by seasons

Season & Variety	Location	Experiment Station	National Average	Yield Gap
Boro BR3	Joydebpur	5.92	4.35	1.57
	Comilla	5.62		1.26
	Habiganj	5.98		1.63
	Barisal	6.10		1.75
	Rajshahi	5.37		1.02
	Rangpur	6.88		2.53
Aman BR11	Joydebpur	6.60	3.21	3.39
	Comilla	5.43		2.22
	Barisal	5.38		2.17
	Rajshahi	4.77		1.56
	Rangpur	5.47		2.26
Aus BR14	Joydebpur	4.2	2.66	1.54
	Comilla	3.9		1.24
	Barisal	4.0		1.34
	Rajshahi	5.28		2.62

Management factors that pull down farm level rice yields are wrong time of planting, use of poor quality seed, unbalanced use of fertilizers and other inputs, failure to control weeds during the critical competition period, and ineffective control of pests and diseases. Soil related factors associated with low farm level rice yield are highly reduced organic matter content, particularly in the north and north-western zone of the country (Table 4), and widespread occurrence of sulphur and zinc deficiencies. Among the other physical factors that often affect rice yield are unfavourable temperature, flood and drought.

Table 4. Soil Organic Matter Content (%) in some Rice Soils.

District	No. of Samples	Range	Mean
Barisal	86	0.91-2.95	1.82
Chandpur	1		1.70
Chittagong	53	0.77-3.15	1.82
Comilla	2	1.40-1.70	1.54
Faridpur	36	0.86-3.12	1.80
Feni	3	1.47-2.28	1.90
Gazipur	40	0.64-2.61	1.66
Habiganj	3	3.86-4.04	3.96
Jamalpur	5	1.52-2.13	1.81
Jessore	1		2.10
Jhenaidah	1		2.30
Khulna	43	1.17-5.03	2.08
Kishorganj	2	1.80-2.00	1.90
Kushtia	29	0.87-2.99	1.84
Mymensingh	1		2.00
Naogaon	42	1.01-2.26	1.86
Pabna	1		2.30
Rajshahi	1		2.10
Tangail	10	1.11-3.11	1.94

To meet the food requirement for the growing population, Bangladesh agriculture has been subjected to the highest cropping intensity of about 180 percent. Farmers often cannot follow the appropriate cropping scheme due to the shortage of draft power, unavailability of labour due to sudden high demand during the peak period when farm activities overlap across the seasons. Thus planting of rice becomes late resulting in reduction of yield at the rate of 60.0, 55.4 and 9.6 kg/ha for each day delay during Boro, Aus and Aman seasons, respectively. Contribution of other production factors depends on seasons and ecosystems. Fertilizer largely contributes to rice yield in all the ecosystems followed by weed control. Contribution of insect control varies with the level of infestations. In most of our studies it remained below the economic threshold level for which a negative contribution was found in some cases (Table 5). Moreover, rice yield decline due to over-mining of soil nutrients, organic matter depletion, floods and droughts, and the use of poor quality seed has not been critically analyzed so far. Therefore, an in-depth assessment of the effect of these factors on rice yield has yet to be understood clearly.

Table 5. Relative Contribution of Production Factors to Rice Yield by Ecosystem

Production Factor	Upland Aus	Transplant Aus	Transplant Aman	Boro
Fertilizer	0.42	0.52	0.77	0.52
Weed Control	0.27	0.53	0.46	0.44
Insect Control	0.05	-0.05	-0.23	0.04

Although the farm level rice yield remains below the attainable yield because of the factors discussed above, their influence is often overshadowed by the most important socio-economic factors that often remain latent. Systematic field monitoring is very much needed to assess the actual productivity that is affected by the socio-economic factors. Such studies were very rare in the past and thus more long-term studies of this nature are essential involving various ecosystems, farm sizes, and both availability and use of credit.

3. PROGRAMMES FOR NARROWING THE YIELD GAP

3.1 Historical Perspective

With the introduction of modern varieties of rice in the country during the early seventies, rice production increased to a great extent but not up to the expectation of the rice scientists. Causes for this low production were not known until 1975-76. Response of rice to fertilization, particularly to nitrogen fertilizers, was studied during the early days of BRRI. Results show that in most cases a very poor agronomic efficiency of nitrogen fertilizer was attained that ranged from as low or slightly over 6 to 28 kg grain per kg of applied nitrogen. BRRI scientists identified for the first time the factor responsible for such low response during the mid-seventies as being the deficiency of sulphur and zinc in many soils of Bangladesh. However, inherent sulphur and zinc deficiency was not widespread in many places, but an induced deficiency was found as a result of stagnation of water. Correction of these deficiencies narrowed down the poor agronomic efficiency further because of increased rice yield in the plots without nitrogen fertilizer.

3.2 Narrowing the Yield Gap

In order to meet the food shortage, there are no other options than bridging the rice yield gap in the country on the one hand, and breaking the yield ceiling of the existing modern varieties on the other hand. The existing modern varieties of rice have come to a stage of stagnation. Attempts are being made to break the present rice yield ceiling by developing and introducing a hybrid rice programme in the country and it will take some time to achieve a practical solution to this problem. Considering the complicated maneuvers and difficulty in launching a hybrid rice programme in a country like Bangladesh where most farmers lack formal education and financial resources, the immediate practical solution to the problem of food shortage would be to narrow the rice yield gap between the attainable and farmer's rice yields. This gigantic task involves, apart from the present technological know-how, solving several physical and socio-economic constraints. The present activities for narrowing the rice yield gap in the national research institutions include:

- Development of shorter duration rice varieties with high yield potential so as to fit into the farmer's cropping pattern. This will help farmers to free the land for the next crop in time and thus a balanced cropping scheme will be possible.

- To sustain soil productivity a programme of introducing integrated use of organic and inorganic fertilizers has been gaining momentum.

- Attempts are being made to strengthen the present linkage between research and extension in order to accelerate dissemination of available technologies among the farmers.

3.3 Issues and Challenges to Narrow Rice Yield Gap

In the recent past Bangladesh had to import cereal food grain to meet the food shortage. Since the early 1980's the volume of such imports tremendously reduced due to the use of high yielding modern varieties of rice, as a result of which the country achieved near self-sufficiency in cereal food grain production. In spite of this, an annual shortage of about 1.5 million tonnes of cereals (Hossain & Shahabuddin, 1999) is reported due to the increase of population at 1.8 percent per annum. With this rate of population growth, the country's total rice requirement will be 35.5 million tonnes to feed 173 million people by 2020 (BARC, 1994). Since there is no scope for horizontal expansion of the rice area, it is the greatest challenge to the policy makers, administrators and rice scientists of the country to produce more food from the limited land available. In order to face this challenge the following issues have to be considered both on short and long-term basis.

- The present available rice production technologies are enough to mitigate the present 1.5 million tonnes cereal food grain shortage. This necessitates a strong agricultural extension programme for dissemination of all these production technologies among the farmers. For example, if we are to mitigate this food shortage from a single rice crop like T. Aman, then we have to increase rice yield by only 0.3 t/ha (1.5 million tonnes/5 million ha = 0.3 t/ha clean rice or 0.46 t/ha rough rice). This can easily be done by increasing the present level of modern variety (MV) adoption from 51 to 55 percent, providing supplemental irrigation, using balanced fertilizers and adopting better plant production measures.

- Farm level irrigation infrastructures are developed during the Boro season which are usually dismantled after the season. These infrastructures should be maintained so as to provide supplemental irrigation in the following T. Aman rice crop, which covers about 47 percent of the total rice area. Although T. Aman is grown rainfed, often it suffers from drought during flowering stage, thereby lowering yield to a great extent. Therefore, the Government should have a policy to support a permanent irrigation infrastructure instead of a temporary one developed mostly by the farmers.

- A strong extension programme should be launched to popularize “Mini watershed” technology developed by BRRI for providing supplemental irrigation to the T. Aman crop during its flowering stage. These mini watersheds can also be used for shelter for fish in a system of rice-fish culture.

- Policy issues relating to production, import and distribution of fertilizer should be reviewed and positive steps be taken to encourage use of balanced fertilizer by the farmers.

4. CONCLUSIONS AND RECOMMENDATIONS

Of the 13.7 million ha of arable land, rice is grown on 10.27 million ha (75 percent) producing 94 percent of total food grain requirement. This is not enough to feed the nation and 1.5 million tonnes annual shortage of food grain exists. To attain full self-sufficiency in food grain production, the rice yield has to be increased without delay by making use of the available technologies. Further work is needed to sustain this productivity by generating new technologies. One way of increasing rice production is to narrow the gap between research stations and actual farm yields. In order to fulfill this challenging job, an integrated effort of researchers, extension workers, administrators and planners is needed to solve issues like: a) government's continued support for rice research to develop further appropriate improved technologies; b) faster dissemination of available technologies to farmers; c) government's support for the development of permanent irrigation infrastructures for providing supplemental irrigation, particularly for the T. Aman crop.

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BRIDGING THE RICE YIELD GAP IN CHINA

Zhu Defeng*

1. INTRODUCTION

Rice is the main staple food in China. About 60 percent of the population live on rice. Over the recent decade, rice has accounted for less than 30 percent of the grain area, but has contributed more than 40 percent of grain production with the highest yield in all grain crops and nearly 40 percent of calorie intake. Rice in China is an important component of rice in the world. Since 1980, the rice planting area in China has accounted for 23 percent of the world's rice area, and contributed 37 percent of the world's rice production. Therefore, rice production in China plays an important role for the Chinese people and also affects the world rice market.

Table 1 Rice Ecological Zone in China (Min. 1989)

Rice Ecological Zone	Proportion of Rice Area (%)	Proportion of Rice Production (%)	Accumulated Annual Temperature (>10^{o}C)	Precipitation (mm)	Cropping System
1. South China, double rice cropping region	17.7	15.7	5800-9300	1200-2500	Three maturing, 73.5 % of double rice.
2. Central China, double and single rice cropping region	68.1	69.9	4500-6500	800-2000	Two or three maturing, 40% of double rice and 60% of single rice.
3. Southwestern plateau region of single and double rice cropping	7.8	7.6	2900-3000	800-1400	Two maturing, 93% of single rice and 7% of double rice.
4. North China, single rice cropping region	3.3	3.4	4000-5000	580-1000	One or two maturing, single rice.
5. Northeast China, early maturing and single rice cropping region	2.6	2.9	2000-3700	350-1100	One maturing, single rice
6. Northwest China, single rice cropping region in dry areas	0.5	0.5	2000-4250	50-600	One maturing, single rice

Since much of China lies within the East Asia Monsoon zone, natural conditions such as sunshine, temperature and moisture suit the cultivation of rice. Wherever rainfall is abundant or irrigation facilities are available, there is rice production. It extends from 18^o to 53^o north latitudes. The main rice growing areas, with more than 90 percent of the total rice area and production, are south of the Qinling Mountains and the Huai River. Rice

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production areas in China are classified into six ecological zones according to natural environmental factors such as rainfall, temperature and cropping system (Table 1).

2. STATUS OF RICE CULTIVATION IN DIFFERENT ECO-SYSTEMS

2.1 Area, Production and Yield Trends in Different Ecologies

Over recent decades, the rice planting area has varied within a relatively small range. In comparison with the 1949 rice area, the rice cultivated area in 1976, which was the largest, only increased by 4.1 percent. However, yield and production of rice in China varied over a larger range. Highest yield in 1997 increased by 234 percent over the yield in 1949. Production in 1997 increased by 313 percent over 1949 (Figure 1).

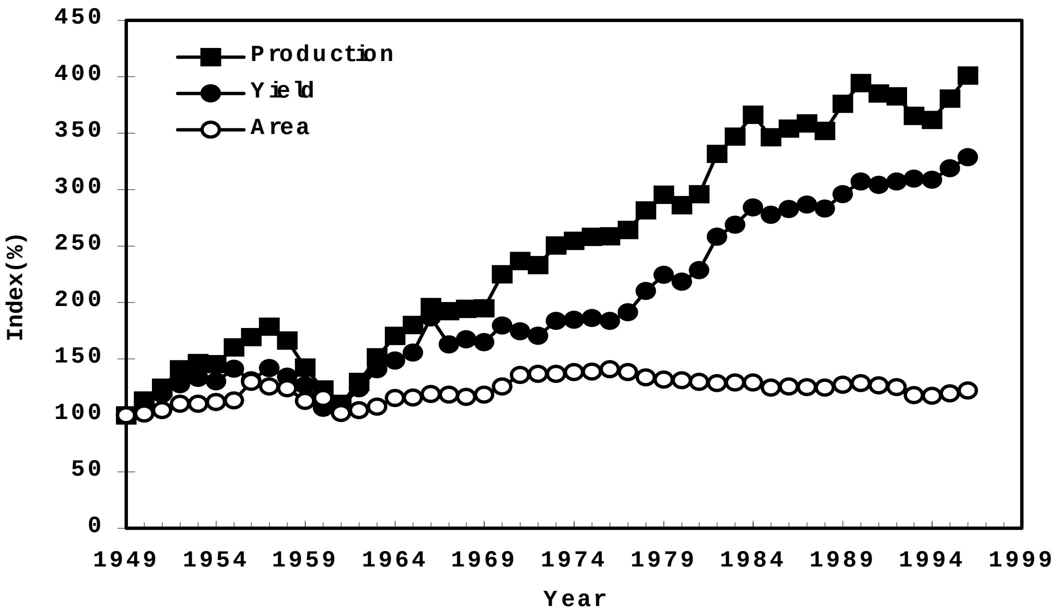

Figure 1. Change in Rice Planting Area, Yield and Production in China (Ministry of Agriculture, 1949-1998)

In this period, rice production is related to yield (Figure 1 and Table 2). However, the rice area has been decreasing from the 1970's. Average annual increase rate of rice yield and production decreased from the 1960's to 1990's (Table 2) due to environmental, technical and socio-economic constraints. This indicates there is difficulty in raising yield and production over the level of high yield obtained at present.

Table 2. Rice Area, Yield and Production and Average Annual Increase Rate of Yield and Production during the Period of 1960's-1990's.

Year	Area kg/ha	Yield kg/ha	Production kg/t	Average Annual Increase Rate of Yield (%)	Average Annual Increase Rate of Production (%)
60's	29125.4	2769	79920	3.3	3.7
70's	34865.0	3571	124437	3.3	4.4
80's	32763.8	5073	166103	2.9	2.6
90's	31523.5	5949	187503	1.5	1.2

Among the contributions of the increase of area and yield to production, 60-85 percent of the increase of production is due to the increase in yield (Zhu, 1997). With the decrease in rice producing area, which resulted from the basic construction and the adjustment of agricultural production infrastructure, and limited area for expansion, increase of yield has assumed the important role in maintaining and raising rice production in China.

Variation of area is related to the reform and adjustment of rice cropping systems. In the 1950's, rice cropping systems were reformed into multiple cropping systems, which changed single rice to double rice, intercropped rice to continuous rice and *Indica* to *Japonica* in late rice in the south of China. At the same time, irrigation systems were improved. This made it possible for some upland to be converted to rice lands. These activities stimulated the rice area to expand to 33m ha in 1956 (Zhu, 1982). At the end of the 1950's, the rice area decreased through the adjustment of unsuitable double rice areas. In the 1960's, however, the double rice area developed gradually but in the 1970's, the double rice area expanded rapidly with the popularization of short growth duration varieties. In 1976, the double rice area occupied 71.3 percent of the total national rice planting area. From the end of the 1970's to current times, the double rice area has shrunk and single the rice area has increased, mainly due to economic constraints and the development of diversified cropping systems (Table 3).

Table 3. Yield of Various Rice Monoculture Production and Rice Cropping Systems in China

Year	Percentage of Area to Various Rice Seasons (%)			Yield (t/ha)		
	Early Rice	Single Rice	Late Rice	Early Rice	Single Rice	Late Rice
1964	27	49	24	2.67	3.15	2.27
1978	38	25	37	4.17	4.66	3.24
1985	32	35	33	5.10	5.96	4.65
1990	28	42	30	5.49	6.50	5.18
1995	27	41	33	5.15	6.74	5.87
1997	26	46	28	5.61	7.17	5.58

Popularization of dwarf varieties at the end of the 1950's in farmers' fields and commercial use of hybrid rice at the end of the 1970's resulted in a quantum jump of yield, which is called as the 'two-time breakthrough' in rice yield in the history of rice production, making the greatest contribution to rice production in China.

In China, irrigated rice is the primary rice ecosystem occupying 93 percent of the total rice area and 96.5 percent of total rice production. Rainfed lowland rice and upland rice stand at 5 and 2 percent of total rice area, respectively and 2.6 and 0.9 percent of total production due to low yields (Table 4).

Upland rice is mainly scattered in the mountain regions, such as Yunnan, Guizhou, Guangxi, Jiangxi, etc. Rainfed lowland rice is mainly distributed in the water limited areas, such as Hebei, Henan, Shangdong, Shaaxi, Liaoning, Jinlin, Heilongjiang, etc.

Yunnan is one of the main areas where upland rice is planted. In the recent decade the upland rice area in Yunnan province is static due to the limitation of low yield (Table 5).

Table 4. Rice Area, Yield and Production by Ecosystem in 1991

Ecosystem	Area ha	Yield kg/ha	Production kg/ha
Irrigated rice	30783	5.9	180830
Rainfed lowland rice	1655	3.0	4965
Upland rice	662	2.5	1655
Flood-prone rice	0	0	0
Total	33100	5.7	187450

Table 5. Area and Yield of Upland Rice in Yunnan Province (Jiang, 1994)

Year	Area kg/ha	Yield t/ha
1953	37.2	0.80
1963	82.5	1.44
1982	165.9	1.81
1983	180.2	1.81

2.2 Production Constraints in Different Ecologies

Lin (1996) analyzed yield gap between actual farmer yield and potential farmer yield under favourable conditions based on the information obtained from the prefectural agricultural bureau survey. In analyzing factors contributing to yield difference, varieties are taken as indicators. Yield difference can be explained by socio-economic and technical constraints. In the analysis technical constraints were classified into four categories: adverse soils, adverse weather, pests and others. Percentage of contribution of constraints to yield difference from survey data is summarized in Table 6.

Table 6. Percentage of Contributions of Constraints to Yield Difference (%)

	Early Rice	Late Rice	Single Rice
Yield difference	100.0	100.0	100.0
Technical constraints	44.9	40.7	43.1
Soils	22.7	20.0	18.7
Pests	4.2	3.4	5.3
Weather	15.7	15.0	16.4
Other	2.3	2.3	2.7
Unexplained	55.1	59.3	56.9

Average losses in the nation as a whole attributed to those identified constraints are 44.9 percent of yield difference for early rice, 40.7 percent for late rice and 43.1 percent for single rice. The balance of yield difference is caused by factors not listed, such as seed impurity, seed regression, bad management, poor extension services, etc.

Among yield losses, the soil-related, weather-related, and pest constraints can be subdivided into more detailed factors.

Table 7 lists the estimated percentages of yield losses at the national level from 20 major individual technical constraints. For early rice, adverse soil, adverse weather and pests contributed 48.8, 28.8 and 8.4 percent, respectively; for late rice, adverse soil, adverse weather and pests contributed 47.4, 32.3 and 6.5 percent, respectively; and for single rice, adverse soil, adverse weather and pests contributed 40.7, 34.5 and 8.5 percent, respectively.

From Table 7, it is evident that the more important technical constraints are deficiencies in nitrogen, phosphorus, potassium, soil organic matter content and trace elements. This reflects that in the long history of intensive cropping of rice, soil fertility has been depleted and cannot be recovered by natural processes. The highly fertilizer responsive varieties give high yield by increasing the fertilizer application, but the efficiency of the increase of yield by the application of fertilizer in farmers' fields decreased.

The second most important factor of yield losses is related to weather, including drought, submergence, cold and heat. Lodging caused by wind and storm is also important. Among the various pests, sheath blight, weeds, striped stem borer and blast are listed.

Table 7. The Top 20 Constraints at the National Level and Percentage of Yield Losses Contributed by them

Early Rice	Yield Loss (%)	Late Rice	Yield Loss (%)	Single Rice	Yield Loss (%)
Potassium deficiency	12.6	Potassium deficiency	14.9	Organic matter deficiency	7.5
Phosphorus deficiency	7.8	Cold at flowering period	8.3	Cold waterlogged soil	7.2
Nitrogen deficiency	6.3	Nitrogen deficiency	7.1	Nitrogen deficiency	7.1
Cold waterlogged soil	6.0	Drought at flowering period	6.8	Phosphorus deficiency	6.8
Organic matter deficiency	5.9	Phosphorus deficiency	6.4	Potassium deficiency	6.5
Cold at seedling period	5.5	Organic matter deficiency	6.2	Flood	6.2
Flood	4.3	Drought at vegetative period	5.1	Drought at flowering period	5.6
Acidity	4.1	Cold waterlogged soil	4.5	Drought at vegetative period	4.8
Trace elements deficiency	3.6	Flood	4.4	Trace elements deficiency	3.7
Drought at flowering period	3.3	Acidity	3.5	Cold at flowering period	3.5
Sheath blight	3.2	Trace elements deficiency	3.5	Submergence at flowering period	2.9
Heat at flowering period	3.1	Sheath blight	2.2	Rain at harvest	2.7
Lodging from wind and storm	3.0	Weeds	1.8	Drought at seedling period	2.7
Submergence at flowering period	2.8	Lodging from wind and storm	2.4	Sheath blight	2.7
Drought at vegetative period	2.7	Submergence at vegetative period	1.5	Weeds	2.6
Swamp soil	2.5	Swamp soil	1.4	Cold at seedling period	2.1
Cold at vegetative period	2.2	Submergence at seedling period	1.3	Acidity	1.9
Rain at harvest	2.0	Submergence at flowering period	1.3	Rats	1.7
Rice blast	1.6	Drought at seedling period	1.2	Striped stemborer	1.6
Weeds	1.6	Rats	1.2	Lodging from wind and storm	1.5
Other	16.0	Other	15.0	Other	18.9
Total	100.0		100.0		100.0

Rainfed lowland and upland rice

Few research institutes are involved in upland and rainfed lowland rice research. Most varieties used in those rice ecosystems are improved varieties and varieties introduced from other countries. Yield of upland and rainfed rice varies with the available water. Therefore water is a main constraint to yield. New varieties with high yield, resistance to disease, especially blast, to drought and good quality are needed.

Most upland rice fields are located in the hilly and mountain areas. Low soil fertility influences the growth and yield. Serious soil erosion makes the soils poor for rice.

Blast is one of the main diseases. Due to the low water level in rice fields, weed control is a problem.

2.2.2 Irrigated rice

Low economic efficiency and transfer of labour

Low profit from rice production affects the enthusiasm of farmers engaged in rice production. Labour cost occupies about 50 percent of cost of production. Due to the high input of labour for transplanting rice, farmers are willing to select a planting method that uses less labour, such as seedling broadcasting and direct rice seeding (Table 8).

Table 8. Cost and profit of different planting methods in rice production in Zhejiang,1995

Season	Planting method	Cost Yuan/ha	Output Yuan/ha	Profit Yuan/ha
Early rice	Transplanting by hand	5475	9225	3750
	Seedling broadcasting	4410	9825	5415
	Direct seeded	4605	10095	5490
Late rice	Transplanting by hand	5675	11304	5630
	Seedling broadcasting	5067	12296	7229

Rural labour has been transferred from agriculture to rural industry, construction and urban activities. Input of labour to rice growing has decreased gradually over the recent decade. The share of rural labour engaged in agriculture decreased from 91.6 percent in 1980 to 70.6 percent in 1997. In some regions, women carry out most of the work in rice production.

Insufficient investment

The Chinese government has made great efforts to increase investment in agriculture. However, it is still far from the actual demand. Low yielding fields that comprise about 25 percent of the total are difficult to improve due to the limited investment.

Due to low profit in rice production, farmers in some regions are unwilling to invest in rice production.

Small-scale farmer structure

The agriculture sector in China has small-scale farms with an average farm size of 0.5-1.0 ha. In the south, where more than 90 percent of rice is produced, farm sizes are smaller. In Zhejiang province where rice area and production occupy 85 percent and 92 percent of provincial grain area and production, there were only 60 thousand farms that averaged more than 0.67 ha of land in 1995. Those farms only account for 6.1 percent of the provincial arable area. The study indicates that when the size of farm is lower than 2 ha, with the increase in farm size, production costs decrease and profits tend to increase.

Climate

Due to heavy population pressure land unsuitable for cropping has been exploited for grain production in many areas. This damages the ecological equilibrium. Floods often occur with uneven distribution of rainfall in the main rice producing areas which cause serious yield losses. In the coastal area typhoons cause lodging of rice, which also result in yield losses. In the ripening period of early rice in the south, continuous rain results in the germination of seed on the panicles in the field which affects yield and quality.

In the south, low temperature at the seedling stage causes the death of seedlings and reduction in spikelet fertility during the flowering period.

In regions with poor irrigation systems drought affects rice growth. If drought occurs at the time of panicle initiation, damage to yield is serious.

Soil

Deficiency in nitrogen, potassium, phosphorus, trace elements and organic matter can be found in rice fields. In recent decades less manure has been used in rice production. Heavy chemical fertilizer application was used in most areas in the main rice producing regions. This has affected negatively the soil structure and fertility, and resulted in rice yield decline in some locations, especially in areas with continuous rice cropping systems.

In low yielding fields, low temperature in soil water, waterlogged soils, acid soils, saline and alkaline soils are critical problems.

Pests

Sheath blight, blast and leaf blight are major diseases. Stem borer, plant hopper and striped stemborer are economically important insects in rice production.

Weeds still reduce yield due to poor weed control and misuse of herbicides.

2.3 Yield potential of released varieties/hybrids in different ecologies

Many varieties and hybrids with high yield, good quality and resistance to diseases and insects are released at the national, provincial and district level. Some of the varieties can be popularized on a large scale and some will disappear at the farmer level due to problems of yield, quality, resistance to pests and adaptation to cropping systems. Rice varieties and hybrids released at the national level in 1998 are listed in Table 9. Most of varieties give more than 5 percent of yield increase over the local check. On an average, new varieties give yield increases in excess of 7.1 percent.

In the southern region testing programme of new bred varieties, some elite varieties and hybrids give yield increases of 3.4 to 21.3 percent over local checks.

Table 9. Rice Varieties and Hybrids Released for Irrigated Ecosystems by the Ministry of Agriculture in 1998

Variety	Type	Yield kg/ha	Percentage of Increase in Yield Over Local Check (%)
Zhongyouzao 5	Early *indica*	5830-6176	5.6
Yujing 6	*Japonica*	9482	13.6
Zhongzuo 93	*Japonica*	6630-7475	3.2
Liaongyan 283	*Japonica*		
Shanyou 77	*Indica* hybrid	7559	8.0
Zhongzao 1	Early *indica*	600-6750	
Zhongsi 2	Early *indica*	5700	7.3
Kyou 402	*Indica* hybrid	7593	10.4
Gongyou 22	*Indica* hybrid	8807	6.3
Shanyouduoxi 1	*Indica* hybrid	8723	3.5
Xieyou 57	*Indica* hybrid	8474	5.8

2.3 Evidence of yield gaps in different ecologies

According to the work done at IRRI and China (IRRI, 1977, De Datta, 1978 and Lin, 1996), the yield gap can been divided into two parts. Yield Gap 1 is the difference between an attainable yield and actual farmer yield that is listed in the statistics. Yield Gap 2 is the difference between an experimental maximum yield that is obtained in the high yielding experiments carried out under the advice and support of rice specialists and scientists (Huang, 1996, Li, 1995, Tan, 1989, Xu, 1994 and Xu, 1996), and an attainable yield under the adaptive trials and good management in farmers' fields. Attainable yield is from an average yield of high yielding varieties in new bred variety tests in the multi-location trials in the different regions. National maximum yield is calculated from farmer yield multiplied by the average increase rate of provincial maximum yield compared to provincial farmer yield in the main rice producing regions. National attainable yield is calculated through farmer yield multiplied by the average increase rate of provincial attainable yield to provincial farmer yield in the main rice producing regions.

The attainable yield is 6,967 kg/ha for early season, 8,653 kg/ha for single season and 7,653 kg/ha for late rice. The maximum yield is 9,830 kg/ha for early season, 11,555 kg/ha for single season and 9,498 kg/ha for late rice. Yield of single season rice is usually higher than early and late rice due to long growth duration and suitable temperature and sunshine (Table 3).

Yield Gap 1 and Yield Gap 2 for nation as a whole is listed in Table 10. Yield Gap 1 is 1,358 kg/ha for early rice, 1,487 kg/ha for single rice, and 2,074 kg/ha for late rice; while Yield Gap 2 is 2,863 kg/ha for early rice, 2,903 kg/ha for single rice, and 1,845 kg/ha for late rice. From the comparison of Yield Gap 1 and Yield Gap 2, the transferable Yield Gap 1 is much larger than non-transferable Yield Gap 2 for early rice and single rice. Yield Gap 1 is caused by technological and sociological constraints. Yield Gap 2 arises from differences in the varieties and production environment, which cannot be easily managed or eliminated.

Table 10. Farmer Yield, Attainable Yield, Maximum Yield (kg/ha) and Yield Gap in Various Seasons

Yield	Early rice	Single rice	Late rice
Farmer yield	5609	7166	5579
Attainable yield	6967	8653	7653
Maximum yield	9830	11555	9498
Yield Gap 1	1358	1487	2074
Yield Gap 2	2863	2903	1845

In the last two decades, rice yield in China increased from 4.25 t/ha in 1979 to 6.32 t/ha in 1997. However, coefficient of variation for yield among provinces decreased from 1979 (Figure 2). This indicates that the yield gap among provinces has shrunk in recent years.

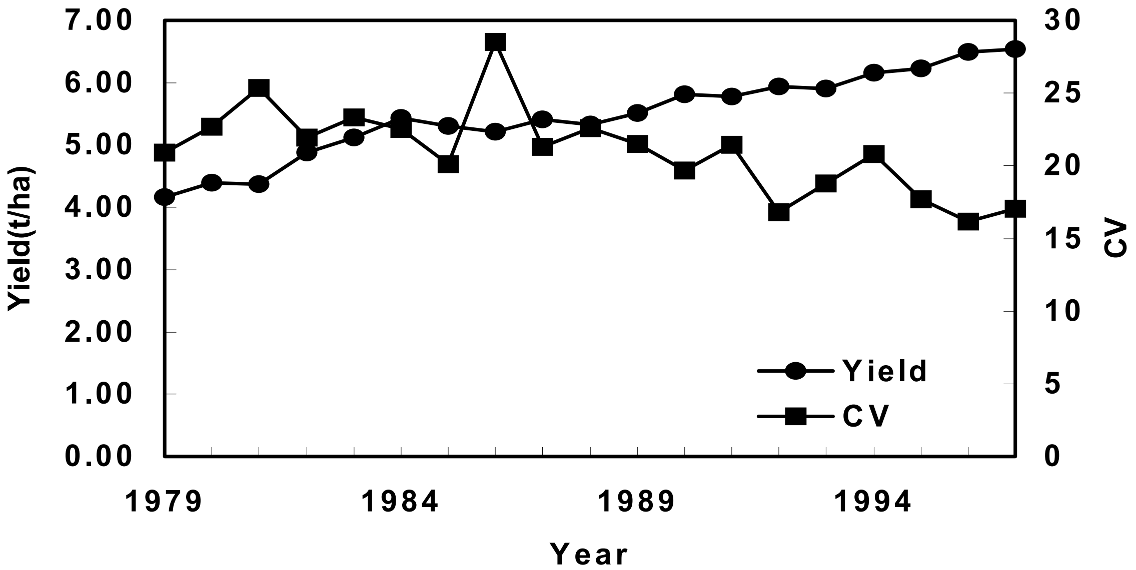

Figure 2. Change of rice average yield and coefficient of variation of yield among province.

3. PROGRAMME FOR NARROWING THE YIELD GAPS

3.1 Historical Perspective

After the People's Republic was founded, land reform was carried out throughout China. By 1956, agricultural cooperatives were set up all over the country, boosting the development of agriculture, including rice production. However, the excessively large scale of the agricultural production units and un-enlightened management affected the development of agricultural production adversely. In 1979 a series of reforms were carried on a system of contracted household responsibility that links remuneration to output based on the collective economy, thus greatly arousing the enthusiasm of farmers. This has greatly contributed to a sharp and sustained increase in rice production since the 1980's.

The state has helped farmers improve conditions for production by investing in capital construction works in farmlands. As a result of decades of work, the national area under effective irrigation has expanded from 18.5 percent of the total cultivated area in 1952 to 45.5 percent, with all rice fields having irrigation facilities. The level of farm mechanization rose sharply during the same period. All these played an important role in guaranteeing a steady increasing yield for rice production.

The development of the chemical industry has increased the application of chemical fertilizers in rice production. The average per hectare application of chemical fertilizer for 1983 was 65.5 kg in terms of pure nutrients.

Efforts have been made to reform cropping systems and raise the multiple cropping index. In expanding the multiple cropping area, much effort was made to popularize rice varieties with different growth duration and introduce a series of relevant management technologies such as close planting and scientific application of fertilizer. Thus, the steady increase of rice yield was assured. At this time, a national network for rice breeding, testing, producing and disseminating semi-dwarf rice varieties was set up. Those varieties have fertilizer- responsive and lodging-resistant characteristics and show high yield potential.

The successful application and popularization of hybrid rice at the end of the 1970's marked another important breakthrough in China's rice production. In 1976 hybrid rice was popularized in rice production in the farmers' fields. Hybrid rice normally yields 15 percent more than inbred. Subsequently, the area sown to hybrid rice expanded rapidly until it occupied 54 percent of the total rice planting area in 1997 (Table 11).

Table 11. Area and Yield of Hybrid in China

Year	Percentage of area sown to hybrid(%)	Yield (t/ha)
1976	0.4	
1978	12.6	
1982	17.0	5.90
1986	27.9	6.60
1990	41.2	6.68
1997	54.5	7.03

3.2 Activities and results of programmes to narrow yield gaps during the last two decades.

- *Poverty relief by deployment of science and technology innovations*

China has set up a programme to organize scientists to help undeveloped regions improve rice production. In undeveloped regions there are one or more factors that limit rice growth, including poor technology of rice cultivation and lack of information. Rice yield is usually substantially lower than in developed regions. Through the programme, high yielding varieties and new technologies on rice cultivation are popularized. Local extension workers and farmers are trained, while the rice yield potential in the area is exploited.

From 1987 to 1989, one group of rice scientists was sent to the rice growing areas of Hunan, Sichuan and Guizhou (Wulin region) to popularize new varieties and cultivation technologies. Through the popularization of new hybrids, improvement in seedling raising, adjustment of transplanting spacing, improvement in fertilizer application, and water management and pest control, the rice yield was increased by more than 30 percent in these areas.

- *Agricultural bumper harvests*

This programme bridges research and production, and stimulates the popularization of research achievements. Since 1986, many grain crop varieties and new technologies, including rice varieties and cultivation technologies have been popularized. At the same time the extension system has been strengthened and farmers have been trained. From 1986 to 1996, the grain increased by more than 30 billion kg through the realization of the programme activities.

- *Basic agricultural construction and integrated agricultural development*

The Chinese government has focused on agricultural infrastructure development and soil conservation. Since the 1950's, irrigation and drainage systems in rice production areas have been improved. That makes possible the expansion of the rice area and the realization of a stable and high yield in areas under various environments. In recent years, high yielding rice producing areas have been developed which transformed some mediocre yielding rice fields into more productive farms.

- *Agricultural jump*

The 1998 plan on agricultural jump aims to integrate the suitable varieties and technology in rice production, and to formulate and popularize the package technology. The programme will accelerate the popularization of new varieties and new technology on rice production.

- *Scientific research programme*

A series of varieties and hybrids were bred in support of this programme. New bred varieties and hybrids gave higher yield potential. At the same time, a package of cultivation practices for new varieties and hybrids made it possible to achieve the yield potential of these varieties and hybrids at farm level.

3.3 Issues and Challenges in Narrowing the Rice Yield Gap in the Country

- *Soil problems in the low and medium yielding area*

There are several soil problems in the low yielding and medium yielding areas. In comparison with high yielding fields, fertility is slightly low in the medium yielding fields. Rice yield in these farms can be raised through the application of improved technologies such as selection of a suitable variety, a rational cropping system, and improved management and the increase of inputs. However, in the low yielding fields, some soil problems such as waterlogging, drought, cold water, acidity and low fertility, etc. need improvement. In such fields, rice yields can be raised through the improvement of soil structure and irrigation and drainage systems in combination with cultivation technologies.

- *Farmer interest and technology*

Low efficiency in rice production affects farmer's enthusiasm towards rice production. Transfer of rural labour has increased from agriculture to rural industry and cities in recent years. Due to low input of labour in rice production, management of rice fields is poor and consequently results in poor yields. The new generation of rice farmers lack the necessary technology for rice production. Training on rice production is therefore necessary for the new generation of farmers.

- *Direction of scientific research*

In recent years most of the funds for scientific research on rice flows to biotechnology. Less funds to support research on agronomy affects adversely the role of agronomy in rice production. Research on agronomy has lagged behind farmers' needs. Some practical problems in rice production that concern farmers need to be solved through agronomic research.

- *Environmental protection*

In recent years, heavy use of chemical fertilizers and pesticides in rice fields is polluting the environment in the field and water systems. Remaining herbicide in rice fields restrains rice growth and emergence of tillers in the early stage. Heavy use of chemical fertilizer destroys soil structure. Efficiency of the increase of yield through nitrogen application decreases in rice production and endangers the environment through leaching and volatilization.

4. CONCLUSIONS AND RECOMMENDATIONS

The average annual growth rate of rice production from 1961 to 1997 was 3.5 percent. Rice planting area decreased from 1976. Increase of rice production is related to yield increase. The main source of increase in rice production has been yield increase, which was made possible through use of modern varieties, cultivation technologies and use of more inputs.

Irrigated rice is the main type of rice ecosystem, accounting for 93 percent of the rice area and 95.5 percent of rice production. There are a few areas of rainfed rice in the limited water environments and upland rice in the mountain and hilly areas.

Low profit from rice production, which is partly caused by the small-scale farms, affects the enthusiasm of farmers who engage in rice production. Deficiency in nitrogen, phosphorus, potassium, trace elements and organic matter content in the soil are the main constraints. Low and high temperature during the various growth phases, flooding, lodging caused by wind and storm, and drought often threaten rice production. Sheath blight and blast are major diseases contributing to yield loss. Striped stemborer, plant hopper and stemborer are major insect pests.

The yield gap between actual farmer yield and attainable yield is 1,358 kg/ha for early rice, 1,487 kg/ha for single rice and 2,074 kg/ha for late rice. Compared with actual farmer yield, attainable yield increased by 24 percent for early rice, 21 percent for single rice and 37 percent for late rice. New varieties and hybrids released can explain about 7.1 percent of yield difference. The improved cultivation technologies contributed 14 to 30 percent of yield difference between actual farmer yield and attainable yield.

To narrow the yield gap between actual farmer yield and attainable yield it is important that new varieties and hybrids and improved cultivation technologies are popularized in farmers' fields. In the execution of the programme to narrow the yield gap, extension workers and farmers were trained, and information and technologies were transferred to rice growing areas. Scientific research programme will bridge the yield gap between attainable yield and maximum yield through the creation of a new generation of varieties and cultivation technologies.

To further narrow the yield gap between actual farmer yield and attainable yield, low yielding and medium yielding fields should be improved through research, use of suitable technologies and/or on-farm infrastructure improvements. Varieties and cultivation technologies to adapt to various biotic and abiotic stresses should be developed and popularized. Training should be emphasized on extension workers and farmers. International and domestic cooperation needs strengthening to exchange experience and technologies.

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BRIDGING THE RICE YIELD GAP IN INDIA

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1. INTRODUCTION

India is one of the countries that took full advantage of the plant type based high yielding varieties of rice since their introduction in the mid-sixties. Spectacular production growth initially through combined growth of productivity and area and later largely through productivity enabled the country to attain self-sufficiency by the early eighties and sustain the same since then. Also, its impact is seen from 12-15 million tonnes of milled rice in buffer stocks and an exportable surplus of 2-5 million tonnes. Nevertheless, whether the country will be able to sustain this status in the absence of some and shrinking of many of the favourable growth factors of the 70's and 80's, is an issue of concern. Assuming the population to grow annually at around 1.9 percent and income around 5 percent the demand projection for sustaining the present level of calorie supply has been estimated to exceed 158 million tonnes by 2010, which amounts to an annual productivity growth of 2.4 percent. The target is no doubt a challenging task, but it is not unachievable given the potential opportunities and avenues yet to be exploited and rapid advances being made in crop improvement research. Of various strategies being contemplated, consolidation of the genetic yield potential of the currently available high yielding varieties in irrigated and semi-irrigated ecologies, raising the ceiling of yield through hybrid technology and New Plant Type varieties and maximization of yield level in relatively favourable rainfed lowland ecologies in eastern India are the predominant thrusts. Consolidation of yield by correction of yield destabilizing factors is, however, considered as the more promising short-term strategy.

An attempt has been made in this exercise to estimate state-wise/region-wise yield gaps in irrigated, semi–irrigated and shallow water rainfed ecologies, to broadly identify key factors contributing to the gaps, to discuss briefly the various developmental programmes launched during the last two decades at national level, and to suggest remedial measures against manageable constraints for narrowing the yield gap.

2. STATUS OF RICE CULTIVATION

India, the largest rice growing country, plants rice over an area of about 43 million ha and produces around 125 million tonnes of rice with yield level still remaining low at around 2.85 t/ha. Contributing over 43 percent to the nation's food grain production, rice is grown under four different ecologies, with the irrigated ecology accounting for the largest area and highest production and productivity closely followed by rainfed shallow lowlands. Rainfed upland, just one half of the rainfed lowland area, produces less than one fifth of it (Table 1). Region-wise, the predominantly rainfed eastern zone accounts for the largest area and production but with the lowest productivity, while the largely irrigated north and south zones together accounting for slightly less area produce one and a half times more than that of

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eastern India with a distinct yield edge (Table 2). The distribution pattern of rice growing districts based on productivity range reveals that of 414 districts less than 9 percent (36) of them have yield levels exceeding 3 t/ha. They are largely located, as one expects, in the high productivity states of Punjab and Tamil Nadu. Around 23 percent (95) falling in the range of 2 to 3 t/ha are in Andhra Pradesh, Haryana, Karnataka, Western Uttar Pradesh and West Bengal. Over 180 districts (68 percent) with yield levels less than that of the national average are distributed largely in the rainfed eastern and central states viz. Bihar, Madhya Pradesh, Eastern Uttar Pradesh, Orissa, Assam, Maharashtra, Rajasthan and Gujarat (Table 3). Surprisingly, 32 percent of the irrigated area falls under the low productivity category. On the basis of average productivity the rice growing States may be grouped into four viz., (i) >3.0 t/ha (Punjab); (ii) 2.5-3.0 t/ha (Haryana and Tamil Nadu); (iii) 2.0-2.5 t/ha (Andhra Pradesh, Karnataka, Uttar Pradesh, West Bengal, Manipur and Tripura); and (iv) <2.0 t/ha (Assam, Bihar, Madhya Pradesh, Orissa, Kerala, Gujarat, Rajasthan, Jammu and Kashmir, Himachal Pradesh and other North Eastern States). The relationship of productivity with major growth factors reveals that it is strongly associated with percentage of HYVs, level of fertilizer consumption and percentage of irrigated area.

2.1 Area, Production and Productivity Growth

Rice production has increased steadily and continuously during the last 10 years touching an all-time record of 125 million tonnes in 1997-98. With the production area getting stabilized at around 43 million ha, the production advance is largely attributable to increased productivity from 2.2 to 2.85 t/ha. The yield growth during the nineties was at a very high rate of 47 kg/year as against 17kg/year during the 80's. The rapid increase appears to be a result of appreciable increase in area under HYVs (58.4 to 74.0 percent), fertilizer consumption (49 to 77 kg/ha) and replacement of old disease-pest susceptible varieties by new resistant types.

The progress measured in terms of growth trend is, however, not impressive, the annual compound growth of production and productivity being 1.84 and 1.54 as against 3.63 and 3.25 of the eighties (Table 4). Zone-wise analysis of growth suggests an equally disquieting trend with the most productive north zone showing very low production and productivity growth of 2.68 and 1.72 as against 5.31 and 4.20 of the 80's and the south zone showing 0.60 and 0.75 in comparison to 2.32 and 2.88 for the corresponding periods. The only redeeming factor that adds strength to our optimism of achieving the targeted growth in the coming decades is the impressive growth rate of the eastern zone.

Analysis of productivity growth by ecosystem, although it was not possible for all the four distinct ecologies, reveals productivity growth to be far higher for rainfed (2.4 percent) and semi-irrigated rainfed ecologies (2.5 percent) as compared to much lower yield growth (1.1 percent) in the irrigated ecology during 1987-97. Significantly there was no impact of growth in area (0.51 percent) during the corresponding period.

2.2 Varietal Development and Its Potential

In the last three decades the country has developed and released for general cultivation over 570 varieties for different ecologies. Unlike in the past, when varietal improvement was lopsided towards irrigated ecology, the trend has started changing since a decade ago, now placing equal emphasis on rainfed ecologies. Of 136 varieties released between 1990 and 1998, 63 were for the rainfed ecologies. The pattern of varietal improvement reveals change in breeding priorities as well. Whereas medium earliness with yield potential close to medium duration varieties and multiple resistance to pests and diseases have received emphasis in the irrigated ecology, breeding for higher yields and better adaptation to shallow water and upland ecologies has been the thrust in the rainfed ecology (Table 5). Varieties gaining popularity are invariably from the region of their development suggesting that specific adaptability is the key to varietal success in ecologically handicapped regions. Though breeding efforts have been made in all seriousness to cater for saline/alkaline and acid/acid sulphate soils, the progress is not as yet to the desired level.

An encouraging development in the nineties motivated by the success story of China is the thrust given to development of hybrid rice technology. Massive support from ICAR–UNDP/FAO–MRF has enabled the country to successfully evolve and commercialize the technology since 1995. As many as six heterotic hybrids with proven yield advantage of a tonne more per hectare than the locally popular variety are planted today over an area of 100,000 hectares in various parts of the country (Table 6). The pace of adoption of the technology is, however, slow and far from the targeted 0.5 million hectares by the year 2000. Less acceptable grain quality, short duration, and disease/pest susceptibility are some of the important factors that impede its pace of growth.

2.3 Yield Gaps and Major Contributing Factors in Different Ecologies

Potential yield of varieties varies with the ecology as well as the agro-climatic region. Precise knowledge on zone and ecosystem specific potential is a pre-requisite for meaningfully determining the still untapped yield of the currently popular high yielding varieties. Plant type-based dwarf variety exclusively tailored for relatively risk free environment is taken as the standard variety for irrigated ecology and its potential used to be assessed from its average performance in country-wide National Demonstrations. Following the discontinuation of the National Demonstration programme since the last 10 years, there is no option but to rely on test location yield of the All India Coordinated Trials being conducted all over the country in all the major ecologies. Mean yield of the top entry at various locations in the given State over the years was taken in the present study as the experimental station (potential/achievable) yield and the State average yield as the actual/achieved yield. The difference in yield levels expressed in percentage was taken as the yield gap. In respect of rainfed ecologies, in the absence of ideal high yielding varieties, improved varieties now being popularized have been chosen as the standard varieties and their potential assessed from their performance in the compact block Frontline Demonstrations (FLD). Mean FLD yield in a given State over a 3-5 year period was taken as the potential yield and that of the check varieties used in the FLDs and State average yield as actual farmers' yield. Yield difference in percentage between FLD yield and State average yield was taken as the yield gap.

2.3.1 Irrigated ecology

State-wise yield gap analysis reveals vast scope for yield consolidation in all the zones (Tables 7 and 8). In the south zone, except Tamil Nadu where the gap is the least (15.6 percent) all are in the range of 34 (Karnataka) to 49.8 percent (Kerala), while in the north zone, Punjab is the only exception, where 78 percent of the potential has already been realized with others remaining with yield gaps of 50 to 57 percent. In the Western and N.W. Hill Zones the gap is too wide, the range being between 47.0 percent in Maharashtra and

75.6 percent in Rajasthan. The same is true of the predominantly rainfed eastern zone with the sole exception of West Bengal (37 percent), which appears to be due to high State average yield boosted by the impressive productivity growth witnessed in about a million ha of *Boro* rice (Table 8). Comparison of the present analysis with that of the one done 10 years ago reveals hardly any difference in yield gap. But this no-change trend should not mean failure or lack of efforts in the last 10 years to narrow the gap. Rather, the rapid and steady productivity advance made since 1987 appears to have contributed to the persistently wide yield gap warranting much more effort to narrow the gap appreciably.

2.3.2 Rainfed ecologies

The estimation of achievable yield through adoption of currently popularized improved varieties reveals similar wide yield gaps in the major rainfed ecologies as well. In the shallow lowland ecology, for instance, it varies from 34.8 percent in Eastern Uttar Pradesh to 59.5 percent in Assam, while it is less than 30 percent in the semi-deep water ecology possibly because of the fact that the potential yield itself is low (2.5 t/ha) (Tables 9 and 10). In the rainfed upland the gap varied from nearly zero in Bihar to 41.6 percent in Maharashtra (Table 11). The no-gap situation in Bihar does not mean that the gap has already been bridged. Comparison of FLD yield level with that of widely cultivated local varieties would show that large yield differences still exist there. A limited study to determine the untapped potential of salt tolerant varieties raised in salt affected areas in Orissa, Maharashtra and Eastern Uttar Pradesh reveal a bridgeable gap of 40-48 percent (Table 12).

2.4 Constraints Contributing to the Yield Gaps

True to the strategy of converting constraints into opportunities, existence of wide yield gaps found across ecologies and zones should be regarded as potential opportunities for raising the yield level and achieving thereby the future production targets. The success level in such ventures would depend on our precisely determining at micro level (village/block level) technological, developmental and socio-economic constraints and finding remedies to keep pace with steadily growing yield level.

An exercise done to diagnose the key constraints reveals them to vary with ecology, zone and State/district (Appendix 1). In high productivity irrigated southern and northern zones over-mining of nutrients and/or faulty irrigation caused salinity/alkalinity, delayed planting due to uncertainty of canal water release in command areas, imbalanced fertilizer nutrient use, sub-optimal plant population, widespread micronutrient (Zn) deficiency and high incidence of pests and diseases constitute the major constraints. In other zones, low/medium fertilizer use, salinity/alkalinity in pockets, widespread P and Zn deficiency, heavy weed infestation and pest/disease pressure are important. As for the high rainfall semi-irrigated coastal areas, saline/acid/acid sulphate soils, saline water inundation, low adoption of HYVs, low to very low fertilizer use, late planting, and disease/pest pressure are constraints in the southern zone, while salinity and deficiency of P, Ca, S, Zn, lack of ideal varieties, low fertilizer use, and submergence/ moisture stress at times seriously affect productivity in the eastern and western zones.

In the rainfed lowlands of eastern India, acid soils of poor fertility, saline soils deficient in N, P and Zn, lack of ideal HYVs, low to very low fertilizer use, submergence in flood prone areas, early/intermittent dry spells, poor plant stand, disease/pest incidence and ineffective transfer of technology besides widespread poverty constitute the key constraints. Acid soils deficient in N, P, Zn, boron and organic matter content, lack of ideal varieties and slow adoption of improved varieties, inadequate supply of quality seed, very low fertilizer use, poor crop stand, severe weed/wild rice infestation, blast and brown spot diseases, moisture stress and slow transfer of technology are the major constraints in the rainfed uplands. In the northeast hill region prevalence of shifting cultivation, excessive dependence on native varieties, limited use of quality seed, soils with low P and Fe toxicity, very low fertilizer use, severe weed infestation and lack of exposure to improved technology packages are the major constraints.

2.5 Programmes for Narrowing the Yield Gaps

The spectacular advance made in rice production was achieved by tapping only a part of the potential of the plant type based high yielding varieties. An analysis done 15 years ago by the International Rice Research Institute revealed that India then fell under the category of countries, wherein hardly 60 percent of their yield potential had been realized, warranting a serious effort to identify the factors contributing to such a wide yield gap and find appropriate technical and developmental remedies. The exercise was largely confined to the irrigated ecology and broadly identified the pest-weed complex, slow spread of HYVs, relatively low level of fertilizer use, soil problems in general (particularly salinity/alkalinity), and inadequate supply of quality seed to be important among many manageable constraints. Research efforts to find solutions to these constraints resulted over the years in a wide choice of HYVs combining the desired level of resistance to most of the pests and development of an effective integrated pest management strategy and area specific packages of cultivation practices. Development initiatives including massive production and supply of quality seed, timely supply of fertilizer nutrients and pesticides, extensive technology transfer programmes of various kinds, favourable policy support measures etc., were also considered important.

2.6 Development Programmes

Historically, launching of Intensive Agriculture Development Programmes in five districts in 1960 marked the beginning of extension efforts for maximum harvests through modern technology followed by the High Yielding Varieties Programme (HYVP), coinciding with the introduction of HYVs of rice and wheat in 1966. The National Demonstrations launched were accelerated following the unprecedented drought which badly affected crop prospects over 44 million ha spread over 269 districts in 1987. A Task Force was consequently constituted by the Planning Commission to develop a "Framework Action Plan" for achieving the targeted 102 million tonnes of rice (262 million tonnes of food grains) by the 7th Plan period ending in 1989-90. Wide differences observed between State-wise potential (National Demonstration average) and actual farmers' (State average) yields helped the Task Force identify on the basis of micro (village, taluka, block) level constraints analysis - 108 potential districts in 25 States/Union territories - and suggest appropriate technological/developmental interventions needed to maximize the yield level. This proved a starting point for the launch of a series of more rice-focussed development programmes with the goal of narrowing the yield gap through effective transfer of high yield technology, better input supply and management, training and development of infrastructure facilities as detailed below.

2.6.1 Rice "Seed Minikit" programme

For the rapid spread of high yielding varieties availability of quality seed in adequate quantity is vital. The realization that production and supply of quality seed through the normal seed chain would take a long time, prompted the Department of Agriculture during the very first decade of the introduction of HYVs to launch the "Seed Minikit" programme with the objective of reaching farmers fast, with new varieties and promoting their increased seed production at farmers' field level. The strategy consists of making available the seed of a newly released variety to farmers in very small quantities at low cost. The programme enables farmers to see for themselves its superiority over what they are growing while facilitating the increased production of its seed for the benefit of fellow neighbouring farmers. This ingenious device continues to effectively supplement the normal seed channel in meeting the demand for quality seed of new varieties.

2.6.2 Rice production training

Exposure of extension personnel at all levels to the latest varietal and production technologies has paid rich dividends in effectively transferring them since 1975, when a State level training programme on Rice Production Technology was sponsored. The one week to three-month training programmes are organized by the ICAR research institutes and State agricultural universities.

2.6.3 Special thrust programmes

Predominantly rainfed eastern India accounts for over 65 percent of the total rice area. Yet, its share to total production is less than 55 percent largely on account of its long stagnating yield at very low levels. Besides hostile weather-related risks, several manageable technological and socio-economic constraints had been impeding the productivity growth until the launch of the centrally sponsored “Special Rice Production Programme” (SRPP) on the recommendation of the Prime Minister's Economic Advisory Council in 1984-85. The thrust of this programme has been to improve the supply of key inputs viz., quality seed, fertilizer, pesticide, plant protection equipment, farm implements as well as irrigation and drainage facilities to a limited extent. The main focus, however, remains awareness creation among farmers of the existence of higher yielding varieties and location specific packages of production technologies. Encouraged by the impact that the experiment made on productivity, the strategy was extended to nearly all the rice growing States through yet another but much more ambitious "Special Food Grain Production Programme" (SFPP) again with the same objective of achieving 262 million tonnes of food grains by the 7th Plan Period. Unlike the block-oriented SRPP confined to 51 districts in 5 eastern States, the district-oriented SFPP-Rice, covered 106 potential districts in 13 States. The SRPP and SFPP-Rice were integrated subsequently into one unified project viz., "Integrated Programme for Rice Development" (IPRD) which covered all the rice growing districts in the country. The unique feature of this programme is its flexibility enabling the States to choose according to their specific needs from among the input components provided under the IPRD viz., distribution of quality seed, micro nutrients, herbicides, pesticides, plant protection equipment and farm implements including power tillers for small and marginal farmers. Extensive field demonstrations and training programme for farmers and farm labourers are other components of the programmes for effective transfer of crop production technology.

Since 1994-95 the ongoing single commodity-oriented IPRD-Rice has now been restructured into a system-oriented "Integrated Cereals Development Programme" in rice-based cropping system areas (ICPD-Rice). The programme launched with the objective of increasing the overall productivity of cereals under rice-based cropping systems is being implemented today in 1,200 identified blocks spread over 16 States, where rice and rice-based cereal productivity levels are below the State/national average. Specifically, ICPD-Rice aims to enhance the total productivity of major rice, non-rice cereal cropping systems on a sustainable basis giving greater emphasis to large scale on-farm demonstrations of latest varieties/hybrids, farmers' training, promotion of eco-friendly crop production/protection packages like IPM and INM, improvement and sustenance of soil health by use of soil ameliorants, creation of competitiveness among farmers to excel in productivity maximization, promotion of quality seed production for handicapped ecologies, and provision of assistance to State agricultural universities (SAUs) for undertaking contractual research on local problems.

2.6.4 Frontline demonstrations

Lack of high yielding varieties which was attributed as the major factor to low productivity of eastern India is no longer valid, as research efforts of the past two decades have led to the development of a reasonably wide choice of improved varieties adapted to highly diverse and complex growing environments. Strangely, such technologies have hardly been exposed to either farmers or extension personnel in the region, necessitating the Directorate of Rice Research to conceive and launch in 1990 the Frontline Demonstration (FLD) programme jointly with the Department of Agriculture, Ministry of Agriculture, State Agricultural Universities and State Department of Agriculture in the region with the objective of demonstrating to farmers the potential and suitability of these technologies in major rainfed ecologies and sensitizing the extension personnel in the region to these developments. The FLD that made visible impact in the region is unique in several respects viz.:

- The large and contiguous area of 10-20 acres/demonstration with surrounding farmers fields serving as the check closely representing the target area/environment provides an effective window to showcase the best technology and realistic assessment of its potential for adoption.

- The site of the demonstration serves as a "field school" for imparting on-farm training to local farmers on various recommended packages of cultivation, while remaining a center for seed increase and facilitating farmer to farmer dissemination of technology.

- Effective scientist-extension-farmer linkage facilitates fine-tuning of the technology based on the feed-back from the FLDs.

The FLDs conducted over 10,300 acres in compact blocks of 10-20 acres per demonstration over the past 9 years in the rainfed ecologies of eastern States and problem specific regions across the country have helped immensely towards the rapid spread of high yield technology in the handicapped ecologies. The yield advantage of the improved varieties over the local varieties was in the range of 77 to 101 percent.

2.6.5 Impact of the development programmes

The impact the various programmes made during 1984/85-1997/98 in eastern India is visible through a variety of indicators which include production/productivity advance, relative share in national rice production, percentage coverage of HYVs, level of fertilizer consumption etc. (Table 13) as detailed below:

- The coverage of HYVs increased from 44 to 63 percent.

- The level of fertilizer consumption increased from 18 kg to 24 kg/ha.

- Rice production increased by 40.34 percent as compared to 35.93 percent in the rest of the zones.

- Share in national rice production increased from 36.7 to 37.9 percent, and of the overall increase of 32.50 million tonnes of paddy, 13.43 million tonnes is from the eastern zone.

- Productivity increased from 1887 kg to 2508 kg/ha and annual productivity growth is 2.05 percent as against 0.75 percent in the southern and 1.75 percent in the northern zones.

3. ISSUES AND CHALLENGES FOR BRIDGING THE YIELD GAPS

- ***Yield plateauing in high productivity areas:*** In States of high productivity like Punjab and Tamil Nadu etc., the yield level is plateauing. Does this trend mean that the goal of bridging the yield gap vis-a-vis currently available varietal technology has been achieved? Could it be a sign of declining factor productivity given the reports of a higher harvestable potential witnessed in some areas/fields in the region. If not, what is the strategy for further raising the productivity? This is a major researchable issue to be tackled before being content with our accomplishments.

- ***Continued imbalanced use of fertilizer nutrients*:** In general and for high productivity areas in particular, imbalanced use of fertilizer nutrients is on the increase largely due to price escalation and distortion, restricted subsidy on P and K and no subsidy on micro-nutrients like Zn, deficiency of which is widespread.

- ***Shrinking labour availability in the rural areas:*** It is increasingly evident that time bound crop management activities account for about 20 percent yield across the ecologies. In the wake of fast migrating rural population to urban areas, timely planting/harvesting etc., in this labour intensive crop is going to be a serious challenge. Impact of this trend is already showing up in States like Kerala, Punjab and Andhra Pradesh.

- ***Location specific production packages for diverse growing conditions under rainfed ecologies:*** Precise environment characterization has to precede development and adoption of location specific crop production packages.

- ***Low input management vis-a-vis risk of crop losses dissuading farmers from high input management in rainfed ecologies:*** More than lack of awareness, poverty coupled with justifiable apprehension on crop success are attributable to the low use of fertilizer and other monetary inputs including quality seed in rainfed eastern States. Without reliable tactical technology packages for risk distribution, legal mechanism for crop insurance/yield guarantee, and improved credit facilities and special incentives, higher input use will not be possible. This requires research input and policy support for motivating farmers towards intensive farming.

- ***Increasing area under low yielding high value rice varieties:*** Prompted by growing export prospects for Indian basmati rice, the area under the traditional variety has grown by 15-30 percent in the traditional basmati growing states like Haryana, Uttar Pradesh, Punjab etc., replacing high yielding non-basmati varieties. The impact of this trend on national production growth warrants close scrutiny for appropriate corrections.

- ***Accessibility to inputs in remote areas and availability of quality seed of appropriate varieties for stress environments:*** Timely supply in adequate quantity of quality seed is the major constraint to productivity growth in the remote North Eastern hill region, while short supply of certified seed of appropriate varieties continues to be the major problem in salt affected areas.

- ***Varietal solution to problematic soils:*** Years of breeding for salt tolerance has yet to come out with high yielding varieties ideally suited to saline/sodic/acidic soils. Increasing severity of the stress is visible in gradually declining productivity.

- ***Withdrawal of subsidy on chemical pesticides and plant protection equipment:*** Pesticide-free pest management in a pest endemic tropical country like India is unthinkable in the absence of host plant resistance. Whether the reported decline in pesticide consumption is on account of either increased exploitation of host plant resistance or adoption of non-pesticide approaches or cost prohibited limited use is a debatable question. As long as need based use of chemical pesticides continues to be a component of IPM, withdrawal of subsidy on them and appliances needs a review.

- ***Least attention to investment intensive development programmes:*** Research findings and practical experience have brought out the fact that drainage improvement in the deltas and waterlogged areas and provision of life-saving irrigation during dry spells in semi-irrigated rainfed areas have increased yield level by 25-30 percent. Modernization of drainage and creation of facilities for conservation of rain water are some of the subject areas where very little has been done.

- ***Utilization of ground water in high rainfall areas in eastern India for bringing more area under productive 'Boro' (winter) rice:*** Besides West Bengal, where rapidly increased *Boro* rice area exploiting ground water has led to a spectacular increase in productivity, equally potential areas with abundant ground water such as Bihar and Assam have yet to be exploited. Sadly, in West Bengal inadequate power/fuel supply has left hundreds of shallow wells under-utilized. Being one of the most potential niches, investment in exploitation of ground water could prove highly rewarding.

- ***Adverse effects of over-mining of ground water and excessive use of irrigation water and N-fertilizer:*** Over exploitation of ground water in some of the eastern States is believed to introduce new problems like high iron and arsenic content, while excessive and unscientific use of irrigation water is turning otherwise healthy and productive soils into saline and less productive farms. Inland salinity, which is continuously on the increase, is regarded as a more serious threat to rice production than coastal salinity. Research and development efforts to check the further spread and to ameliorate already affected areas should receive priority.

4. CONCLUSIONS AND RECOMMENDATIONS

Given the fact that the area under rice is nearly stabilized at around 42 million ha, the only option left for achieving the future production targets is vertical yield improvement. Amidst a disturbing scenario of declining productivity growth, especially in the northern and southern zones and shrinking natural resource bases, opportunities for sustaining the current level of sufficiency are seen in the vast under-exploited potential of rainfed eastern India, existence of sizeable untapped yield potential in the currently available high yielding varieties, and technological innovations like hybrid technology for raising the genetic yield ceiling and plugging of yield eroding biotic and abiotic stresses. Consolidation of already gained genetic potential in irrigated and shallow lowland ecologies should be our short term strategy for sustained production/productivity growth. Micro-level constraints analysis at village/block levels is the pre-requisite for mounting appropriate research/development efforts and harvesting maximum possible potential. While the knowledge base in this regard is satisfactory for irrigated ecology it is incomplete in respect of the rainfed lowland ecology. As for the status of key components of growth, technology in terms of appropriate HYVs and production packages and inputs (quality seed, fertilizer nutrients and pesticides) are adequate for both the ecologies. However, time bound crop management activities i.e., timely planting, irrigation, weeding, plant protection and harvesting constituting the third component and accounting for more than 20 percent of the harvestable yield is far from satisfactory. Technology transfer needs innovation and augmentation in respect of the rainfed ecology. On the basis of the perception of the problem and research/ development/policy support needs (Appendix 2) for overcoming them, the following strategies are suggested:

4.1 Irrigated Ecology

- Development and use of technological packages for reversing the declining trend of factor productivity in rice-rice and rice-wheat cropping systems.

- Augmentation of breeding research for development of (a) higher yielding varieties combining multiple stress tolerance with emphasis on salinity/alkalinity and (b) hybrids with higher productivity stability and acceptable quality for areas approaching potential yield.

- Promotion of selective mechanization in intensively cropped areas to ensure timely cultural operations in the wake of increasing labour shortage and prohibitive wage structure.

- Development and adoption of effective technological and social devices for enhanced water use efficiency in the irrigation command areas.

- Ensuring adequate power/fuel supply to already energized wells in well-irrigated pockets in general and shallow wells in the *Boro* areas in the eastern region.

- Modernization in phases of drainage in the major rice growing deltas and waterlogged areas.

4.2 Shallow Lowland Ecology

- Precise delineation of diverse growing conditions on the basis of micro-level constraints analysis for development of location specific varietal and production technologies.

- Special efforts/mechanisms for production and supply in adequate quantity of quality seed.

- Encouraging with incentives for production of quality seed for fragile environments like saline/alkaline soils, flood prone areas etc.

- Creation of infrastructure facilities preferably at block level for buffer stocking of seed of short duration varieties (10-15 percent of the seed requirement of the block) for re-sowing under situations of crop losses due to early flash floods/long dry spells.

- Development of facilities for providing limited life-saving irrigation when needed most in semi-irrigated rainfed lowland ecologies.

4.3 Cross Ecology

- Timely supply of all essential inputs, especially quality seed and fertilizer.

- Restoration fully of the subsidy on P and K fertilizer, extension of subsidy to micro-nutrients (zinc) and provision of at least partial subsidy on selected pesticides.

- Promotion of integrated pest management giving emphasis to the bio-control component as well as integrated nutrient management placing emphasis on inclusion of a leguminous crop in the cropping system.

- Improvement of credit facilities in areas of low productivity which is attributable largely to poor economic status of the peasantry to use the recommended level of purchased inputs.

- Continuous support to FLD, SFPP/IPRD/ICRD.

Table 1. Area, Production and Productivity of Rice in India

	Irrigated	Rainfed Lowland	Rainfed Upland	FloodProne/ DeepWater
Area (m.ha)	17.8 (42.0)	15.0 (35.5)	7.0 (16.8)	2.4 (5.7)
Production (m.t)*	52.0 (63.5)	22.0 (26.8)	4.7 (5.7)	3.3 (4.0)
Productivity(t/h)*	2.97	1.47	0.67	1.37

Figures within parenthesis represent percentage area/production
* Milled rice

Table 2. Contribution of Geographic Zones to Rice Production

Zone	Area (m. ha)	% Total Area	Production* (m. t)	% of Total Production	Average Yield (kg/ha)
East & North East	18.4	44	43.5	37	2367
South	7.7	18	31.0	26	3728
North & North West	9.0	21	30.0	25	3281
West*	7.4	17	13.8	12	1878

* Paddy

Table 3. Distribution of Districts Based on Rice Productivity (1994-95)

State	Yield Range (t/ha)						Total
	>3.5	3.0-3.5	2.5-3.0	2.0-2.5	1.5-2.0	<1.5	
Andhra Pradesh	0	1	11	6	4	1	23
Assam	0	0	0	0	10	13	23
Bihar	1	0	0	4	7	38	50
Gujarat	0	0	0	3	7	6	16
Haryana	2	1	7	3	0	0	13
Himachal Pradesh	00	0	0	1	0	10	11
Jammu & Kashmir	0	0	0	0	1	0	1
Karnataka	0	2	7	3	5	2	19
Kerala	0	0	1	4	6	3	14
Madhya Pradesh	0	0	0	3	1	43	47
Maharashtra	0	0	0	4	3	22	29
Orissa	0	0	0	0	4	26	30
Punjab	6	7	1	0	0	0	14
Rajasthan	0	0	0	2	0	20	22
Tamil Nadu	9	7	3	1	1	1	22
Uttar Pradesh	0	0	3	18	24	18	63
West Bengal	0	0	2	8	4	3	17
Total	**18**	**18**	**35**	**60**	**77**	**206**	**414**
%	**4.3**	**4.3**	**8.5**	**14.5**	**18.6**	**49.8**	

Table 4. Trends of Area, Production and Yield Growth of Rice in Major Rice Growing States/Zones

State/Zone	1981-82 to 1989-90			1990-91 to 1997-98		
	Area	Production	Productivity	Area	Production	Productivity
West Bengal	1.12	6.82	5.64	0.28	2.06	1.78
Bihar	0.29	4.17	3.87	-0.25	5.59	5.85
Orissa	0.40	3.98	3.58	0.22	-0.48	-0.70
Assam	0.51	1.08	0.57	0.01	1.15	1.14
East Zone	**0.60**	**4.68**	**4.06**	**0.06**	**2.12**	**2.05**
Uttar Pradesh	-0.18	5.46	5.65	0.31	3.03	2.72
Punjab	5.38	6.74	1.28	1.46	1.99	0.51
Haryana	2.39	2.25	-0.14	4.62	4.19	-0.41
Jammu & Kashmir	-0.23	-0.40	-0.18	0.25	-0.59	-0.84
Himachal Pradesh	-1.44	-1.89	-0.46	-0.43	0.73	1.16
North Zone	**1.06**	**5.31**	**4.20**	**0.94**	**2.68**	**1.72**
Andhra Pradesh	0.56	2.60	2.03	-1.69	-1.00	0.65
Tamil Nadu	-1.89	4.04	6.04	2.49	2.05	-0.43
Karnataka	0.35	0.24	-0.11	1.04	2.89	1.84
Kerala	-4.17	-3.07	1.15	-3.14	-1.54	1.65
South Zone	**-0.55**	**2.32**	**2.88**	**-0.15**	**0.60**	**0.75**
Madhya Pradesh	0.27	2.19	1.91	0.60	1.25	0.64
Maharashtra	-0.09	-0.67	-0.58	-0.95	1.96	2.94
Gujarat	0.41	-0.34	-0.74	2.42	4.39	1.92
Rajasthan	-3.15	-0.32	2.92	2.96	3.54	0.56
West Zone	**0.15**	**1.11**	**0.96**	**0.47**	**1.77**	**1.30**
All India	**0.37**	**3.63**	**3.25**	**0.30**	**1.84**	**1.54**

Table 5. High Yielding Rice Varieties Released for Different Ecologies During 1990-1998

Release Committee	Irrigated			Rainfed Lowland			Rainfed Upland	Total
	Early	Med	Late	SW	SDW	DW		
Central	3	5	2	1	1	---	4	16
State (21)	19	44	---	30	3	3	21	120
Total	22	49	2	31	4	3	25	136

Popular Varieties:

Irrigated:

Medium/Med.late – Vijetha (A.P), HKR126, CSR10(Har), PR110(Pu), TKM10 (TN), Pantdhan 10 (U.P.), Meher(0), Mahamay a (M.P.) SKU 27 (Kash) – Av. yield 4.7 to 5.0 t/ha

Rainfed Shallow water:

Ranjit, Bahadur (Ass), Shyamala (M.P.), Ratnagiri 3 (Mah), NEH Mega Rice 1&2 (Megh), Manika, Mahalaxmi (Ori), Co45 (TN), Bipasa (W.B.) – Av. yield 4.0 to 4.6 t/ha

Semideep:

Purnendu (W.B.), Jalalahari(U.P.), Hemavathi (Kar) – Av. yield 3.0 to 3.4 t/ha

Deep water:

Jalapriya, Jalanidhi (U.P.), Jitendra (W.B.) – Av. yield 2.0 to 2.2 t/ha

Upland:

Narendradhan 97 (U.P.), Khandagiri, Ghateswari, Nilagiri (Ori), GR5 (Guj), Birsadhan 103, 104, Vandana (Bih), Luit, Kapilee (Ass), Mtu 9993 (AP) – Av. yield 1.7 to 3.5 t/ha

Table 6. Salient Features of Released Hybrids

Name of Hybrid/Year of Release	Duration (days)	Yield in OFT (t/ha)		Yield adv. Over Check (%)	Released for the State of
		Hybrid	Check		
APHR-1 (1994)	130-135	7.14	5.27 (Chaitanya)	35.4	Andhra Pradesh
APHR-2 (1994)	120-125	7.52	5.21 (Chaitanya)	44.2	Andhra Pradesh
MGR-1 (1994)	110-115	6.08	5.23 (IR 50)	16.2	Tamil Nadu
KRH-1 (1994)	120-125	6.02	4.58 (Mangala)	31.4	Karnataka
CNRH-3 (1995)	125-130	7.49	5.45 (Khitish)	37.4	West Bengal
DRRH-1 (1996)	125-130	7.30	5.50 (Tellahamsa)	32.7	Andhra Pradesh
KRH-2 (1996)	130-135	7.40	6.10 (Jaya)	21.3	Karnataka
Pant Sankar Dhan-1 (1997)	115-120	6.80	6.10 (Pant Dhan-4)	9.7	Uttar Pradesh
CORH-2 (1998)	120-125	6.25	5.20 (ADT 39)	20.2	Tamil Nadu
ADTRH-1 (1998)	115-120	7.10	4.90 (ASD-18)	44.9	Tamil Nadu
Sahyadri (1998)	125-130	6.64	4.89 (Jaya)	35.8	Maharashtra
Narendra Sankar Dhan-2 (1998)	125-130	6.15	4.94 (Sarjoo-52	24.5	Uttar Pradesh
PHB 71 (1997*)	130-135	7.86	6.14 (PR 106)	28.0	Haryana, U.P, TN.

*Private bred hybrid released by CVRC

Table 7. Yield Gap in Major Rice Growing States 1990/91 - 1997/98

State	Paddy yield (kg/ha)		Yield Difference (kg/ha)	Gap of St. Av. over Exptl. Av.
	State Av.	Exptl. trial Av.*		
South Zone				
Tamil Nadu	4460	5286	826	15.6
Andhra Pradesh	3767	5882	2115	36.0
Karnataka	3456	5250	1794	34.2
Kerala	2857	5690	2853	49.8
North Zone				
Punjab	5042	6460	1418	22.0
Haryana	4074	7396	3322	44.9
U.P.	2870	6598	3728	56.5
East Zone				
West Bengal	3147	5003	1856	37.1
Orissa	1993	5620	3627	64.5
Bihar	1811	6083	4272	70.2
Assam	1954	6437	4483	69.6
Eastern U.P	1881	6598	4717	71.5
Manipur	3233	7619	4386	57.36
Tripura	2932	6331	3399	537
West Zone				
Maharashtra	2380	4501	2121	47.1
Gujarat	2146	5557	3411	61.4
M.P.	1581	4710	3129	66.4
Rajasthan	1582	6485	4903	75.6
N.W. Hills				
J & K	2774	7254	4480	61.8
Himachal Pradesh	1976	5003	3027	60.5
All India	**2759**	**5781**	**3022**	**52.3**

*Mean yield of best entry (Irrigated Medium) at AICRIP test locations over 7 years period.

Table 8. Yield Gap in The Rainfed Lowland Ecologies in The Eastern States (1990/91-1997/98)

State	Paddy Yield (kg/ha)		Yield Gap (kg/ha)	Gap between St.Av. and Exptl. Av. %
	State Av.	Exptl. trial Av.*		
Orissa	1993	4944	2951	59.7
West Bengal	3147	4673	1526	32.7
M.P.	1581	4048	2466	60.9
Assam	1954	4829	2875	59.5
Eastern U.P.	1500	5067	3265	64.4
Bihar	1811	5288	3476	65.7

* Mean yield of best entry (rainfed shallow lowland) at AICRIP test locations over 7 years period

Table 9. Achievable Paddy Yield Through Improved Varieties in Rainfed Ecologies: 1. Shallow Lowland (Frontline Demonstration)*

State		Varieties	Mean FLD Yield (kg/ha)**	Mean Yield Advantage (kg/ha) over		Gap over FLD yield
				Check Var. (%)	State AV.(%)	
Assam	TV:	Bahadur, Ranjit, Satya, Basundara, Laxmi, Salivahana	4854	1712 (54.5)	2890	59.5
	CV:	Pankaj, Manoharsali Mahsuri	3142			
	SA:	Improved and Traditionals	1964			
Bihar	TV:	Manak, Jayshree, Rajshree	4356	1703 (64.2)	2328	53.7
	CV:	T141, Bako1	2653			
	SA:	Improved and Traditionals	2028			
Eastern M.P.	TV:	Mahamaya, Kranti, Rs 74-11	4464	1764 (65.3)	2536	56.8
	CV:	Safr 17, Mahsuri	2700			
	SA:	Improved & Traditionals	1928			
Eastern U.P.	TV:	Jalashree, Jayalakhsmi	2762	964 (53.8)	960	34.8
	CV:	Safr52, Mahsuri	1792			
	SA:	Improved & Traditionals	1802			
Orissa	TV:	Mahalakhsmi, Kanchan, Manik	4655	1180 (34.0)	2671	57.4
	CV:	CR1004, Savithri, Swarna	3475			
	SA:	Improved & Traditionals	1984			
W. Bengal	TV:	Manasarovar, Salivahana, IR42	4430	935 (26.8)	2581	58.3
	CV:	Pankaj, Mahsuri Swarna, Radha	3495			
	SA:	Improved & Traditionals	1849			

* Area covered ranged between 632-1220 acres every year in compact blocks of 10-20 acres/demonstration (Assam: 180-400; Bihar; 100-200; East: M.P: 200-300; East. U.P: 100-240; Orissa: 60; W. Bengal 80-320)

** Mean paddy yield over five years (1993-94 to 1997-98)
TV = Test varieties; CV= Check varieties; SA = State average

Table 10. Achievable Yield Enhancement Through Improved Varieties in Rainfed Ecologies: 2-Semideep Water (Frontline Demonstrations)*

State		Varieties	Mean FLD Yield (kg/ha)**	Mean yield advantage (kg/ha) over		Gap over FLD Yield
				Check Var.	State Av.	
Eastern U.P.	TV:	Madhukar, Jalapriya	2412	912 (60.8)	610	25.3
	CV:	Jalmagna, Chakia 59, Saupamki	1500			
	SA:	Improved & Traditionals	1802			
W. Bengal	TV:	Sobita, Dinesh, Golak, Saraswati	2615	943 (56.4)	766	29.3
	CV:	Mahsuri, Iradrasail, Patnai,	1672			
	SA:	Improved & Traditionals	1849			

* Area covered ranged between 50-400 acres every year in compact blocks of 10-20 acres/demonstration. (W. Bengal: 100-400; eastern U.P. 50)

** Mean paddy yield over 4 years (1993-94 to 1997-98)
TV = Test varieties; CV = Check varieties; SA = State average

Table 11. Achievable Yield through Improved Varieties in Rainfed Ecologies: 3-Uplands (Frontline Demonstrations)*

State		Varieties	Mean FLD Yield (kg/ha)**	Mean Yield Advantage (kg/ha) Over		Gap Over FLD Yield
				Check Var. (%)	State AV. (%)	
Bihar	TV:	Kalinga 3, Vandana, Birsa 201, Tulasi	2032	1202 (144.8)	4	0.2
	CV:	Brown Gora	830			
	SA:	Improved & Traditionals	2028			
Eastern M.P	TV:	Aditya, Annada, Poornima	2793	943 (51.0)	865	31.0
	CV:	Safri 12, Chaptigurumaha	1850			
	SA:	Improved and Traditionals	1928			
Eastern U.P.	TV:	NDR 118, Narendra 97	3616	1550 (75.0)	1814	50.2
	CV:	Indrasail, Saket 4, Johria	2066			
	SA:	Improved & Traditionals	1802			
Orissa	TV:	Nilagiri, Chandeswari, Vandana, Kandagiri, Heera	2940	1645 (126.1)	956	32.5
	CV:	Chatka, Saria	1305			
	SA:	Improved & Traditionals	1984			

* Area covered ranged between 282-438 acres every year in compact blocks of 10-20 acres/demonstration. (Bihar: 100-200; East M.P.: 120; East UP: 50-100; Orissa: 60))

** Mean paddy yield over 2-5 years (1993-94 to 1997-98)
TV = Test varieties; CV = Check varieties; SA = State average

Table 12. Achievable Yield Enhancement Through Improved Varieties in Salt Affected Areas in Irrigated Ecology: (Frontline Demonstrations)*

State		Varieties	Mean FLD Yield (kg/ha)**	Mean Yield Advantage (kg/ha) Over		Gap Over FLD Yield
				Check Var. (%)	State AV. (%)	
Maharastra	TV:	CSR 10,	4350	770 (21.5)	1810	41.6
	CV:	PNL 1	3580			
	SA:	Improved & Traditionals	2540			
Eastern U.P	TV:	CSR 10, Narendra, Usar 1, Usar 2	2970	700 (30.84)	1168	39.3
	CV:	Saket 4, Sarjoo 52	2270			
	SA:	Improved and Traditionals	1802			
Orissa	TV:	Lunishree	3810	1060 (38.5)	1826	47.9
	CV:	Patnai	2750			
	SA:	Improved & Traditionals	1984			

* Area covered ranged between 35-110 acres every year in compact blocks of 10-20 acres/demonstration.

** Mean paddy yield over 2-3 years (1995-96 to 1997-98)
TV = Test varieties; CV = Check varieties; SA = State average

Table 13. Relative Contribution of Eastern India for Rice Production Advance During 1986/87-1997/98

	East Zone			All India		
	1986-87	**1997-98**	**Increase (%)**	**1986-87**	**1997-98**	**Increase (%)**
Area (m.ha)	17.64 (42.8)	18.63 (42.9)	0.99 (5.61)	41.17	43.42	2.25 (5.39)
Production (m.ha)	22.19 (36.7)	31.14 (37.9)	8.95* (40.34)	60.54	82.20	21.66 (35.78)
Productivity (kg/ha)	1258	1672	414 (32.9)	1417	1893	422 (28.69)
HYV (%)	44.0	63.0		58.4	74.0	
Fertilizer con. (Kg/ha)	18.0	24.0		49.0	77.0	

* Percentage contribution of Eastern India to national production increase during 1986/87-1997/98 = 41.32.

Figures in parenthesis underlined denote % of All India figures.

APPENDIX 1

MANAGEABLE CONSTRAINTS TO RICE PRODUCTIVITY IN DIFFERENT REGIONS/ECOLOGIES

SOUTHERN REGION

Commands and deltas:

- Over irrigation and poor drainage causing salinity/alkalinity
- Less than optimum plant population
- Delayed planting due to late release of canal water
- Imbalanced fertilizer use
- High incidence of pests and diseases
- Weed infestation

High rainfall coastal area:

- Saline/acid/acid sulphate (Kuttanad) soils
- Periodic inundation by saline water
- Low adoption of HYVs
- Late and staggered planting
- Low to very low fertilizer use
- Disease-pest incidence

Low rainfall and dry zones:

- Poor soil fertility with low organic matter content
- Poor drainage and salinity in lowlands
- Low fertilizer use and low use efficiency
- Widespread Zn deficiency
- Low adoption of HYVs
- Poor plant population
- High weed infestation
- Short to prolonged drought
- Disease-pest incidence

NORTHERN REGION

Command area:

- Faulty irrigation/brackish water/high water table causing salinity/alkalinity
- Low organic matter content with varied macro and micro nutrient deficiencies (N, P, S, Fe, Mn, Zn)
- Imbalanced fertilizer use

- Less than optimum plant population
- Delayed planting due to labour constraint
- Weed infestation
- Disease-pest incidence (BI, BLB, WBPH, SB, Sh. BI)

<u>EASTERN REGION</u>

<u>Commands and deltas:</u>

- Low P and widespread Zn deficiency
- Delayed/prolonged transplanting
- Low and imbalanced fertilizer use
- Poor plant population
- Poor water management due to poor drainage
- Weed infestation
- Pest-disease incidence

<u>Rainfed lowland ecology:</u>

- Acid soils of low fertility with low N, P and deficiency of Zn, Mo
- Saline soils deficient in N, P and Zn in coastal areas
- Lack of ideal HYVs and slow adoption of improved varieties
- Inadequate supply and use of quality seed
- Low fertilizer use and poor use efficiency
- Submergence in flood prone and waterlogged areas
- Early and intermittent drought spells
- Inadequate and delayed supply of quality seed
- Poor plant stand
- Disease-pest incidence
- Lack of exposure to productive technology packages
- Widespread poverty

<u>Rainfed uplands:</u>

- Acid soils with low organic matter content, low N and P and widespread Zn, Boron deficiency
- Lack of ideal HYVs and slow adoption of improved varieties
- Inadequate supply and use of quality seed
- Very low fertilizer use
- Severe weed infestation
- Poor crop stand
- Moisture stress at more than one growth stage
- Blast and brown spot diseases
- Lack of exposure to productive technology packages
- Widespread poverty

NORTH EAST INDIA HILL REGION:

- Prevalence of 'shifting' cultivation
- Excessive dependence on native varieties
- Poor coverage of HYVs
- Limited use of quality seed
- Low 'P' availability and Fe toxicity in pockets
- Very low fertilizer use
- Severe weed infestation
- Low adoption of improved production technologies
- Soils difficult to work with when wet
- Lack of exposure to productive technology package

WESTERN REGION:

- Salinity and deficiency of P, Ca, S in coastal areas
- High water table in middle Gujarat, over-mining of water in south Gujarat causing salinity, faulty water management in the command areas of Western Vidharbha etc., causing salinity/alkalinity.
- Low fertilizer use and poor use efficiency
- Periods of moisture stress in rainfed and partially irrigated areas
- Poor plant population
- Heavy weed infestation in Vidharbha and South Gujarat
- Low adoption of improved cultivation package for drilled rice
- Disease/pest pressure

NORTH WEST HILL REGION:

- Saline/alkaline soils in Jammu, sodic soil in Kangra and acidic soil in Mandi
- High water table and faulty irrigation system
- Low organic matter content
- Low fertilizer use
- Delayed and prolonged transplanting

CENTRAL REGION:

- Low water retention capacity of soils
- High fixation of P and deficiency of N, Zn, Mo
- Waterlogging at early stages and drought at late stages
- Severe weed (wild rice) infestation
- High incidence of pests (GM)

APPENDIX 2

REMEDIAL MEASURES AGAINST MANAGEABLE CONSTRAINTS TO HIGHER PRODUCTIVITY IN IRRIGATED ECOLOGY

- Use of quality seed
- Replacing old susceptible varieties with more stable disease-pest resistant/salt tolerant new varieties.
- Increased level of fertilizer use in areas of moderate and low fertilizer use.
- Correction of distorted fertilizer nutrient use in high productivity areas.
- Enhanced use efficiency of fertilizer by soil test-based application of major/micro nutrients.
- Reversing the declining factor productivity through appropriate soil management strategies in major rice-based cropping systems, especially rice-wheat and rice-rice.
- Correction of wide-spread deficiency of zinc, sulphur etc.,
- Amelioration of inland salinity/alkalinity affected areas
- Promotion of integrated nutrient management packages wherever practicable and needed
- Ensuring optimum plant population by close planting of healthy seedlings.
- Introduction of mechanized transplanting/wet direct seeding to ensure timely planting in areas where delayed planting is inevitable due to labour shortage, high wage structure etc.,
- Promotion of integrated pest management practices in pest-endemic areas.
- Effective and timely control of weeds using recommended weedicides.

Rainfed Lowland:

- Adoption of improved varieties of medium late maturity combining photosensitivity.
- Use of quality seed
- Resorting to transplanting in shallow lowlands where sustainable water depth never exceeds 30cm and direct seeding in semi-deep water areas.
- Ensuring optimal stand establishment by adopting closer spacing in transplanted areas and by using 20 percent higher seed rate in direct sown ecologies.
- Moderate application by drilling of fertilizer nutrients (a dry sown crop fertilized adequately can withstand better flash floods in August-September)
- Effective pest-disease control by adopting integrated pest management practices.

Rainfed Upland:

- Adoption of early maturing varieties well adapted to direct seeding and varied levels of moisture stress.
- Ensuring optimum plant population by adoption of line sowing/using higher seed rate.
- Practicing deep summer ploughing and adoption of appropriate rain water management devices for better moisture conservation and utilization.

- Soil conservation measures to minimize soil and nutrient losses.
- Moderate use of fertilizer nutrient (NPK) and fine tuning of N application.
- Start seed bed preparation by harrowing before seeding and pre-emergence application of recommended weedicides followed by raking/hoeing and hand-weeding once or thrice depending on the severity of weed infestation.
- Management of blast disease (especially seedling blast) either by use of resistant varieties or suitable fungicide application.
- Development and use of risk distribution strategies.

BRIDGING RICE YIELD GAP IN INDONESIA

Abdul Karim Makarim[*]

1. INTRODUCTION

There is a growing demand for rice with increase in population. As rice is still the major staple food in Indonesia, the task of increasing rice production continues to engage the attention of national planners. There are five identified avenues to increase rice production, namely: a) by increasing the area under rice production through either increasing the cropping intensity or expansion into new lands; b) by increasing rice productivity; c) by stabilizing rice yields; d) by narrowing the rice yield gap; and e) by reducing yield losses during harvest and post-harvest (CRIFC 1991). In this context, increasing cropping intensity is related to the improvement/building irrigation systems to enable planting of two or three rice crops per year. Productivity is related to finding new high yielding rice varieties that potentially increase the yield per ha; stabilizing rice yields by better pest management to prevent or to control pest attacks and disease incidence; and post-harvest activities related to development of harvest and post-harvest technologies. The efficacy and efficiency of those methods for increasing rice production differ from one region to another, which are dependent on natural and socio-economic conditions. The objectives of this paper are to present the variation of rice yields in Indonesia, identify the causes of yield gaps, and delineate unmanageable and manageable factors to bridge the yield gaps.

Large variations in rice yield levels in Indonesia are due to many factors. Those factors have different scales of magnitude within regions, provinces, and districts up to farmers' field level. Those factors are also classified as manageable and unmanageable. Yield gaps, therefore, should be divided into different scales and management. Yield gaps at different levels in various areas are indicated by the lowest and the highest yields of rice in such areas as compared to their average.

The priorities of reducing yield gaps (bridging) are possibly either to increase the lowest yield to the average or to increase yields that give the highest impact to rice production of those areas. The data on rice yields at provincial level are presented in Table 1, while described yield gaps are presented in Figure 1.

2. MAJOR RICE YIELD GAPS

Indonesia is a large tropical country that consists of thousands of islands located in two Oceans (Indian and Pacific), lying between two continents (Asia and Oceania). Therefore, the spatial weather and soils vary widely. Those variables could be separated into: a) unmanageable variables (solar radiation, minimum and maximum air temperatures, soil texture etc.), and b) manageable variables (water flows and distribution, poor drainage, soil fertility, chemical toxicities etc.). Besides these natural conditions, other factors such as

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farmers' traditional methods and knowledge, availability of technology, and socio-economic factors also determine and influence rice yield levels.

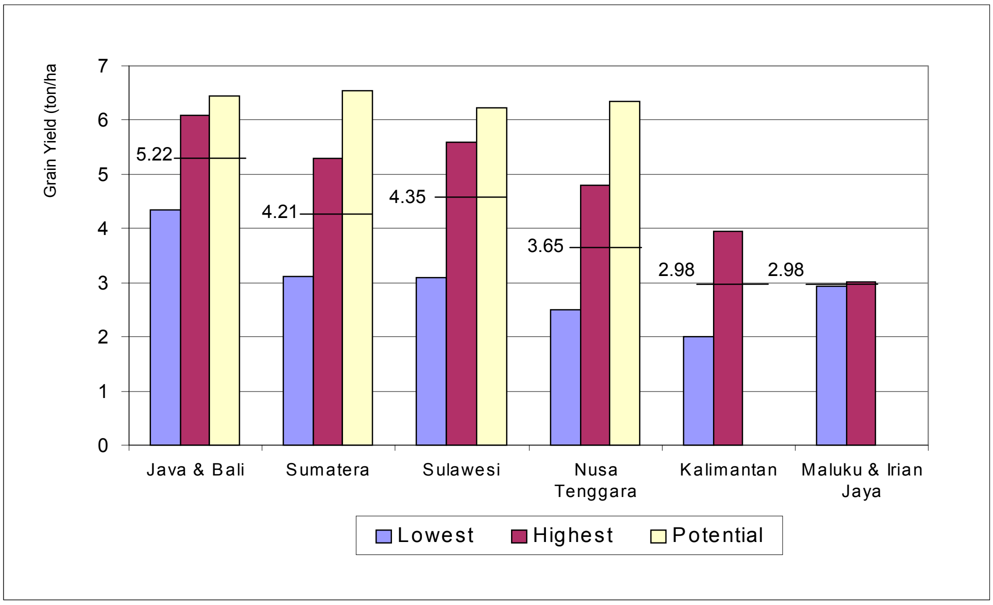

Figure 1. Rice Yield Gap in Indonesia

In 1996 there were 10,251,393 ha of rice harvested area in Indonesia with a production of 48,188,255 tonnes of grain, and an average yield of 4.70 t/ha. However, the yields usually range from 2.01 to 6.09 t/ha. Yield potential ranges from 5.788 to 7.087 t/ha which indicates that there is still a wide gap from the actual yield level in farmers' fields.

Based on the average yield levels of rice there are three groups of regions (demarcated by major rice yield gaps) in Indonesia namely: Group I - Java and Bali (5.36 t/ha), Group II - Sulawesi, Sumatra and Nusa Tenggara (4.1-4.6 t/ha), and Group III - Kalimantan, Maluku and Irian Jaya (<3.0 t/ha). The major constraints and limitations of rice yields in those areas are different so that the strategies to reduce yield gaps among regions or to increase the average yield levels in those regions should be specific and peculiar to each region or group.

2.1 Yield Gaps at Regional Level

In group I (Java and Bali), the rice yield at provincial level ranges from 5.28 to 5.61 t/ha (average of 5.36 t/ha), except Jakarta with 4.85 t/ha (Table 2). In general, in this region almost no technical problems are confronted to limit relatively high yield level. The constraints are mostly in social and economical aspects such as low price of product, i.e., less profit compared to the profits obtained if producing other commodities. Increasing the efficiency of production is more beneficial than increasing inputs to obtain higher yield, which increase farmers' profits and cause less chemical pollution. Improving grain quality of rice is more beneficial in order to get higher prices and profit.

In group II (Sulawesi, Sumatra and Nusa Tenggara) rice yields vary from 3.18 to 4.77 t/ha with an average of 4.35 t/ha. In Sumatra generally, the problems of low rice yield are edaphic factors such as poor drainage, iron toxicity and high acidity either due to high sulphate or organic acids. In Sulawesi and Nusa Tenggara, the limiting factors in obtaining higher rice yields are dry climate, water shortage and drought. In both sites the problems and constraints could be overcome with large scale amelioration or improvement of supplementary irrigation systems. In Sumatra, improvements of drainage systems, application of rock phosphates and/or dolomitic limestone are required to increase rice yield or to shorten rice yield gaps. In Sulawesi and Nusa Tenggara improvement of irrigation systems or in some instances, pumping ground water may be important to increase rice yield. In those areas soil fertility is relatively good. In this group it is important to adopt the specific, adaptive rice varieties such as a drought tolerant varieties, acid tolerant varieties and high iron tolerant rice varieties. Such varieties are available in Indonesia for dissemination to rice farmers.

In group III (Kalimantan, Maluku and Irian Jaya), rice yields range from 2.63 to 3.10 t/ha with an average of 2.91 t/ha. In this group, the problems are complex, edaphic and socio-economic factors such as iron toxicity, soil acidity, poor drainage, lack of human resources, technology and low quantity and quality of production inputs are major constraints. However, the priorities to increase rice production in these areas are through farmers' education/training and guidance to adopt new and simple technologies such as adaptable varieties, good seed, simple tools and machinery.

2.1 Rice Yield Gaps at Provincial Level

Yield gaps at provincial level are divided into yield gap among the average yields in the district levels and gaps of the actual yield level to the potential yield level. In group I in West Java, the average rice yield is 5.28 t/ha and ranges from 4.34 to 5.59 t/ha. Therefore, the actual rice yield gap among districts in West Java is 1.25 t/ha. On the other hand, rice potential yields range from 6.14 to 7.09 t/ha with an average of 6.62 t/ha. The gap between the average actual yield and the potential yield in west Java is 1.34 t/ha. In Central Java, the average rice yield is 5.32 t/ha and ranges from 4.49 to 6.09 t/ha. Therefore, the actual rice yield gap among districts in Central Java is 1.60 t/ha. On the other hand, rice potential yields range from 5.85 to 6.78 t/ha with an average of 6.32 t/ha. The gap between the average rice yield and the potential yield in Central Java is 0.99 t/ha. In East Java, the average rice yield is 5.48 t/ha and ranges from 4.48 to 5.85 t/ha. Therefore, the actual rice yield gap among districts is 1.37 t/ha. On the other hand, rice potential yields range from 5.79 to 6.74 t/ha with an average of 6.27 t/ha. The gap between the average rice yield and the potential yield in East Java is 0.79 t/ha. In Bali the average rice yield is 5.36 t/ha and ranges from 5.22 to 5.65 t/ha. Therefore, the actual rice yield gap among districts is very small (0.43 t/ha). In Bali, the irrigation network called *Subak* system is very effective in water distribution to farmers' fields. Water management is controlled by groups of farmers. Therefore, the gaps of rice yields among farmers' rice fields are very small. On the other hand, rice potential yields range from 6.00 to 6.92 t/ha with an average of 6.46 t/ha. The gap between the average rice yield and the potential yield in Bali is 1.10 t/ha.

In group II in West Sumatra, the average rice yield is 4.69 t/ha and ranges from 3.89 to 5.29 t/ha. Therefore, the actual rice yield gap among districts in West Sumatra is 1.40 t/ha. On the other hand, rice potential yields range from 6.64 to 6.97 t/ha with an average of 6.81 t/ha. The gap between the average rice yield and the potential yield in West Sumatra is 2.12 t/ha, much higher compared to the group I (Java and Bali). In South Sulawesi, the average rice yield is 4.77 t/ha and ranges from 3.46 to 5.60 t/ha. Therefore, the actual rice yield gap among districts in South Sulawesi is 2.14 t/ha. High variation in gaps of rice yields in the farmers' fields is mainly due to the availability of irrigation water. On the other hand, rice potential yields range from 5.98 to 6.24 t/ha with an average of 6.11 t/ha. The gap between the average rice yield and the potential yield in South Sulawesi is 1.34 t/ha. In East Nusa Tenggara, the average rice yield is 3.18 t/ha and ranges from 2.50 to 3.39 t/ha. Therefore, the actual rice yield gap among districts in East Nusa Tenggara is 0.89 t/ha. Low rice yields in the farmers' fields are mainly due to the lack of irrigation water. On the other hand, rice potential yields range from 6.31 to 6.39 t/ha with the average of 6.35 t/ha. The gap between the average rice yield and the potential yield in East Nusa Tenggara is 3.17 t/ha. The potential yield in this area is high due to high solar radiation. The maximum and minimum air temperatures are not a constraint to rice crop production. In general, water is not a limiting factor and no soil fertility constraints affect the rice crop.

In group III, the average rice yields in Kalimantan, Maluku and Irian Jaya are 2.93, 2.96 and 2.80 t/ha, respectively, lower than that of group II (4.35 t/ha). In Kalimantan, the descending order of yield gaps are South Kalimantan (1.26 t/ha), Central Kalimantan (0.81 t/ha), West Kalimantan (0.65 t/ha), and East Kalimantan (0.21 t/ha). Rice yield gaps among farmers' fields in Maluku and Irian Jaya are not significant, because the yield levels are mostly low. Therefore, the important thrust is to increase rice yield, at least to come close to the average yield of group II.

3. STRATEGY FOR BRIDGING RICE YIELD GAPS

In brief, strategies for bridging rice yield gaps in Indonesia are as follows:

a) to improve the infrastructure and methodology (technical improvement, socio-economic improvements, better policy environment) such as construction and improvement of irrigation systems including groundwater exploitation, improved drainage systems, and soil amelioration;

b) to set priorities on increasing rice yields of the districts having lower average yield compared to the average yield level of their province;

c) site specific improvements: prescription farming, using adaptable rice varieties etc.

Major improvements should be carried out in Group II (Sumatra, Nusa Tenggara and Sulawesi) to overcome major constraints, such as water shortages, poor drainage, Fe toxicities and acid soils, low prices of the product, and marketing. The examples of major improvements are construction and improvement of irrigation systems, drainage systems, soil amelioration, transport systems, market systems, and price policies. In this case group I (Java and Bali) will not be considered as important, because the facilities in those regions are already considered sufficient, having good natural resources (high soil fertility and sufficient water resources).

Prioritized districts in each province to increase rice yield or to reduce yield gaps are using the aforementioned method. In group I, there is no special district to prioritize to increase rice yields. In this area, bridging rice yield gaps should be done in line with increasing the efficiency of production inputs such as adopting prescription farming, and using high-value rice varieties (of high grain quality with high price). Using the prescription farming procedure, in which the needs for fertilizers on rice are calculated based on soil tests, targeted yield levels and climate, the efficiency of fertilizer usage could be reduced or even the rice yield could be increased. Examples of prescription farming results are presented in Table 3.

In group II, the districts that are below average are Riau, Jambi, Bengkulu, South Sumatra, Central Sulawesi, Southeast Sulawesi and East Nusa Tenggara (NTT). Riau, Jambi, Bengkulu and South Sumatra are located in east Sumatra and have mostly acid, light texture and infertile soils. Therefore, besides the major improvements as mentioned before, rice fields in these sites also require K and probably micronutrients (Cu and Zn). In newly opened irrigated rice fields in Indragiri Hulu and Riau, the rice plants failed to produce good grain yield for almost six years due to iron toxicity and micronutrient deficiencies whereas in the surrounding areas rice crops produced normal narrow grain yield (Makarim et al. 1997). In Central and Southeast Sulawesi and East Nusa Tenggara, besides the major improvements as mentioned before, application of micronutrients (Cu and/or Zn) is required due to neutral to high pH of soils in this region.

In group III (Kalimantan, Maluku and Irian Jaya), since in most districts rice yields are still low, all districts try to increase rice yields through better guidance, improvement of farmers' technical skill, good seeds and adaptable rice varieties.

The details of strategies are presented as the thrusts to increase rice yields and bridging rice yield gaps (Table 4). Based on sources of yield variation and constraining factors in each region, provinces or districts, appropriate solutions have been identified.

4. CONCLUSIONS

Appropriate strategies in bridging the rice yield gaps should be relevant to:

Facilities:
- Irrigation systems
- Drainage systems
- Transportation
- Markets

Agronomic Factors:
- Prescription farming (fertilizer and organic matter)
- Water management (irrigation, drainage)
- Pests and disease control
- Seeds and variety improvement
- Tools and machinery

Economic Factors:
- Price of inputs (fertilizer, insecticides, etc)
- Price of outputs (rice, grain)
- Capital (credit)

- Labour costs

<u>Social Factors:</u>

- Motivated farmers
- Guidance and information systems
- Set value (higher status of good farming practices)

<u>Policy:</u>

- Better credit
- Price (floor pricing)
- Import controls

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Table 1. Harvest Areas, Production and Yield of Lowland Rice in each Province in Indonesia in 1996

Province	Harvest Area (ha)	Production (tonnes)	Actual Yield (t/ha)	Range of Actual Yield (t/ha)
1. D.I. Aceh	339785	1400425	4.12	3.75-4.81
2. North Sumatra	716182	2966681	4.14	3.57-4.66
3. West Sumatra	411716	1929622	4.69	3.89-5.29
4. Riau	116766	389776	3.34	3.12-3.47
5. Jambi	152383	530186	3.48	3.14-3.97
6. South Sumatra	395253	1456587	3.69	3.26-4.22
7. Bengkulu	91259	337835	3.70	3.51-3.84
8. Lumping	370942	1620487	4.37	4.16-4.65
Sumatra	**2594286**	**10631599**	**4.10**	**3.12-5.29**
9. DKI Jakarta	3576	17347	4.85	
10. West Java	1957743	10342690	5.28	4.34-5.59
11. Central Java	1534936	8170309	5.32	4.49-6.09
12. Yogyakarta	100125	562025	5.61	4.74-5.85
13. East Java	1529309	8377019	5.48	4.48-5.85
Java	**5125689**	**27469390**	**5.36**	**4.34-6.09**
14. Bali	155964	836047	5.36	5.22-5.65
15. Western-S.E. Nusa	268327	1232870	4.59	3.84-4.80
16. Eastern-S.E. Nusa	101657	323246	3.18	2.50-3.39
17. East Timor	17418	48835	2.80	
Bali & S.E. Nusa	**543366**	**2440998**	**4.49**	**2.50-5.65**
18. West Kalimantan	242030	674537	2.79	2.29-2.94
19. Central Kalimantan	102530	269530	2.63	2.01-2.82
20. South Kalimantan	355378	1103402	3.10	2.69-3.95
21. East Kalimantan	82436	248596	3.02	2.89-3.10
Kalimantan	**782374**	**2296065**	**2.93**	**2.01-3.95**
22. North Sulawesi	103130	446693	4.33	3.88-4.52
23. Central Sulawesi	163500	561383	3.43	3.10-3.57
24. South Sulawesi	841066	4008277	4.77	3.46-5.60
25. S.E. Sulawesi	77887	276556	3.55	3.10-3.70
Sulawesi	**1185583**	**5292909**	**4.46**	**3.10-5.60**
26. Maluku	6626	19619	2.96	2.94-3.01
27. Irian Jaya	13469	37675	2.80	
Maluku & Irian Jaya	**20095**	**57294**	**2.85**	**2.94-3.01**
INDONESIA	**10251393**	**48188255**	**4.70**	**2.01-6.09**

Source: BPS (1998): Produksi Padi di Indonesia 1997 Ramalah III. BPS.

Table 2. Rice Yield Gap at Provincial Level

Region	Actual Yield (ton/ha)		Yield Gap A	Potential Yield (ton/ha)	Yield Gap B
	Average	Range			
GROUP I					
1. DKI Jakarta	4,85				-
2. West Java	5,28	4,34-5,59	1,25	6,16-7,09	1,33
3. Central Java	5,32	4,49-6,09	1,60	5,85-6,78	0,99
4. Yogyakarta	5,61	4,74-5,85	1,11	5,85-6,78	0,70
5. East Java	5,48	4,48-5,85	1,37	5,79-6,74	0,78
Java	5,36	4,34-6,09	1,75	5,79-7,09	1,08
6. Bali	5,36	5,22-5,65	0,43	6,00-6,92	1,10
Java & Bali	**5,32**	**4,34-6,09**	**1,75**	**5,79-7,09**	**1,12**
GROUP II					
7. DI Aceh	4,12	3,75-4,81	1,06	6,19-6,40	2,17
8. North Sumatra	4,14	3,57-4,66	1,09		
9. West Sumatra	4,69	3,89-5,29	1,40	6,64-6,97	2,12
10. Riau	3,34	3,12-3,47	0,35		
11. Jambi	3,48	3,14-3,97	0,83		
12. South Sumatra	3,69	3,26-4,22	0,96	6,12-6,39	2,57
13. Bengkulu	3,70	3,51-3,84	0,33		
14. Lampung	4,37	4,16-4,65	0,49		
Sumatra	4,10	3,12-5,29	2,17	6,12-6,97	2,45
15. North Sulawesi	4,33	3,88-4,52	0,64		
16. Central Sulawesi	3,43	3,10-3,57	0,47	6,37-6,49	3,00
17. South Sulawesi	4,77	3,46-5,60	3,14	5,98-6,24	1,34
18. S.E Sulawesi	3,55	3,10-3,70	0,60		
Sulawesi	4,46	3,10-5,60	2,50	5,98-6,49	1,77
19. Western-S.E. Nusa	4,59	3,84-4,80	0,96		
20. Eastern-S.E. Nusa	3,18	2,50-3,39	0,89	6,31-6,39	3,17
S.E. Nusa					
Sumatra, Sulawesi & S.E Nusa	**3,96**	**2,50-5,60**	**3,10**		
21. East Timor	2,80				
GROUP III					
22. West Kalimantan	2,79	2,29-2,94	0,65		
23. Central Kalimantan	2,63	2,01-2,82	0,81		
24. South Kalimantan	3,10	2,69-3,95	1,26		
25. East Kalimantan	3,02	2,89-3,10	0,21		
Kalimantan	2,93	2,01-3,95	1,94		
26. Maluku	2,96	2,94-3,01	0,07		
27. Irian Jaya	2,80				
Kalimantan, Maluku & Irian Jaya	**2,88**	**2,01-3,95**	**1,94**		
INDONESIA	**4,70**	**2,01-6,09**	**4,08**	**5,79-7,09**	**1,74**

Table 3. Examples of Results of Prescription Farming in West Java using PADI300.CSM Simulation Model (Makarim 1999)

Location Number	Farmer Number	District	Regency	Village	Farmer				Optimum Dosage				Predicted Yield kg/ha	Note
					Urea kg/ha	SP-36 kg/ha	KCl kg/ha	ZA kg/ha	Urea kg/ha	SP-36 kg/ha	KCl kg/ha	ZA kg/ha		
1	1	Garut	Selawi	Cigawir	240	190	125	0	175	35	79	0	6072	P, K Def. & Fe Tox.
2	2			Cinunuk	130	210	100	0	162	3	74	0	6195	Low K
	3				440	270	70	0	162	3	74	0	6195	
	4				360	200	72	0	162	3	74	0	6195	
3	5	Sumedang	Darmaraya	Cibogo	180	110	70	0	103	40	78	0	6530	P, K Def. & Fe Tox.
	6				180	110	90	0	103	40	78	0	6530	
	7				120	120	60	0	103	40	78	0	6530	
4	8		Sumedang Utara	Marga mukti	200	75	50	0	103	63	69	0	5659	P Def.
5	9	Cianjur	Cilaku	Sirnagalih	200	100	100	0	115	39	30	0	6552	P Def., Low K, potential, Fe Tox
6	10		Bojong Picung	Cibarengkok	380	150	38	0	175	0	59	0	6072	Good
	11				150	150	60	0	175	0	59	0	6072	
	12				430	280	140	0	175	0	59	0	6072	
	13				200	300	0	0	175	0	59	0	6072	
7	14		Ciranjang	Mekar Galih	200	100	100	0	175	14	79	0	6072	K Def , Fe & Mn Tox.
8	15	Subang	Pagaden	Sumur Gintung	300	300	0	0	199	74	54	0	5279	P def
	16				250	100	50	0	199	74	54	0	5279	
	17				200	100	0	0	199	74	54	0	5279	
	18				300	150	0	0	199	74	54	0	5279	
9	19		Binong	Nangerang	200	50	50	0	175	30	94	0	5648	Fe & Mn Tox.

Table 4. Thrusts in Bridging Rice Yield Gaps in Indonesia

No.	Sources of Variation	Factors/Constraints	Solutions
1.	Yield potential (Java and Bali)	Weather condition (Solar radiation and air temperatures)	High yielding variety, time of planting
2.	Water Availability/ irrigation (Nusa Tenggara and Sulawesi)	Drought with different levels	Improved irrigation, variety adaptable to drought and/or short duration
3.	Soil Properties	Acidity, Fe toxicity, Salinity (Sumatra, Kalimantan, Irian)	Water control (drainage), ameliorant (rock P dolomitic lime), tolerant varieties
4.	Shallow top soils, poor drainage, sandy texture (Kalimantan)	Soil Properties	Deep plowing, drainage, O.M.
5.	Soil fertility Pests and diseases	a. Nutrient deficiency b. Pest and disease problem	Prescription farming IPM, harvest and planting at the same time
6.	Availability of manpower and machinery (Maluku, Irian, Kalimantan, NTT)	Labour	Introduce tools and machinery for harvest, planting, and soil tillage
7.	Economic factors	Prices, costs Markets, transport, capital, credits	Stable price, profitable; systems of markets and transportation
8.	Social factors	Willingness to plant rice; Values (feel ashamed of failure or proud of success), guidance	Information system. Strengthen the function of farmers' groups : Koperasi; Professional farmers' groups (KTNA)
9.	Policy	Injustice and imbalanced supports	Credits, owners limitation, floor price, import control

BRIDGING THE RICE YIELD GAP IN THE PHILIPPINES

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1. INTRODUCTION

Rice remains the agricultural commodity with foremost political and economic significance in the Philippines. As a major staple, rice accounts for 35 percent of average calorie intake of the population and as much as 60-65 percent of the households in the lowest income quartile (David and Balisacan, 1995). Moreover, rice farming is the source of income and employment of 11.5 million farmers and family members. Rice contributes 13 percent to the Consumer Price Index (CPI), 16 percent to the Gross Value Added (GVA) of agriculture, and 3.5 percent to the Gross Domestic Product (GDP) (Gonzales, 1999). Due to its economic importance, rice has become the central focus of government agricultural policies.

Recent trend analyses indicate that the growth of the rice sector has become completely dependent on yield improvements (David and Balisacan, 1995 and Gonzales, 1998). Yield improvement can come in either of two ways: a) by shifting the yield frontier, i.e., breeding varieties that have significantly higher yield potential than our current varieties, e.g., New Plant Type; and b) by developing and promoting yield-enhancing technologies such as the use of high quality seeds and efficient fertilizers. The first option is not attainable in the immediate future considering that the yield potential of the majority of the newly-released varieties have not yet surpassed the yield of IR8, which was bred in the late 1960's. The second alternative is more plausible because there are available yield-enhancing technologies.

2. STATUS OF RICE CULTIVATION

2.1 Area, Production and Yield Trends in Different Agro-ecologies

Trends in palay (rough rice) production, area harvested, and average yield per hectare are shown in Table 1. For the past three decades, palay production has increased from 5 Mmt (million metric tonnes) in 1970 to 11 Mmt in 1997 at an average annual rate of 3 percent. Consequently, area harvested also increased from 3.1 Mha (million hectares) in 1970 to 3.84 Mha in 1997, which grew at an average of 0.89 percent per year. In 1997, the national average yield per hectare was 2.93 mt/ha (metric tonne per hectare). The irrigated areas produce the highest average yield with 3.4 mt/ha, followed by the rainfed ecosystem at 2.1 mt/ha, and the upland areas at 1.5 mt/ha. However, production and area harvested were exceptionally low in 1998 due to the occurrence of the El Niño phenomenon.

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Table 1. Philippine Palay Production, Area Harvested, and Yield/Hectare by Ecosystem.

ITEM	YEAR								
	1970	1975	1980	1985	1990	1995	1996	1997	1998
	Production(m/mt)								
All	5.32	6.38	7.65	8.81	9.32	10.54	11.28	11.27	8.55
Irrigated	2.95	3.45	4.51	5.82	6.60	7.60	8.23	8.48	
Rainfed	2.01	2.60	2.88	2.83	2.59	2.76	2.82	2.59	
Upland	0.36	0.34	0.26	0.15	0.13	0.19	0.23	0.21	
	Area Harvested (m/ha)								
All	3.11	3.63	3.47	3.31	3.32	3.76	3.95	3.84	3.17
Irrigated	1.43	1.49	1.61	1.84	2.01	2.33	2.48	2.50	
Rainfed	1.29	1.74	1.60	1.33	1.21	1.30	1.30	1.21	
Upland	0.38	0.39	0.27	0.14	0.10	0.12	0.16	0.14	
	Yield per Hectare (mt/ha)								
All	1.71	1.76	2.2	2.66	2.81	2.8	2.86	2.93	2.7
Irrigated	2.06	2.31	2.8	3.17	3.29	3.26	3.31	3.39	
Rainfed	1.56	1.49	1.8	2.12	2.13	2.11	2.16	2.14	
Upland	0.94	0.86	0.98	1.12	1.31	1.54	1.43	1.5	

Source: PhilRice-BAS Rice Statistics Handbook, 1997.

Sources of production growth were analyzed and discussed in the paper by David and Balisacan (1995). In their analysis, the nature of rice production growth was partitioned into three distinct phases: before 1965, 1965-1980, and 1980-1994. According to them, the growth in the pre-1965 period was due to the expansion of area in all production eco-systems. During this period, yield improvements as a source of growth were not a dominant factor. Moreover, the average growth rate of production from 1965 to1980 had reached its peak mainly due to the impact of the Green Revolution. The adoption of high yielding varieties and intensive use of fertilizers led to a high production growth rate. The dominant source of production growth was increased yields which accounted for more than 60 percent of the of production increases. The period after 1980 was characterized by declining growth rate of production and yield levels. Production growth due to area expansion became stagnant, thus making the yield parameter the main source of rice production growth.

2.2 Production Constraints and Issues in the Rice Industry

Despite technological breakthroughs in rice research, farm yield levels are still way below their maximum potential due to biological, technical, physical, socio-economic and policy constraints.

2.2.1 Biological-technical-physical constraints

<u>Technology plateau:</u> After the introduction of IR 8 in the late 1960’s, which triggered the green revolution in Asia, no genetic material introduction with the same magnitude of technological innovation has taken place. It is generally agreed among rice scientists that the technology plateau in rice took place in the late 1980’s.

Emergence of biotype: Rice production declined after the mid 1980's due to the emergence of new biological problems. The development of new strains and biotypes of rice pests were compounded by the regular occurrences of natural calamities such as floods and drought. Reduced hectarage, poor maintenance of irrigation facilities, urbanization, and post harvest losses contributed to this decline.

Low technical efficiency: 'PhilRice' studies show that farmers have low technical efficiency relative to the best farmer performance. Also, first generation varieties are still used by nearly half of the farmers. Moreover, these varieties produce relatively low yield, poor grain quality, low milling recovery, and poor tolerance to biotic and abiotic stresses. Seeding rates are still high at 120 to 200 kg/ha.

Problem soils and declining soil fertility: An estimated 1.2 million ha which is about one half of the national rice hectarage, are classified as problem soils. Of the total hectarage of problem soils, 600,000 ha have adverse water and nutrient conditions; 100,000 ha are saline-prone; 10,000 ha are alkaline; 15,000 ha are peat soils; and 500,000 ha are acid sulphate soils.

2.2.2 Socio-economic constraints

Socio-Economic constraints are composed of farmers' limited management capabilities to make correct decisions to increase their yield levels (hence profit) and the unfavorable policy environment which inhibits them from fully optimizing their decision making process.

Limited management skills of farmers: On average, there are more rice farmers in the Philippines who have limited skills in making rice farming an agribusiness venture. The relatively low fertilizer use and proper timing of application, accompanied by poor cultural management practices are major sources of inefficiency.

Deteriorating terms of trade: Although nominal protection of domestic rice production has been positive over the years, net effective protection has been declining due to higher protection on tradable inputs and overvaluation of exchange rates. This declining incentive implies bias against the rice sector in macro level resource allocation, and loss of benefits to farmers at the micro level.

Lack of appropriate and adequate infrastructure: Because of limited access to credit for processing and storage facilities, farmers are forced to sell their marketable surplus during harvest months when prices are low. Farmers cannot wait for a good price because they do not have a place to dry or store their rice. As a result, wholesalers dictate prices to retailers and consumers.

Another problem is the lack of effective irrigation systems, which is primarily constrained by: a) the substantial increase in costs for irrigation development; and b) management problems for large scale irrigation projects.

2.3 Yield Potential of Released Varieties

Based on multilocation advanced yield trials, the highest maximum yield recorded for irrigated lowland released varieties is 10.3 t/ha for PSB Rc34, a farmers' selection, followed closely by PSB Rc66 with 10.2 t/ha. A promising rice line, which was still subject to approval for release as a rice variety in 1999, has a maximum yield of 12.0 t/ha. PSB Rc4 and PSB Rc20, on the other hand, have the lowest maximum yield of 6.1 t/ha.

Among the three recommended hybrids, PSB Rc72H has the highest maximum yield of 9.9 t/ha. These hybrids have a relatively lower maximum yield than the national record because they are recommended only for specific areas in the country where they have out yielded the inbred check by at least 12 percent.

For the less favorable environments, the highest maximum yield was attained by PSB Rc14 at 5.1 t/ha among the rainfed-recommended varieties, 5.5 t/ha by PSB Rc48 for the saline prone areas, 6.0 t/ha by PSB Rc3 for the upland ecosystem, and 4.7 t/ha both for PSB Rc44 and PSB Rc46, which are the only varieties recommended for cool elevated areas.

2.4 Evidence of Yield Gaps

Rice Yield Gap Analysis in the Philippines

The yield gap is the difference between potential yields and actual yields (Roetter, et al, 1998). The yield gap can be divided into two parts. Yield Gap I is the difference between experimental station yields and potential farm yields. It exists mainly because of environmental differences between experiment stations and the actual rice farms. The potential farm yield can be approximated by the yield obtained in on-farm experiments under non-limiting input condition. Yield Gap II is the difference between the potential farm yield and the actual farm yield. This gap reflects biological constraints, soil and water constraints and socio-economic constraints that compel farmers to use inputs at a level much below the technical optimum (Figure 1). A part of Yield Gap II could be reduced through research, development, and extension, e.g., developing resistant cultivars against various biotic (insects and diseases) and abiotic water-related stresses and through appropriate socio-economic policies.

Evidence from research stations suggests that substantial productivity gains are technically possible for rice. Yet farm level output continues to rise very slowly, if not stagnating in the past decades. At present, the average farmers' yields only range from 50 to 70 percent of the on-farm experiment yield and only very few farmers have yields that are comparable to the demonstrated potential in on-farm experiments. The yield gaps that currently exist are consequences of biological constraints, soil and water constraints, and socio-economic constraints that compel farmers to use inputs at a level much below the technical optimum. Analysis shows that the average yields in the on-farm experiments from 1991 to 1995 were 5.7 t/ha during wet season and 7.5 t/ha during dry season while the average yields of the farmers are only 3.7 t/ha in the wet season and 3.9 t/ha during dry season. This corresponds to a yield gap of 2 t/ha during the wet season and 3.9 t/ha during the dry season (Table 2).

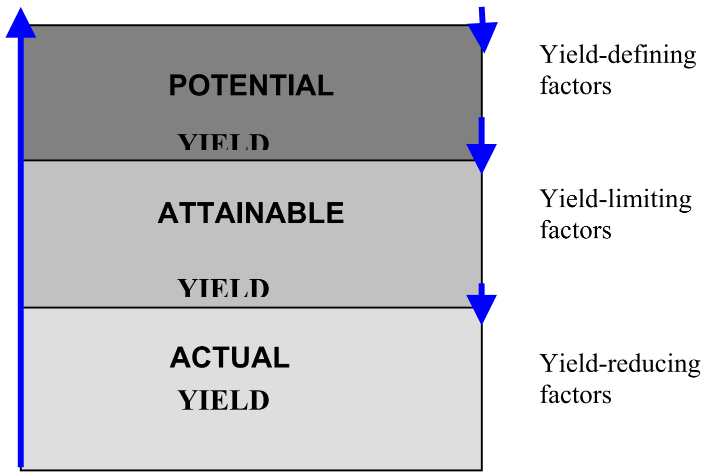

Figure 1. Yield gap analysis framework.

Table 2. Yield Gaps in Rice Production

	Wet Season	Dry Season
Simulated Potential	7.8	9.0
On-farm Experiment	5.7	7.5
Actual	3.7	3.9
Yield Gap I	2.1	1.5
Yield Gap II	2.0	3.6

Simulated potential obtained by WOFOST 7.1 crop model
On-farm experiment is average of LTCCE from 1991-95
Actual yield based on RBFH survey data 1996-97

3. PROGRAMME ACTIVITIES FOR NARROWING THE YIELD GAPS

With the current yield gap scenario faced by the country, the following activities are being vigorously pursued by the Philippine government in general and PhilRice in particular, to address the issue of rice yield gaps.

3.1 Making the Rice Research-Development-Extension (RDE) More Effective

The national rice RDE thrusts (Figure 2) emerged from an old structure that was implemented by PhilRice since it started its operations in 1987. PhilRice's experience in its 13 years of R&D suggests the need to improve the synchronization of technologies, avoid missing technology components, reduce the lag phase from development to promotion of technologies, and develop location-specific technologies.

The different RDE programmes currently implemented are interdisciplinary and ecosystem-based that integrate all the necessary components in each programme. These programmes are: a) Transplanted Irrigated Lowland Rice; b) Direct-Seeded Irrigated Lowland Rice; c) Hybrid Rice; d) Rice for Adverse Environments; e) Rice-Based Farming Systems; f) Rice and Rice-Based Products; g) Policy Research and Advocacy; and h) Technology Promotion and Development. Programme outputs are packages of technologies for specific ecosystems. In the Transplanted Irrigated Lowland Rice Programme, for example, researchers with diverse expertise work closely to develop a package of technologies for transplanted irrigated lowland ecosystems that would include the appropriate variety and the corresponding pest management options, nutrient management, and farm equipment. This programme involves a pool of researchers composed of breeders, geneticists, plant pathologists, entomologists, communication specialists, and policy researchers.

PhilRice's collaboration with the national agencies through the National Rice R&D Network and international agencies strengthens the RDE and improves its effectiveness in addressing problems.

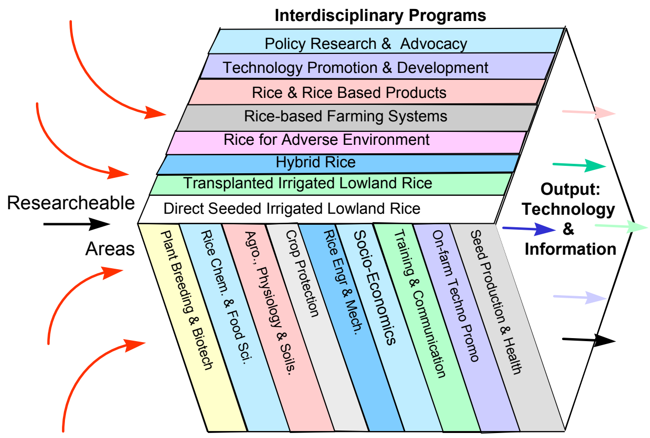

Figure 2. Conceptual paradigm of the integrated rice R&D structure and programmes.

3.2 Improving the Long Term Yield Stability of Varieties through Breeding

From 1990 until 1998, the Philippine Seed Board has approved about 41 varieties for commercial release (as shown in Appendix 1). Of these, 21 varieties are suited for irrigated areas, 12 for rainfed areas, 3 for upland ecosystems and 4 for adverse environments. There are also three hybrid varieties that were developed to adapt to certain local conditions. These are PSB Rc26H (Magat), PSB Rc72H (Mestizo) and PSB Rc76H (Panay). These varieties were developed using mostly conventional methods. One variety was developed using anther culture. Most of the released varieties are of the IR 8 plant type that has a potential yield of 10 tons per hectare.

It has been observed that many of the released varieties often succumb to pests and diseases after a few years from their release. To remedy this problem, plant breeders are using different approaches, both conventional and biotechnological, to improve yield stability. Some approaches being to increase yield stability including alien gene transfer, and use of novel genes.

Conventional methods and biotechnology: As part of the national R&D programme for rice, the improvement of the performance of varieties is being pursued using both conventional and biotechnological approaches. Current goal of the programmes on irrigated rice (transplanted and direct seeded) is to increase average yield in the experiment stations all over the country to about 7.5 t/ha by the year 2001. This is being tackled by improving the resistance of new varieties against pests and diseases and tolerance to abiotic stresses such as drought. New materials are being used as source for these characters through hybridization and biotechnology.

Location-specific release of varieties: Another approach that is being pursued is the selective release of varieties for specific problem areas or regions. This is being pursued for areas like upland, saline-prone, and cool elevated areas. Regional releases undergo rigid testing including pre-release to farmers before final release. Pre-releases ensure acceptability of recommended varieties by farmers.

3.3 Improving Crop Protection and Pest Management

Pests and diseases are the significant factors that contribute to crop losses. An analysis done by Hossain, et al, showed that the production losses due to all reported source of loss were 945 kg/ha during the wet season and 1298 for the dry season. This represents 29 and 34 percent for wet season and dry season production, respectively. Except for calamities, such as typhoon and drought, the yield loss due to insects and diseases is the highest contributor (Table 3). The yield loss accounted for by insects and diseases was 26 percent in the wet season and 16 percent in the dry season. The major pests reported were golden snail, stemborer, tungro, BPH and rice bugs. Prevention of these losses would translate into increased productivity.

Table 3. Yield Losses Reported by Farmers from Household Survey, 1992-94.

Characteristics	Wet Season	Dry Season
Yield at harvest	3,270	3,822
Production losses	945	1,298
Drought	198	759
Typhoon/strong wind	358	253
Floods	49	27
Insect and diseases	250	206
Inferior variety	25	11
Lack of capital	48	42
Others	17	0
Expected normal yield	4,215	5,120
Loss as percent of harvest	28.9	34.0

Source: Hossain, M., Gascon, F. and Revile M., 1995

Documentation of pest outbreaks in the country, which are caused by major rice pests in the Philippines is vigorously pursued. The pest profile of major rice pests and disease such as tungro, rice black bug and yellow stemborer serve as a guide to researchers in studying appropriate control measures.

PhilRice has established one of its branch stations in Mindanao, the PhilRice Midsayap branch, as the Rice Pest Management Centre in the country to coordinate all research activities on rice pest management.

3.4 Efficient Use of Fertilizer

Two aspects of nutrient management are being worked out in the Philippines, namely: improving balanced fertilization and determining the proper amount and timing of application. Despite the perennial presence of fertilizer as a component of government rice programmes, the average fertilizer use of rice farmers in the country is still relatively low when compared with the past and present fertilizer recommendations. Evidence shows that balanced fertilization strategy has a higher yield compared to farmer's mode of application. At present, research is being undertaken to come up with site-specific fertilizer recommendations.

Based on the Balanced Fertilization Strategy (BFS) of the Bureau of Soils and Water Management, the recommended average kg N-use is lower by 46 percent during the wet season, but only by 20 percent for the dry season (Table 4). One possible constraint in using the optimal amount is the high cost of this input. Although farmers recognize the importance of fertilizer in getting higher yields, farmers are not applying it because its price becomes prohibitive. The share of fertilizer ranges from 13 to 15 percent of production cost.

Timing of application and placement is also very crucial to increased yield. The leaf color chart (LCC) based fertilizer application is proven to attain higher yields at lower fertilizer rate. Data from farmers' fields showed that a given target yield can be attained with a significantly lower fertilizer rate. For example, a yield of 4 t/ha can be attained with only 50 kg/ha of N-fertilizer compared to almost 120 kg/ha N-fertilizer applied by farmers (Table

5). This technology is currently being promoted for adoption by farmers. PhilRice conducts studies to come up with a site-specific nutrient management recommendations on NPK for both wet and dry seasons.

Table 4. Farmers' Fertilizer Use and BFS Recommendation.

	Average Farmer[1]		BFS Recommended[2]		% Difference	
	WS	***DS***	***WS***	***DS***	***WS***	***DS***
N	54	100	100	125	46	20
P	11	33	30	30	63	-10
K	8	26	30	30	73	13
Yield	3.73	3.85	3.98	4.44	6.5	15.3

[1] 1996-97 RBFH Survey
[2] TechnoDemo protocol, 1998

Table 5. Method of Nitrogen Application in Nueva Ecija, Philippines, WS 1998.

Method	Yield (t/ha)	N Applied (kg/ha)	Factor Productivity (kg yield/kg N)
LCC	4.16	52	80.0
SPAD	4.17	81	51.5
FP	4.16	118	35.2

Source of Basic Data: ASD, PhilRice, 1997

Further efficiency gains can be made by deep placement of nitrogen fertilizer rather than broadcasting it. Further work needs to be done, however, to generate economically viable deep placement fertilizer application technology.

Temporary fertilizer subsidies to farmers may be cost effective in stimulating farmers to adopt and appropriately use fertilizer together with new production technologies. Further, it may be effective in overcoming the fixed costs related to adoption of new technologies and inducing farmer experimentation and learning during the period of rapidly changing technological phase. However, such temporary subsidies should be phased out as adoption of the recommended rate becomes widespread in the target areas.

3.5 Use of Quality Seeds

The national survey of rice farmers in 30 rice-producing provinces conducted in 1997 revealed that although nearly 100 percent of our rice farmers are using modern rice varieties, only about 15 percent are using high quality seeds which include foundation, registered and certified seeds. Most of them still use either homegrown seeds or farmers' seeds exchanged with neighbours. One basic reason for this low percentage of certified-seed usage is the lack of sufficient certified seeds, or if available, the high cost of quality seeds make it unaffordable to farmers.

Use of quality seeds has a yield advantage over that of farmers' ordinary seeds. Analysis of actual on-farm data shows that the average yield of farmers using quality seeds is 12.6 percent higher than the mean yield of farmers using their home saved seeds across seasons. Thus, with the use of quality seeds alone, the yield gap can be lowered substantially. When aggregated for all irrigated areas, this translates into a production increment of 1.14 million tons of paddy (Table 6).

PhilRice maintains the National Seed Production Network (SeedNet), which is composed of 90 seed growers all over the country. The SeedNet helps ensure enough supply of seeds for local farmers. PhilRice produces foundation seeds for distribution to the network. Through its technology promotion programme, PhilRice pursues a wide-scale promotion on the use of certified seeds.

Table 6. Seed Utilization and Yield by Seed Class, Philippines, 1996-97.

Seed Class	Percent Using	Yield
Quality Seeds	15	4,010
Farmer's Seeds	85	3,560
Yield Advantage		12.6%
Aggregate Production Increment		1.14Mmt

Source of Basic Data: RBFH Survey 1996-97, SED

3.6 Expansion of Irrigated Areas

With a comparatively small area for rice production, one way to increase output is to increase the proportion of irrigated areas. With the favourable crop environment afforded by irrigated areas, not only cropping intensity is doubled, but also yield. Historical data analysis shows that the irrigated ecosystem has a yield advantage of more than one ton per hectare compared to rainfed areas yields. It is also important to improve maintenance of existing systems to prevent further deterioration (Table 7).

Under the *Agrikulturang Makamasa (*Flagship programme of the government in agriculture), the government will invest substantially in the expansion of irrigated areas. The target is to increase the irrigated area by about 100,000 ha per year. This will be done through the rehabilitation of old irrigation facilities or construction of new ones.

Table 7. Yields of Irrigated and Rainfed Rice, 1970-1997.

Year	Ecosystem		Difference
	Irrigated	Rainfed	
1970-79	2.44	1.37	1.07
1980-89	3.14	1.80	1.34
1990-97	3.40	1.81	1.59
Average	**2.99**	**1.66**	**1.33**

Source of Basic Data: Philippine Rice Statistics, 1999

3.7 Intensifying Technology Promotion

The full productivity effects of yield-enhancing technologies can be best realized if the technically inefficient farmers can attain the performance of those operating in the frontier of current production technology. In order to bring the technology closer to farmers, PhilRice initiated the setting up of technology demonstration farms across the country. These farms showcase high yield technologies appropriate to the location. Results of the 'Techno-Demo' data analysis show that with better management and appropriate technology, yield increase of more than one ton per hectare can easily be realized (Table 8).

Technology demonstration areas are established all over the country, technically supervised by PhilRice in cooperation with the local technicians and farmer cooperators. These demonstration areas showcase the latest rice technologies for adoption by farmers. Some of the technologies demonstrated are balanced fertilization, integrated pest management, and hybrid rice production. Field days are conducted to gather more farmers from other areas.

In support to these activities, PhilRice conducts massive training of rice farmers and extensionists to build their technical capability. Print and audio-visual materials have been developed to serve as useful reference materials to farmers and extensionists.

Table 8. Reduced Yield Gap II due to Technology Demonstration.

	Wet Season	Dry Season
On-farm Experiment	5.7	7.5
Actual	3.7	3.9
Techno-demo	4.9	5.5
Yield Gap Iia	2.0	3.6
Yield Gap Iib	0.8	2.0
Yield Gap II reduction	1.2	1.6
On-farm experiment is average of LTCCE from 1991-95		
Actual yield from techno-demo data		

4. CONCLUSIONS AND RECOMMENDATIONS

There is a considerable yield gap between experiment station yields and farmer's yields, which can be narrowed by increasing productivity. Although we have already developed technologies for increased productivity, some policy measures need to be initiated to maximize the potential of these technologies. Researchers should continue generating new technologies and fine tune existing ones to suit the needs of resource-poor and resource-rich farmers in the different environments. Policy and decision makers should ensure the timely delivery of the required inputs of production, e.g., quality seeds, fertilizer, irrigation and water to the farmers. Lastly, there is a need to strengthen further the existing extension systems in the country. Without an efficient extension system, technologies generated will not find their own way to the farmers.

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APPENDIX 1.

Rice Varieties Approved by Philippine Seed Board for Commercial Release from 1990-1998

Year	Variety	Popular Name	Breeding Institution	Ecosystem	Average Yield (mt/ha)	Maximum Yield in Test Sites (mt/ha)
1990	PSB Rc 1	Makiling	IRRI	Upland	2.40	3.90
1991	PSB Rc 2	Molawin	IRRI	Irrigated	4.90	7.10
1991	PSB Rc 4	Nahalin	IRRI	Irrigated	4.60	6.10
1992	PSB Rc 6	Carranglan	PhilRice	Irrigated	5.70	6.90
1992	PSB Rc 8	Talavera	PhilRice	Irrigated	5.40	7.10
1992	PSB Rc 10	Pagsanjan	IRRI	Irrigated	5.10	7.50
1992	PSB Rc 12	Caliraya	UPLB	Rainfed TP*	3.80	4.00
1992	PSB Rc 14	Rio Grande	UPLB	Rainfed TP*	3.80	5.10
1993	PSB Rc 16	Enanno	Traditional	Rainfed DS**	2.70	4.30
1994	PSB Rc 18	Ala	IRRI	Irrigated	5.10	6.50
1994	PSB Rc 20	Chico	IRRI	Irrigated	5.20	6.10
1994	PSB Rc 22	Liliw	UPLB	Irrigated	5.00	7.20
1994	PSB Rc 24	Cagayan	MRC	Rainfed	3.10	4.10
1994	PSB Rc 26H	Magat Hybrid	IRRI	Irrigated	5.60	7.60
1995	PSB Rc 28	Agno	IRRI	Irrigated	4.70	9.00
1995	PSB Rc 30	Agus	IRRI	Irrigated	4.70	8.00
1995	PSB Rc 32	Jaro	UPLB	Irrigated	4.70	8.80
1995	PSB Rc 34	Burdagol	Farmers'seln	Irrigated	4.80	10.30
1995	PSB Rc 36	Ma-ayon	Traditional	Rainfed	2.70	4.90
1995	PSB Rc 38	Rinara	Traditional	Rainfed	3.20	4.40
1995	PSB Rc 40	Chayong	Traditional	Rainfed	2.80	4.40
1995	PSB Rc 42	Baliwag	PhilRice	Rainfed	3.20	3.60
1995	PSB Rc 44	Gohang	IRRI	Cool Elevated	4.20	4.70
1995	PSB Rc 46	Sumadel	IRRI	Cool Elevated	4.20	4.70
1995	PSB Rc 48	Hagonoy	IRRI	Saline Prone	2.70	5.50
1995	PSB Rc 50	Bicol	IRRI	Saline Prone	2.97	4.30
1997	PSB Rc 3	Ginilingan Puti	Traditional	Upland	2.90	6.00
1997	PSB Rc 5	Arayat	IRRI	Upland	2.90	4.20
1997	PSB Rc 52	Gandara	IRRI	Irrigated	5.30	9.00
1997	PSB Rc 54	Abra	IRRI	Irrigated	5.00	6.60
1997	PSB Rc 56	Dapitan	PhilRice	Irrigated	5.30	7.50
1997	PSB Rc 58	Mayapa	UPLB	Irrigated	4.90	7.30
1997	PSB Rc 64	Kabacan	IRRI	Irrigated	5.00	8.90
1997	PSB Rc 66	Agusan	PhilRice	Irrigated	5.20	10.20
1997	PSB Rc 72H	Mestizo Hybrid	IRRI	Irrigated	5.40	9.90
1997	PSB Rc 60	Tugatog	IRRI	Rainfed DS**	3.60	4.50
1997	PSB Rc 62	Naguilian	PhilRice	Rainfed DS**	3.70	4.70
1997	PSB Rc 68	Sacobia	IRRI	Rainfed DS**	3.40	4.40
1997	PSB Rc 70	Bamban	IRRI	Rainfed DS**	3.20	4.50
1998	PSB Rc74	Aklan	UPLB	Irrigated	5.20	8.30
1998	PSB Rc76H	Panay Hybrid	AgroSeed	Irrigated	4.70	7.90

Source: Obien 1998
* Transplanted
** Direct Seeding

BRIDGING THE RICE YIELD GAP IN SRI LANKA

Madduma P. Dhanapala*

1. INTRODUCTION

Rice is the staple food of 18.6 million Sri Lankans and is the livelihood of more than 1.8 million farmers. More than 30 percent of the total labour force is directly or indirectly involved in the rice sector. The annual per capita consumption of rice was around 92 kg in 1998 and is dependent on the paddy production in the country and the price of imported wheat flour. In 1998 total production was 2.69 million mt of rough rice (paddy), which is about 96 percent of the national requirement. With the present population growth rate of 1.2 percent, slightly increasing per capita consumption, requirements for seed, and for wastage in handling, Sri Lanka needs about 3.1 million mt of paddy by the year 2005 (Annex 1). Hence, it is projected that the national average yield should increase to 4.1 t/ha to feed the population of Sri Lanka in 2005.

2. PRESENT STATUS OF RICE CULTIVATION

2.1 Area, Production and Yield Trends in Different Ecologies

In Sri Lanka, rice is grown under a wide range of physical environments such as different elevations, soils and hydrological regimes. There is a wide range of climatic and soil conditions in the country. The annual rainfall ranges from 600 mm in the arid areas to 6,000 mm in the very wet areas. Elevation ranges from mean sea level (MSL) to 2,575 m above MSL and the average temperature ranges from 30 ^{o}C at the MSL to 15 ^{o}C at the upper most elevations. Rice lands are distributed in almost all the above agro-ecological environments except for elevations above 1,200 m MSL. Hence, compared to many other rice growing countries, Sri Lanka grows rice under a wide range of environmental conditions.

Based on the total annual rainfall, Sri Lanka is broadly divided into three climatic zones:

Dry Zone (DZ)	Rainfall < 1,500 mm
Intermediate Zone (IZ)	Rainfall 1,500 – 2,500 mm
Wet Zone (WZ)	Rainfall > 2,500 mm

Similarly, the island is divided into three major elevation zones:

Low Country (LC)	MSL 0 - 300 m
Mid Country (MC)	MSL 300 - 800m
Up country (UC)	MSL 800 and above

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By combining the two parameters above (rainfall and elevation), seven major agro-ecological zones (AEZ) have been identified (LCDZ, LCIZ, LCWZ, MCIZ, MCWZ, UCIZ and UCWZ). These AEZ were further subdivided into 24 agro-ecological regions, considering the rainfall distribution, soil type and the landform. Rice is grown in all the agro-ecological regions except in WU_1, WU_2, WU_3 and IU_2. If water conditions are right, almost all kinds of soils could be used for rice cultivation. In Sri Lanka, the hydromorphic associates of almost all its great soil groups are used for rice cultivation (Panabokke, 1996).

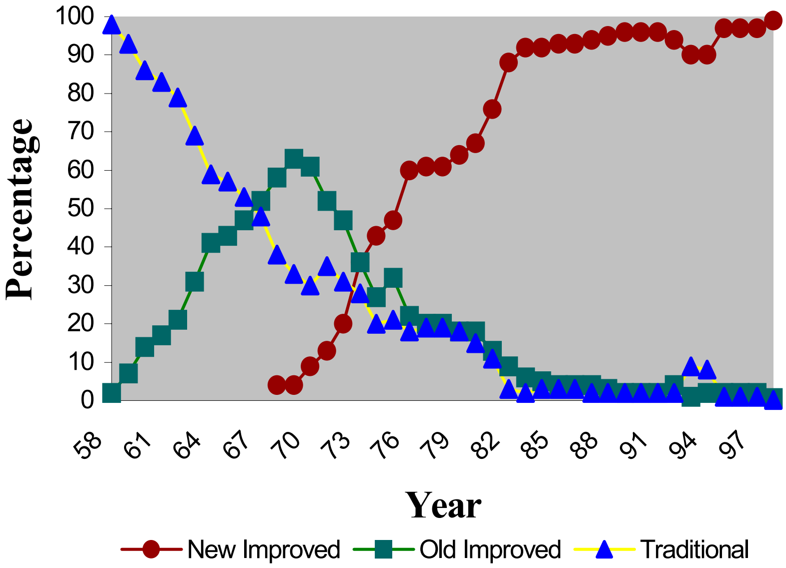

Figure 1. Percentage Distribution of Varietal Categories in Sri Lanka, 1958-1998.

The distribution of rice lands in Sri Lanka reveals, to some extent, the diverse nature of the various inland valley systems. About 75 percent of the rice lands in Sri Lanka are located within inland valley systems of varying form and size and the balance of 25 percent are located in coastal plains and associated flood plains (Panabokke, 1996).

The rice lands in Sri Lanka are further categorized either as irrigated (major and minor irrigation systems) or as rainfed and are cultivated in two distinct cultivation seasons. The major cultivation season (Maha) which is from late September to early March is fed with inter-monsoon rains and with the Northeast monsoon, which is well distributed in the Island. The minor cultivation season (Yala), which is from early April to early September, brings rain mostly to the Southwest region of Sri Lanka. Therefore, the extent under paddy cultivation in Yala is lower than that of Maha season(Table 1).

Table 1. Average Area Cultivated and the Projections for the Future

Land Category	Season	Average Area Cultivated (ha)	Average Grain Yield (t/ha)	Anticipated Area to be Cultivated (ha)	Present Cropping Intensity	Anticipated Cropping Intensity
Major Irrigation	Maha Yala	256,000 177,000	4.66 3.90	275,000 183,000	140	150
Minor Irrigation	Maha Yala	136,000 56,000	3.27 3.03	148,000 87,000	109	135
Rainfed	Maha Yala	168,000 77,000	2.99 2.55	173,000 99,000	98	110

National average yield of rice in Sri Lanka increased from around 2 t/ha in the 1970's to 3.5 t/ha by the early 1980's. Since then it remained stagnant despite 95 percent of the rice extent being brought under improved cultivars (Figure 1). However, yields higher than the national average were recorded in major irrigation systems where water supply is assured. In minor irrigation and rainfed systems, a lower grain yield was recorded due to various stresses and risk factors involved in crop management (Table 1). The present national average (3.7 t/ha) is around 50 percent of the genetic potential (6-7.5 t/ha) of improved cultivars recommended for cultivation in Sri Lanka (Table 2).

Table 2. Percentage Extent Cultivated by Different Varieties of Rice and the Yield Potential

Variety	Age (Months)	Cultivated Extent (% of the total)	Yield Potential** (ton/ha)
Bg 300	3.0	21.68	6.5
Bg 352	3.5	11.83	7.0
Bg 94-1	3.5	11.7	7.0
Bg 350	3.5	7.04	7.0
BG 450	4.5	5.57	7.0
Ld 355	3.5	4.39	5.0
Bg 379-2	4.0	4.33	7.5
Bg 403	4.0	4.22	7.5
Bw 351	3.5	1.74	7.0
Bg 400-1	4.0	1.60	7.5
Bg 304	3.0	1.42	6.0
Bw 267-3	3.0	1.35	4.0
At 353	3.5	0.96	6.0
Bg 357	3.5	0.50	7.5
Traditional	-	1.08	2.5
Others (> 20 varieties)		20.6	-

Bg - Batalagoda, At - Ambalantota, Bw - Bombuwela, LD - Labuduwa
** - Yield potential at respective breeding stations

2.2 Production Constraints in Different Agro-ecologies

Existence of a yield gap between the potential yield of cultivars and the productivity realized in farmers' fields is evident in many developing countries. In the recent past, researchers have been successful in improving the genetic potential of new cultivars by introducing an improved plant type, but farmers failed to exploit this potential. The obvious reasons cited for this yield gap in many instances are crop management deficiencies resulting from socio-economic and/or institutional constraints.

Expression of grain yield potential of a rice cultivar is determined by its interaction with climatic, edaphic and biotic components of the environment. The highest potential for rice productivity is in the Low Country Dry and Intermediate Zones where solar radiation and other climatic parameters are conducive and the edaphic environment is relatively favourable. Apart from relatively low solar radiation during Yala, lower yield potential in the Wet Zone is also due to excess water associated with various soil problems.

A collaborative investigation undertaken by the Australian National University (ANU), Commonwealth Scientific and Industrial Research Organization (CSIRO) and the Department of Agriculture, Sri Lanka (DOASL) to quantify the yield gap and identify reasons, has revealed that the yield disparity between the farmer and researcher managed blocks were significant and can be narrowed down economically. The yield gap was due to compounded effects of many factors attributed to the farmers' perception of production technologies. In many instances, the predominant factors were weeds, insect pests and inefficient management practices. (Dhanapala et al.., 1984; Perera et al., 1990). In these studies, only the disparity between important management practices (stand establishment, weed control, fertilizer use, pest and diseases management) and seed quality were seriously considered. However, the contribution of some obvious edaphic and climatic factors determining yield was inadvertently neglected. Practices such as non-seasonal, untimely staggered cultivation, neglecting the optimum use of climatic parameters to increase productivity were not considered. These practices resulted in a build up of pest and disease pressure due to overlapping cropping cycles. Further, the factors influencing chemical, physical and biological properties of soil to improve and sustain fertility, the major determinant of crop productivity in the tropics, were totally ignored. Quality of land preparation, growth duration and appropriateness of the cultivar for a given ecology and pre- and post-harvest losses were considered less important. These shortfalls led to the neglect of vitally important climatic, edaphic, biotic and management yield determining parameters.

A subsequent farm household survey conducted by Herath Banda et al. (1998) revealed that weed infestation was the most disastrous constraint to production across all agro-ecologies followed by either excess and/or deficit of water. The problem of weeds is severe in the Dry Zone and could be related to the availability of water as most farmers use standing water in controlling weeds. The estimated cost for controlling weeds in rice was over 20 US$ per ha (Herath Banda et al., 1998). Excess water problem is serious in the Wet Zone and in the other areas during crop establishment as more than 90 percent of the rice crop in Sri Lanka is direct seeded. Water deficit for rice cultivation in the Dry and Intermediate Zones could lead to substantial yield loss as in many instances the crop is subjected to terminal drought. Even though the pest and diseases were problematic for rice cultivation in the early 1970's, with the increase in the usage of improved varieties with required genetic resistance to many biotic stresses and improvement of farmer pest management practices, they are less important to farmers today. These household survey findings reflect the farmer's attitude towards production constraints to achieve his target yield from his paddy plot with low yield potential. However, the real constraints to increase the yield potential of these production plots could be different. Obviously the major yield determinant is the inherent soil fertility, though given less attention in very many instances in these investigations.

Wickramasinghe et al. (1995), found that not only the national rice grain yield is stagnating, but also the grain yields in research fields are gradually declining. The grain yield of rice cultivars grown with high N fertilizer in long term N response studies showed a well defined declining trend over time. The yields of 7 t/ha or more achieved during the late 1970's with improved semi-dwarf rice cultivars in these experimental plots were never recorded. In long term studies (36 seasons) at RRDI, Batalagoda, Sri Lanka, without the use of any form of added fertilizer, but depending solely on the inherent soil fertility under maximum cropping intensity, yields around 2.5-3 t/ha were observed. This suggests that the inherent soil nutrient supply is sufficient only for a grain yield of about 2.5-3 t/ha in these fields.

Studies have also shown that at RRDI, Batalagoda, to produce 5.5 t/ha of paddy, a direct seeded 4 month rice crop would absorb about 16 g N per m^{-2} while a transplanted crop would absorb about 12 g N per m^{-2}. Further studies have revealed the existence of a non linear relationship between total leaf N at flowering and grain yield suggesting that the yield could be further increased with increased uptake of N but never beyond 6.5 t/ha. This suggests that not only N, but also other factors are responsible in limiting grain yield of rice. Some extensive soil analytical studies performed in Sri Lanka revealed that the micronutrient status of rice soils are at endangered levels. This is so specifically for Zn, Cu, Fe and S. Toxic levels are reported only for Fe and Mn in isolated instances (Deb et al., unpublished) where Fe toxicity is frequently reported in the Wet Zone of Sri Lanka. Studies on the response of the rice plant to added micronutrients also revealed that Zn and Cu are deficient in some areas. In plant analyses studies, Zn, Cu, S and Fe were reported deficient from previous investigations (Deb, unpublished). Therefore, it was understood that the reduced nutrient uptake at important growth stages of the rice crop due to reduction in soil nutrient supply was a major limitation to increased rice yields.

Apart from the biotic and edaphic factors, climatic factors are also responsible for the yield gap. In the early days, farmers used to cultivate the rice crop with the onset of the monsoon. Timely cultivation and collective participation were primary considerations in rice culture. Togetherness and correct timing in planting and harvesting within the season, reduced the risk of terminal drought and pest and disease incidences. Cultivation of around 70 percent of the total extent of rice under irrigation does not necessarily imply the availability of an assured supply of water for rice cultivation. Many reservoirs (minor irrigation) are seasonal and are used for supplementary irrigation only. On many occasions the rice crop may be subjected to water stress during its growth cycle. Therefore, timely cultivation with the onset of the monsoon is essential to reduce risk of terminal drought. The practice of collective cultivation of the same growth duration rice cultivars is rare today. Further, early crop establishment helped the farmers to cultivate medium duration (4-4½ months) rice cultivars with higher grain yield potential where they exploited the growing environment to a maximum by harnessing the solar energy for a longer period. However, the use of medium duration cultivars is declining gradually and is less than 18 percent at present.

There are complex socio-economic and institutional constraints hindering the productivity of rice. The escalating cost of production of rice along with the increasing cost of living affected the investment power of the farmer on inputs in rice cultivation. This along with the inherent poverty, small land holding sizes and unattractive land tenure system further aggravated the capacity to invest on inputs. Inferior quality inputs, difficulty in obtaining agricultural credit facilities and labour shortage also directly affected the output from rice farming. Breakdown of the agriculture extension system affecting the technology transfer process reduced the lateral transmission of information. Moreover, social status of the farmer in the open and competitive market has made rice cultivation unattractive, particularly to the younger generation. These socio-economic and institutional problems encountered by the farmer have an indirect effect on the rice production sector in Sri Lanka. Problems in marketing and lack of comparative advantage further aggravated the problem by discouraging farmers, thus widening the yield gap.

The constraints for increasing productivity by bridging the yield gap are complex and can be categorized into 3 groups. They are: environmental, institutional, and socio-economic constraints.

3. PROGRAMME FOR NARROWING THE YIELD GAP

A comprehensive programme to overcome most of the above constraints to improve productivity and profitability was formulated by the DOASL in the mid 1990's. Bridging yield gap is the immediate output of the activities listed in this package. Simultaneously, reduction of cost of production, prevention of pre and post harvest losses and improvement of farm income by value addition etc., are also anticipated.

3.1 Increased Paddy Production

Increase in total rice production could be achieved by increasing the cultivated land area and yield per unit area under rice. Production extent in the country cannot be increased any further, but the cropping intensity could be increased from the present 119 percent to about 130 percent so that the total annual cultivated extent would be 0.96 million ha. More of the neglected rainfed rice lands in the Low Country Wet Zone as well as those with supplementary irrigation facilities (minor irrigation systems) in the Dry and Intermediate Zones have to be given due priority in the rehabilitation process to improve cropping intensity as envisaged.

3.2 Bridging the Yield Gap

In the comprehensive programme developed by the DOASL to improve productivity, a technical component addressing issues pertaining to genotype and environment interaction are discussed below.

3.2.1 Appropriate cultivars

Emphasis is given to location specific cultivars to maximize the use of natural resources. Grain yield of rice could be increased by growing medium duration (4 month) cultivars rather than short duration cultivars. It is intended to increase the present extent under medium duration cultivars (4 month) wherever possible. However, when water is limiting, increasing the cultivated extent using short duration cultivars (3-3.5 month) with intensive management is recommended.

3.2.2 Use of quality seed rice

Use of quality seed rice to maximize yield and to maintain quality of the harvest is encouraged. However, supply of seed rice to farmers at an affordable price at the correct time is increasingly difficult. Therefore self-seed rice production is encouraged while the farmer is supplied with mini-kits of seed with new cultivars for multiplication. Private sector participation in the seed industry is also encouraged by the government.

3.2.3 Collective and timely (seasonal) cultivation

Timely cultivation with the onset of monsoon rains is essential to economize on the use of inputs and to maximize the use of natural resources. Delayed planting especially in the Maha (October-March) season affects the growth and the age of the rice crop. Farmers are encouraged to follow a uniform cultivation calendar without any overlapping of different growth stages in a given tract. This would help to integrate crop management practices on a tract basis thus reducing time spent on maintaining individual crops. Further, it would make the job of extension and related supporting services easy as well as organizing marketing and other activities properly.

3.2.4 Soil fertility improvement and sustenance

Improvement of the soil's physical, chemical and biological status for its sustainability is the key feature of this whole package of practices. At present, due to the increased cropping intensity and high temperature, the organic matter content in rice fields in the Dry and Intermediate Zones of Sri Lanka has been reduced to less than 1 percent. The use of improper implements for ploughing has led to the formation of a shallow plough layer or hardpan resulting in poor plant growth and grain yield. The topsoil is often coarse textured and therefore the addition of organic matter, especially rice straw and/or animal waste and ploughing occasionally to a depth of about 20-25 cm is considered advantageous in the majority of the rice lands. Macro and micronutrients, based on soil test values, are added at the correct time.

3.2.5 Crop management

3.2.5.1 Stand establishment

Predominantly, stand establishment in rice in Sri Lanka is carried out by direct sowing. Transplanted rice in Sri Lanka is negligible as the labour cost is high. It is always recommended to transplant medium aged (4-4.5 months) rice while direct seeding short age (3-3.5 months) rice. This is also important to maximize the grain yield as well as to minimize the nutrient removal from the soil. Maintaining optimum plant density as recommended for different age classes of rice could further increase grain yield while saving the valuable soil nutrients.

3.2.5.2 Weed management

Weed management is a major problem in rice as water is limiting in most instances. It is recommended to practice integrated weed management by proper land preparation and by using manual, mechanical and chemical weed management practices. Use of correct herbicides at the appropriate stage of crop growth and application of the correct dosage is considered important to improve the effectiveness of the chemical.

3.2.5.3 Insect pest and diseases management

More emphasis is given to use safer insecticides at correct amounts to minimize pest damage. By implementing the IPM strategies it is intended to reduce the cost while reducing environmental pollution.

3.2.5.4 Nutrient management

Management of the major nutrients such as N, P and K with micronutrients where needed is another area with high priority in this package of practices. Nitrogen management of the growing rice crop is very important as return to all the other practices depends on proper N management of rice. Location specific target yield based fertilizer guidelines are available for all the age classes of rice for ready reference.

3.2.6 Post harvest management

Post harvest losses in rice in Sri Lanka are as high as 15 percent of the grain yield. It is intended to reduce this loss by proper time of harvesting, correct processing and storage. Value addition to rice is considered important in order to increase the income from rice farming in Sri Lanka.

3.2.7 Rice-based integrated farming

To maximize the profit and to sustain a conducive soil environment, integration of crops and livestock is encouraged wherever possible.

3.3 Development of Farmer Organizations

To improve the status of the farmer, it is intended to develop farmer organizations which could function in organizing all the activities related to farming. In this regard, to avoid socio-economic and institutional constraints, a well defined role is played by an agricultural extension worker in organizing farmers for collective cultivation, timely supply of agricultural inputs, organizing credit and marketing facilities etc., so that no bottlenecks are anticipated in the production programme.

4. EXPECTED OUTPUT BY IMPLEMENTING THE TECHNOLOGICAL PACKAGE

With the adoption of the above package of practices it was clearly demonstrated that the average yield of many systems of rice cultivation could be increased (Table 3).

Table 3. Average Yield Recorded (1998) with the Implementation of the Technological Package in Two Representative Rice Growing Districts in Dry and Intermediate zones

Land Category	Season	Farmers Average Grain Yield, t/ha		Grain Yield Potential (t/ha)**
		Ordinary Farmer (Normal Management)	With Improved Management*	
Major Irrigation	Maha Yala	4.66 3.90	6.4 5.9	8.3[a] 7.6[a]
Minor Irrigation	Maha Yala	3.27 3.03	4.8 4.9	8.8[b] 8.0[b]
Rainfed	Maha Yala	2.99 2.55	3.5 -	6.0[c] -

*Average yield of a yaya (whole tract) cultivated using improved technological package of practices.
** Highest yield of a yaya cultivated using improved crop management practices
a Ampara, b Kurunegala, c Varietal adaptability trials, Kurunegala
Source: Extension and Communication Center, Department of Agriculture, Sri Lanka

On average, a yield increase of about 30 percent could be easily achieved with the adoption of the above package. It is therefore intended that the national average rice yield will also increase up to the expected targets. It is well established that with the existing technology, a grain yield of 8-10 tonnes of paddy per ha is possible in favourable well managed irrigated lowland rice lands in the Dry and Intermediate Zones of Sri Lanka. Even in the rainfed high risk environments in the Dry and Intermediate Zones, grain yield achieved using the improved technological package was comparable with the national average yield (Table 3).

The Government of Sri Lanka has already launched a special "rice productivity enhancement programme" to implement the above technological package on tract basis in irrigated and rainfed rice lands, on continuously increasing extents as depicted below.

In the initial year 5 percent of the extent in both irrigated and rainfed lands will be brought under this programme. From the second year onwards an additional 5 percent of the extent under irrigated lands and 2.5 percent of the extent under rainfed lands will be introduced in each season giving a time series extent to cover nearly 35 percent of the total cultivated extent of the land in both seasons (Table 4).

Table 4. Expansion of Area ('000 ha) under the Yaya Programme, from 1998 to 2005

Irrigation System	Maha		Yala	
	1998	2005	1998	2005
Major	12.80	102.40	8.85	70.80
Minor	6.80	54.40	2.80	22.40
Rainfed	8.40	37.80	3.85	17.33

It is anticipated that these technological package demonstration sites will act as dissemination centres where the technology will be laterally spread. With the successful adoption of this package it is expected that the average grain yield in the major, minor irrigation and rainfed systems will be increased to 5.66, 5.42 and 3.89 t/ha respectively. It is expected that, once this reasonably profitable package of practices is demonstrated, the cultivated extent will be increased as the marginal lands identified at present could easily be brought under cultivation. The anticipated cropping intensity will average around 130 percent, thus bringing the total annual cultivated extent during both seasons to about 0.95 million hectares (Table 3), which would ultimately increase the total rice production of the island.

5. CONCLUSIONS

- Yield potential of a cultivar is only a hypothetical concept determined by a complex series of interactions with the components of the environment it is exposed to.

- Disparity between the yield realized by the farmer and the potential of a cultivar in a given environment could purely be due to compounded effects of crop management deficiencies attributed to the inadequacies of knowledge and the poor management skills of the farmer.

- Reasons for such a disparity may be technical, institutional or socio-economic. The yield gap thus observed could be bridged economically with a technological package of practices if institutional and socio-economic constraints are eliminated.

- Productivity improvement by bridging the yield gap should be addressed in a broader sense to harness the maximum potential of the climatic, edaphic and biotic components of the environment. Some of these components can be modified but some are beyond the control of the farmer.

- An appropriate technological package to express the potential of the cultivar in a given environment should be formulated and introduced to improve management skills of the farmer.

- Organized rice farming through farmer organizations and a collective approach for cultivation, supply of inputs, organizing credits and marketing of the products is of paramount importance for the very survival of the rice farmer in Sri Lanka.

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Annex 1.

Projected Rice Requirement for Sri Lanka from 1999-2005

Year	Population Projection (mil.)	Per Capita Consumption (Kg)	Milled Rice Requirement (‘000 mt)	Rough rice requirement (‘000mt)
1999	18.85	92.0	1734.20	2809.49
2000	19.04	92.5	1761.20	2851.73
2001	19.23	93.0	1788.39	2894.27
2002	19.43	93.5	1816.71	2938.56
2003	19.62	94.0	1844.28	2981.70
2004	19.82	95.0	1882.90	3042.12
2005	20.01	96.0	1882.90	3101.67

BRIDGING THE RICE YIELD GAP IN THAILAND

Tawee Kupkanchanakul*

1. INTRODUCTION

Rice is the most important food crop in Thailand. The total area under rice is estimated to be about 11 million ha representing approximately 40 percent of the cropped land area. Rice lands can be classified as irrigated, rainfed lowland, deepwater, and upland ecosystems. More than 80 percent of the rice growing area in Thailand is under rainfed conditions where rice is usually grown only once a year in the wet season, where the monsoon rain is the single source of water supply for rice cultivation. Less than 20 percent of the area is under irrigated conditions where rice can be grown not only in the wet season but also in the dry season because irrigation water supply is available. In the 1997/98 crop year, the wet season rice accounted for 88 percent of the annual rice area and 80 percent of production. Dry season rice accounts for 12 percent of the area and 20 percent of production. Rainfed lowlands account for approximately 75 percent of the wet season rice area, and 68 percent of production. Deepwater and uplands account for a further 1.92 and 0.58 percent of the wet season rice area, and about 1.17 and 0.32 percent of production, respectively. Annual production in 1997/98 crop year was about 23.580 million tonnes. Some 18.789 million tonnes representing approximately 80 percent of the annual production is produced in the wet season when average yield is very low, at around 2.24 t/ha. Only 4.791 million tonnes representing approximately 20 percent of the annual production is produced in the dry season when average yield is relatively high, in the range of about 4.31 t/ha.

The general policy for rice production in Thailand is to produce rice for self-sufficiency and surplus for export to earn foreign exchange. Currently, it aims to produce about 22-23 million tonnes of paddy annually comprising 13-14 million tonnes for domestic consumption and about 8-9 million tonnes of paddy, which is equivalent to 5.5 million tonnes of milled rice, for export. Major production comes from the wet season rice crop with the supplement of the dry season crop.

2. STATUS OF RICE CULTIVATION IN DIFFERENT ECOLOGIES

2.1 National Rice Production Status

The area planted to rice in Thailand showed an increasing trend from the 1960's to the 1980's with approximately 2 percent growth rate, which leveled off in the 1990's. The annual rice cultivated area in the 1960's, 1970's, 1980's and 1990's was about 6.698, 8.468, 9.932, and 9.865 million ha, respectively. Average yield and total production showed an increasing trend from the 1960's to the 1990's with approximately 1.70 and 3.01 percent growth rate, due mainly to an increase in irrigated and dry season rice production. Average

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yield in the 1960's, 1970's, 1980's and 1990's was about 1.57, 1.91, 2.02, and 2.28 t/ha with annual production of about 9.942, 14.625, 19.090, and 20.62 million tonnes, respectively.

The wet season rice growing area in Thailand showed an increasing trend from the 1960's to the 1980's with approximately 2.2 percent growth rate, and tended to decrease in the 1990's. The average wet season rice cultivated area in the 1960's, 1970's, 1980's and 1990's was 6.698, 8.171, 9.212, and 9.077 million ha, respectively. The wet season rice yield showed an increasing trend from the 1960's to the 1990's with approximately 1.25 percent growth rate. The average wet season rice yield in the 1960's, 1970's, 1980's and 1990's was 1.57, 1.71, 1.90, and 2.07 t/ha, respectively. The wet season rice production showed an increasing trend from the 1960's to the 1990's with approximately 3 percent growth during the 1960's-1980's and 1.5 percent in the 1990's. The average wet season rice production in the 1960's, 1970's, 1980's and 1990's was 9.942, 13.678, 16.693, and 17.370 million tonnes, respectively.

The extensive dry season rice production programme in Thailand began in the 1970's. Cultivated area, yield and production of dry season rice exhibited an increasing trend. In the 1970's, 1980's, and 1990's the area planted to dry season rice was 0.371, 0.678, and 0.781 million ha, with average yields of 3.31, 3.61, and 4.23 t/ha, resulting in dry season rice production of 1.417, 2.397, and 3.291 million tonnes, respectively.

2.2 Area, Production and Yield Trends in Different Ecologies

As mentioned earlier, rice production in Thailand can be classified into 4 ecosystems; irrigated, rainfed lowland, deepwater, and upland. Rainfed lowland is the most predominant rice ecology in Thailand followed by irrigated, deepwater and upland. There is no data available to compare the production classified by different ecologies. In a survey conducted by the Monitoring and Evaluation Section, Rice Research Institute, about 96.7, 2.9, and 0.4 percent of rice cultivated areas in the 1987/88 crop year were planted with lowland, deepwater, and upland rice varieties (Rice Research Institute, 1993) where about 15 percent of lowland areas were irrigated. IRRI (1993) reported that the area under rainfed lowland, irrigated, flood prone, and upland ecosystems in Thailand for the 1991/92 crop year was 8.756, 0.720, 0.660, and 0.053 million ha representing 78.6, 14.4, 6.6, and 0.4 percent of the total rice area, respectively. During the 1991/92 cropping year, the yield contribution to the total rice production of the country from rainfed lowland, irrigated, deepwater, and upland ecosystems was 15.760, 2.880, 1.320, and 0.080 million tonnes, or 78.7, 14.4, 6.5, and 0.4 percent of the total rice production, respectively. Average yield was highest in irrigated, followed by flood prone, rainfed lowland, and upland ecosystems, at about 4.0, 2.0, 1.8, and 1.5 t/ha, respectively (IRRI, 1993). There was no significant change in the area under the rainfed lowland environment, but the area under irrigation increased while areas under deepwater and upland ecosystems decreased significantly during the past two decades (Table 1).

Rainfed Lowland: Rainfed lowland is the predominant rice ecology in Thailand. In the 1977/78 crop year, rainfed lowland accounted for 78.1 percent of the wet season rice area and 68.0 percent of production or about 60 percent of annual production (Table 1). The importance of the rainfed lowland ecology to national rice production was generally recognized. In the 1997/98 crop year, it occupied about 75 percent of the wet season rice area and 62 percent of production or about 49 percent of annual rice production. Average yield in the rainfed lowland of Thailand was extremely low, at about 1.30 t/ha during the 1977/78 crop year and 1.87 t/ha in the 1997/98 crop year (Table 1), which needs to be improved.

Irrigated: The irrigated ecology is the most favourable environment for rice production. The importance of the irrigated ecosystem to rice production in Thailand has two aspects: increased rice production in the wet season and in the dry season. In the 1977/78 crop year, the irrigated ecosystem accounted for about 13 percent of the annual rice cultivated area (0.705 million ha in the wet season and 0.461 million ha in the dry season) and 17 percent of production (2.120 million tonnes in wet season and 1.586 million tonnes in dry season). In the 1997/98 crop year, the irrigated ecosystem accounted for about 32 percent of the area (1.905 million ha in the wet season and 1.112 million ha in the dry season) and 49 percent of production (6.761 million tonnes in wet season and 4.791 million tonnes in the dry season). The average yield of irrigated rice was 4.31 t/ha in the dry season and 3.55 t/ha in the wet season, which is about 90 percent higher than rainfed lowland rice (Table 1).

Deepwater: Vast rice growing areas in the Central Plain of Thailand are subject to long periods of deep flooding annually. In the 1972/73 crop year, Kongchantuk (1972) reported that about 0.82 million ha of rice areas were planted to floating rice varieties. Recently, Molle and Keawkulaya (1998) reported changes in rice ecology in the Central Plain of Thailand, attributed to land modifications and infrastructure made to control flood which resulted in the reduction of the deepwater area. The harvested area under the deepwater ecosystem was estimated at about 0.810 million ha (9.77 percent of the wet season rice area) in 1977/78 and 0.160 million ha (1.92 percent of the wet season rice area) in 1997/98. However, the area under the deepwater ecosystem is believed to be higher but most fields are very often left unplanted during the flooding period. Yield contribution from the deepwater ecosystem was small, approximately 1.442 million tonnes in the 1977/78 and 0.312 million tonnes in the 1997/98 crop years (Table 1). Average yield in the deepwater ecosystem was generally low, at about 1.95 t/ha.

Upland: Upland rice constitutes the smallest rice ecology in Thailand. In the 1977/78 crop year, the area under the upland ecology was estimated to be about 0.300 million ha representing approximately 3.62 percent of the wet season rice area (Table 1). A drastic reduction in rice area under the upland ecosystem was observed in the past two decades. In the 1997/98 crop year, upland rice accounted for less than 1 percent of the area and production.

2.3 Production Constraints in Different Ecologies

Rainfed Lowland: Rice production in the rainfed lowland environment, being dependent on rainfed conditions, is very vulnerable to climatic variability. Yield fluctuation is common among rice grown in rainfed environments. Major production constraints are: rainfall variability, drought, submergence, and inherent low soil fertility, especially in the northeastern region (Table 2). Infrastructure at farm level in most rainfed lowland rice areas is very poor and cannot support a high level of rice production.

Irrigated: The irrigated ecosystem is the most favourable environment for rice production. Production constraints are generally not related to climatic factors but biotic factors i.e. diseases and insect pests such as yellow orange leaf virus in the central region during 1968-1971, blast in the central region in 1975-1977, neck blast in the northern region in 1994, ragged stunt in the central region in 1977-1978 and 1989-1980 , brown plant hopper in the central region in 1989-1990, while golden apple snail and rats are rampant in most years. Water scarcity in the dry season is also a most important constraint for rice production in irrigated environment such as in the 1994 dry season.

Deepwater: Drought at early vegetative phase, long term deep flooding at late vegetative phase to early ripening phase, and weed competition are the most important production constraints in the deepwater ecosystem. Very abnormal deep flooding in the 1995/96 crop year caused serious yield losses in this ecosystem.

Upland: Drought, poor soil fertility, and weed competition are the most important production constraints in upland ecosystem.

2.4 Yield Potential of Released Varieties and Evidence of Yield Gaps in Different Ecologies

Rainfed Lowland: Released rice varieties for the rainfed lowland ecology are shown in Table 3. Most of the rainfed lowland rice areas are planted to improved traditional and local varieties which vary among locations. These varieties are mostly photoperiod sensitive. Their yield potential is generally lower (about 4.5-6 t/ha) but they have better grain quality and characteristics than HYVs. The most common popular variety currently grown in the rainfed lowland areas is Khao Dawk Mali 105. In the 1997/98 crop year, Khao Dawk Mali 105 occupied approximately 26 percent of the area and contributed 22 percent to wet season rice production (Centre for Agricultural Statistics 1999a).

Rainfed lowland rice is generally grown under poor conditions, i.e., poor crop management with low inputs and is subjected to climatic variability. Therefore, the yield gap in the rainfed lowland ecosystem is very high. Narrowing yield gaps in the rainfed lowland ecology is more difficult than in irrigated environments because of uncontrollable environmental factors.

Irrigated: Released rice varieties for the irrigated ecology are shown in Table 3. Most of the dry season irrigated rice areas are planted to several high yielding varieties (HYVs) such as Chainat 1, Suphanburi 60, Suphanburi 90, RD23, RD10, RD15, Suphanburi 1, and Suphanburi 2. But Chainat 1 is the most popular variety currently grown in the irrigated ecosystem. In the 1998 dry season, Chainat 1 accounted for approximately 57 percent of the area and 58 percent of production (Centre for Agricultural Statistics 1999b). Yield potential of these varieties is high at about 6-8 t/ha. Yield gaps in irrigated ecologies are still high, especially in wet season rice cropping, due mainly to limited irrigation water, low inputs used, and crop losses caused by diseases, insects and pests. Narrowing yield gaps in the irrigated ecology is still possible.

Deepwater: Released rice varieties for the deepwater ecosystem are shown in Table 3. Most of the deepwater areas are planted to local and traditional improved varieties such as Pan Tawng, Khao Banna, Plai Ngahm Prachinburi, Huntra 60, Leb Mue Nahng 111, Pin Gaew 56 etc. Yield potential of deepwater rice varieties, both local and traditional, are generally low, giving about 3-4 t/ha. However, newly developed improved plant type deepwater rice lines have higher yield potential of about 4-5 t/ha. The yield gap in the deepwater ecosystem is generally small.

Upland: Released rice varieties for the upland ecosystem are shown in Table 3. The yield potential of these varieties is generally low, often about 2-3 t/ha. Similar to the deepwater ecology, the yield gap in the upland ecosystem is also small.

3. PROGRAMME FOR NARROWING THE YIELD GAPS

3.1 Historical Perspective

Increasing rice production in Thailand in the past was largely attained by expanding the cultivated areas and to some extent, by increasing the yield. Since rice land is limited and expanding the cultivated area to marginal land will result in low yields, increasing the yield therefore, seems to be the most effective means to increased rice production. In Thailand, good grain characteristics and quality are the most important traits needed to be maintained while efforts are made to improve average yield. Therefore, average yield in Thailand is relatively low compared to other countries in this region.

3.2 Activities and Results of Programmes to Narrow Yield Gaps During the Last Two Decades

To narrow yield gaps during the past two decades, several programmes/activities have been implemented.

Rice Varietal Improvement Programme: Development of HYVs is the most effective means of narrowing yield gaps which contributed greatly to increasing rice production. Narrowing the yield gap through the development of HYVs became successful in irrigated environments, especially in dry season rice production. Several HYVs with different disease and insect pest reaction notably RD10, RD21, RD23, Suphanburi 60, Suphanburi 90, Suphanburi 1, Suphanburi 2, Khao Jao Hawm Suphanburi, Khao Jao Hawm Khlong Luang 1, Phisanulok 60-2, and Chainat 1, were developed in the past two decades. Some varieties are still popular and widely grown until the present time. The average yield of these varieties was estimated to be about double that of traditional varieties.

Seed Production and Seed Exchange Programme: The importance of good seed in crop production is generally acknowledged. Farmers usually keep their own seed for next season's planting. The quality of farmers' seeds is generally lower than the standard. In order to improve rice yield and grain quality by utilization of standard seed in rice production, a seed production and seed exchange programme was implemented during 1981-1986. Instead of buying rice seed from seed agencies at high cost, farmers can bring their own seed in exchange for good seed at the same price.

Production Technology Improvement Programme: Apart from cultivar development, improvement of production technology is needed in narrowing the yield gaps. In general, transplanting is the most popular planting method for rice production, but is labor intensive for seedling preparation and transplanting, resulting in high cost of production. In order to reduce the cost of rice production and increase yield, wet seeded rice technology or "*Nah*

Wan Namtom" has been developed. The project was implemented in 1981-1986 under the 5th National Economics and Social Development Plan. Wet seeded rice technology is widely adopted by farmers. More than 90 percent of irrigated rice areas are currently using the wet seeded rice method.

Rainfed Rice Improvement Programme: The first phase of the programme was implemented during 1983-1985 under the 5th National Economics and Social Development Plan and extended to the second phase during 1986-1990 under the 6th National Economics and Social Development Plan. The main objective is to improve rice production in rainfed environments, especially in poor smallholder subsistence lowland rice farms, through technology development and technology transfer. Several improved rice varieties/lines such as RD6, RD7, RD8, RD10, RD13, RD15, RD23, BKN6902-3-1, BKN7914-179-4-1 and Niew Ubon 1 were recommended. Apart from cultivar development, production technology for rainfed rice, especially crop establishment by direct dry seeded method was developed for drought prone environments (Rice Research Institute 1987a). About 20 percent of rice areas in the rainfed lowland ecology are currently dry seeded.

Upland Rice Production Improvement Programme: The programme was implemented during 1982-1986 under the 5th National Economics and Social Development Plan. It was the continuation of the original upland rice production improvement programme under The Royal Initiated Project. The objective of the programme was to increase the level of rice self-sufficiency in the upland ecosystem. Several upland rice varieties such as Sew Mae Jan, Khao Pong Krai, Jao Haw, Nam Roo, R258, R293, Blechai, and Motoza, were developed.

Land Consolidation, Dike and Ditch Construction Programme: Apart from component technology development, infrastructure and rehabilitation of paddy fields was also needed in narrowing the yield gap because rice cultivars can fully express their yield potential only when they are planted under a favourable environment. Favourable environments permit an effective use of inputs for yield improvement. Most of the ricelands in Thailand, especially in the rainfed ecosystem, have poor infrastructure. Therefore, rainfed rice is generally grown under poor management with low inputs, resulting in very low yield, usually less than 2 t/ha. The land consolidation, dike and ditch construction project aims to improve the infrastructure of paddy fields and increase rice yields. About 0.275 million ha of rice land have been consolidated and 1.655 million ha had dike and ditch systems constructed, mainly in the central region (Table 4). Yield increase after land consolidation was estimated to be about double the average yield in this ecosystem. The programme will be continued to further expand the area under land consolidation by about 10,000 ha annually.

Water Resources Development Programme: By nature rice is a water-loving plant. Research in Thailand indicated that water consumption for rice production was estimated at about 9,400 m^3/ha in the wet season and 12,500 m^3/ha in the dry season, approximately 50 percent higher than for other crops (Tawng-Aram, 1986). Water resources for rice production in Thailand is limited, especially in dry season rice cropping. The central and northern regions are mainly irrigated (Table 5). More water resources development and irrigation facilities are needed in narrowing rice yield gaps.

Irrigation Pumps for Rice Cultivation Programme: To utilize available water from rivers, canals, and lakes as supplement water for rice cultivation, irrigation pumps are installed in areas where natural water resources are available. The energy source for pumping is mainly electricity. In the 1987/88 crop year, approximately 0.173 and 0.130 million ha of the rice cultivated area in the wet and dry seasons were under this project (Table 5).

3.3 Issues and Challenges in Narrowing the Rice Yield Gap in the Country

Rice production in Thailand in the past three decades has been a balance between yield and quality. Emphasis is currently more on quality than quantity. Consequently, the national average rice yield is still low inspite of the several programmes that had been implemented in narrowing rice yield gaps during the past two decades. Since land and water resources for rice production are limited and the country has to increase its production to meet the increasing demand for domestic consumption and to be more competitive in the world market, the national rice industry needs an effective production system to narrow the yield gaps. Both agricultural technology development and farm infrastructure improvement are, therefore, of utmost importance.

Rainfed Lowland Ecology: To narrow the yield gap in the rainfed lowland ecology, improvement of farm infrastructure such as land leveling, irrigation and drainage facilities, and farm road construction are needed. Improvement of farm infrastructure creates a favourable environment for rice growth and effective utilization of inputs for rice production. Good Agricultural Practices (GAP) for rice production in rainfed environments are being developed.

Irrigated Ecology: Irrigated rice will become the most important rice ecosystem and contribute significantly to national rice production in the future. Good practices for rice production at all growth phases, and post-harvest technology are needed in narrowing the yield gap in the irrigated ecology. Exploration of water resources and improvement of farm infrastructure can significantly increase rice yield.

4. CONCLUSIONS AND RECOMMENDATIONS

Rice is the most important crop in Thailand. The total area under rice is estimated to be about 11 million ha, representing approximately 40 percent of the cropped land area. Rice lands can be classified as irrigated, rainfed lowland, deepwater, and upland ecosystems. The average rice yield in Thailand is relatively low, often less than 2 t/ha. Several attempts have been made to improve rice yield in the past two decades through varietal and agronomic improvement and the development of water resources for rice production. Yield improvement through these efforts was small and needed to be further enhanced.

Rainfed lowlands and irrigated areas are the most important rice production ecosystems in Thailand. In the 1997/98 crop year, rainfed lowlands accounted for 66 percent of the area and 49 percent of production while irrigated rice accounted for 32 percent of the area and 49 percent of production. The area under deepwater and upland ecologies are very minor and contribute very little to national rice production. Yield gaps in rainfed lowlands and irrigated ecologies are high.

Rice production in the rainfed lowland environment being dependent on rainfed conditions, is very susceptible to climatic variability which results in low yields. Major production constraints are related to poor paddy field infrastructure and unfavourable environmental factors such as rainfall variability, drought, submergence, and inherent low soil fertility. To narrow the yield gap in rainfed lowland environments, improvement of farm infrastructure such as land leveling, irrigation and drainage facilities modifications, and farm road construction should be done before the introduction of improved production technologies. Technology components to improve rice yield in the rainfed ecosystem are the adoption of improved varieties, use of healthy and good seed, appropriate field preparation and planting methods, optimum planting date and proper crop management, soil fertility improvement and correct fertilizer application, good water control, integrated crop protection, proper harvesting date, and post-harvest technologies.

In irrigated ecosystems where most environmental factors are favourable for rice growth, development and production, narrowing the rice yield gap in these ecosystems should be done through the application of good agricultural practices for rice production during all growth phases. The development of HYVs will contribute greatly in narrowing the yield gap in irrigated environments. Hybrid rice with acceptable grain quality is also possible. The utilization of good and healthy seed can play an important role in increasing rice yield. Good land preparation with an appropriate planting method such as the wet seeded rice cultivation method will guarantee good crop stand establishment. Water management and correct fertilizer application for proper crop growth and development at all growth stages and high production are also needed in narrowing the yield gap. Adoption of integrated crop protection technologies to control pests and weeds can significantly increase rice yield in irrigated ecosystems. Harvesting the crop at about 30 days after seed-set and reducing grain moisture to about 14 percent can further reduce yield losses and maintain good grain quality, especially in dry season rice cropping.

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Table 1. Estimated Harvested Area, Yield, and Rice Production in Thailand in 1977/78 and 1997/98 Crop year by Ecologies

Ecologies	Area (million ha)		Yield (t/ha)		Production (million tonnes)	
	1977/78	1997/98	1977/78	1997/98	1977/78	1997/98
Wet Season						
Irrigated	0.705	1.905	3.01	3.55	2.120	6.761
Rainfed lowland	6.474	6.223	1.30	1.87	8.420	11.632
Deepwater	0.810	0.160	1.78	1.95	1.442	0.312
Upland	0.300	0.048	1.31	1.75	0.393	0.084
Wet Season Rice	***8.289***	***8.336***	***1.49***	***2.25***	***12.375***	***18.789***
Dry Season						
Irrigated	0.461	1.112	3.45	4.31	1.586	4.791
Dry Season Rice	***0.461***	***1.112***	***3.45***	***4.31***	***1.586***	***4.791***
Annual	***8.750***	***9.448***	***1.59***	***2.50***	***13.921***	***23.580***

Table 2. Some Chemical Properties of the Rice Land Soil in Different Regions (Adapted from Srisen et al., 1979)

Region	Chemical Properties				
	pH	Organic Matter (%)	CEC (me/100g)	Available P (ppm)	Extractable K (ppm)
Northeastern	5.0	0.72	4.9	3	47
Northern	5.7	2.50	11.8	8	106
Central	5.5	2.45	22.1	7	215
Southern	5.0	2.36	7.8	9	84

Table 3. Yield Potential of Released Varieties and Yield Gaps in Different Ecologies

Ecologies	Released Varieties	Yield Potential (t/ha)	Yield Gaps
Irrigated	RD10, RD21, RD23, Suphanburi 60, Suphanburi 90, Suphanburi 1, Suphanburi 2, Khao Jao Hawm Suphanburi, Khao Jao Hawm Khlong Luang 1, Phisanulok 60-2, and Chainat 1	6-8	high
Rainfed Lowland	RD6, RD8, RD15, Khao Dawk Mali 105, Khao Tah Heang 17, Chumpae 60, Niew Ubon 1, PathumThani 60, Pitsanulok 60-1, Leaung Pratew 123, Kaen Jan, and Phattalung 60	4.5-6.0	very high
Deepwater	RD17, RD19, Huntra 60, Prachinburi 1, Plai Ngahm Prachinburi, Pin Gaew 56, Leb Mue Nahng 111, and Tapow Gaew 161	3-4	small
Upland	Sew Mae Jan, Khao Pong Krai, Jao Haw, Nam Roo, R258, Goo Maung Luang, and Dawk Phayom	2-3	small

Table 4. Land Consolidation, Dike and Ditch Construction for Rice Production by Region as at end of 1996. (Centre for Agricultural Statistics 1998)

Region	Land Consolidation (ha)		Dike and Ditch (ha)	
	Intensive	Extensive	Indirect	Direct
Northern	10,380	73,521	51,920	133,278
Northeastern	6,684	30,442	224,555	21,362
Central	77,140	76,468	139,744	853,537
South		112	29,918	20,763
Total	**94,205**	**180,542**	**446,137**	**1,028,939**

Table 5. Water Resources Development Completed and Pump Irrigation for Rice Cultivation in Thailand as at end of 1996. (Centre for Agricultural Statistics 1998)

Region	Total Irrigated Area (ha)	Pump Irrigation for Rice Cultivation Area (ha)	
		Wet Season	Dry Season
Northern	1,248,841	51,938	59,642
Northeastern	818,228	72,890	26,253
Central	2,162,628	37,635	28,901
South	484,040	10,773	15,056
Whole Kingdom	**4,713,738**	**173,235**	**129,851**

BRIDGING THE RICE YIELD GAP IN VIETNAM

Bui Ba Bong *

1. INTRODUCTION

Vietnam has 33 million ha of land, of which 7 million ha are agricultural land and rice occupies 4.2 million ha. Rice is the staple food of the Vietnamese people providing 80 percent of the carbohydrate and 40 percent of the protein intake in the diet. It is the predominant crop in most of the ecological regions of the country (Table 1). The sown area was 7.5 million ha in 1998 producing 30 million tonnes of paddy (Table 2). The national average yield is 4 t/h. During the last 10 years the rate increases per year of rice production, sown area and average yield in Vietnam were 5.3, 3.0 and 3.5 percent, respectively. Thanks to the continuous increase in rice production, Vietnam could supply rice to the world from 1989 and has now become the world's second largest rice exporter. The quantity of rice exported reached 3.8 million tonnes in 1998 (Table 3).

The area and yield of different rice crops are shown in Table 4. The popular high yielding rice varieties in the Mekong Delta are shown in Table 5. The improved high yielding rice varieties in the Red River Delta are indicated in Table 6. The area, yield and production of hybrid rice are shown in Table 7.

Rice is grown in three major ecosystems a) irrigated and intensive b) rainfed and flood prone and c) upland. The irrigated and intensive ecosystem occupies 60 percent of the rice land, while the rainfed and flood prone and the upland ecosystems occupy 32 and 8 percent, respectively.

2. RICE ECOSYSTEMS

In Vietnam, rice is grown in almost all ecological regions with variable topography and the growing areas lie within the tropics (8^o N-23^o N; 15^o S). In the southern delta, the climate is warm-humid all year round with ample sunshine. The northern delta is in the tropical monsoon area with cold winters. The highlands in the north have cool summers and bitterly cold winters, while the highlands in the central region are cool all year round with a long dry season. The central coast of the country has a mixture of northern and southern climates. These characteristics create diversity in rice culture separated by three distinct ecosystems: irrigated and intensive, rainfed and flood-prone and upland.

2.1 Irrigated and Intensive Ecosystem

Irrigated areas lie mainly in the Red River Delta of the north and Mekong River Delta of the south. In the Red River Delta, rice is cultivated with other upland crops in various cropping patterns. In the lowland irrigated areas, two rice crops or two rice crops plus one

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upland winter crop are planted. In the Mekong River Delta, most irrigated areas are planted to two rice crops: winter-spring and summer-autumn and in some areas three rice crops per year are grown. The yield in the irrigated systems reaches 6-7 t/ha in dry season (spring) and 4-5 t/ha in wet season (summer).

2.2 Rainfed Lowland and Flood-prone Ecosystem

In the past, Vietnam had 300,000 ha of the floating rice in the Mekong River Delta (water level is as deep as 3 m at flowering time). But since 1983, these areas were converted to irrigated areas with 2-3 rice crops pear year when the new canals were constructed. In the Mekong Delta at present there are some 600,000 ha of medium-deepwater with floodwater depths of 30-100 cm. Most of the rice is rainfed, and is unlikely to be replaced by irrigated rice because of the limitation of freshwater resources. Traditional varieties are grown which are photoperiod sensitive, with a yield range from 2.5 to 4.5 t/ha. In shallow rainfed lowlands, improved varieties of medium growth duration (130-150 days) are planted. Yield levels of 5-6 t/ha could be obtained. The yield is usually affected by the water depth. A sampling survey showed that the average yield was 3.05 t/ha for <40 cm water depth, 2.76 t/ha for 40-80 cm and 2.14 t/ha for depths around 80 cm.

2.3 Upland Ecosystem

Upland rice in Vietnam is grown in about 0.45 million ha. This comprises 8 percent of the total rice area in the country. It is grown by 54 ethnic groups of which 50 groups practice shifting cultivation. The total affected area represents about 8 million ha where some 3 million ethnic minorities live. The usual range of annual rainfall is 1,400-1,800 mm but it is very erratic and droughts are common. Slash-and-burn shifting cultivation is the predominant cultivation system. Rice is planted using a stick with 5-10 seeds/hole and holes are dug 20-30 cm apart. Almost no fertilizers or chemicals are used. The yield varies from 0.6 to 2.0 t/ha. After 2-3 years, the farmers abandon the land and move to a new location for planting. Traditional varieties are planted, most of which are sticky varieties, and maturity duration is often in the 130-160 day range. Land degradation and poor soil fertility are serious problems in the upland ecosystem.

3. YIELD GAP AND STRATEGY TO NARROW THE YIELD GAP IN MAJOR RICE ECOSYSTEMS

3.1 Irrigated and Intensive Ecosystem

Problems:

- Stagnant yields in irrigated lowlands.
- Biotic stresses, for example: sheath blight, blast, bacterial blight, brown plant hopper, stem borer, thrips, and leaf-folder.
- Abiotic stresses, for example: acid sulphate soils, salinity, and drought (in rainfed lowlands).
- Lack of early maturing high yielding varieties.
- Low seed yields of hybrid rice.
- Too few parental lines for developing hybrids for Vietnam.
- Too few heterotic hybrids suited to the Red River and Mekong River deltas.
- Poor grain quality of inbreds and hybrids.

Solutions:

- Breeding of high yielding varieties of various maturity groups and good grain quality, including scented rice.
- Breeding high yielding hybrid rice, adaptable to the Red River and Mekong River deltas and possessing acceptable grain quality.
- Breeding of genetically diverse parental lines (cytoplasmic male sterility and temperature-sensitive genetic male sterility- CMS and TGMS) to develop hybrid rice.
- Developing hybrid rice seed production technology.
- Management strategies for durable pest resistance that account for varietal diversity, crop nutrition, cultural techniques, and integrated pest management (IPM).
- Quantifying nutrient balances for present and future productivity levels.

Expected Results:

- To sustain rice yield with no symptoms of yield decline or declining factor productivity, and with high output-input ratios.
- To achieve an average annual increase of 3 percent in rice yields for more stable productivity. By 2005, the average rice yield in irrigated areas would be 5 t/ha per crop.
- Meeting the needs of domestic and international customers with varieties of high quality grain.
- Development of a hybrid seed industry resulting in the generation of rural employment opportunities.

3.2 Rainfed Lowland and Flood-prone Ecosystem

Problems:

- Soil problems: acid sulphate soils and saline soils in the Mekong River Delta and degraded soils in the Red River Delta.
- Erratic distribution of water, drought in the early season and the severity of flooding in the latter part of the wet season.
- Insect pests and diseases: stem borer, brown plant hopper, bacterial leaf blight.

Solutions:

- Breeding for varieties with tolerance to abiotic stresses.
- Improved soil management for different types of acid sulphate soils, particularly use of phosphorus; toxicity thresholds for rice and screening for phosphorus efficiency and iron and aluminum toxicity.
- Organic matter management and sustainable agriculture on degraded soils.
- Upland crops in rotation with rice in single-rice cropping areas to increase water-use efficiency.

Expected Results:

- Rice yield could be increased by 0.5-1.0 t/ha per crop.

3.3 Upland Ecosystems

Problems:

- Soil degradation and erosion; low soil fertility; subsoil acidity; low availability of phosphorus and potassium; lack of organic matter; and lack of nitrogen.
- Irrigation not available; and frequent droughts.
- Lack of improved (high yielding) varieties adapted to the diversity and variability of the uplands; limited number of crop species suitable for upland ecosystems; weeds; blast; nematodes; and rice bugs.

Solutions:

- Varietal improvement: Evaluation of traditional cultivars collected and identification of traditional cultivars tolerant to drought and phosphorus deficient soils, resistant to blast and nematodes, tolerant to soil acidity, and with good competitiveness for weeds. Improved germplasm to be introduced.
- New tools for ecosystem management: Crops, hedgerows, and cover crop species tested and evaluated for their efficiency in protecting the soil surface from erosion and preventing pest and disease buildup; appropriate farming systems including integration of livestock and fish culture. Pest and disease management developed; management practices of crop residues tested and evaluated for their effects on the long-term management of organic matter and phosphorus; and new weeding tools developed.

Expected Results:

- Improved productivity in the uplands, expected yield to be increased by 1 t/ha.

4. CONCLUSIONS

In the coming years, to meet the increasing food demand of the population (from 76 million in 1998 to 100 million in 2010), rice production in Vietnam should be steadily increased. The area under rice production will not be expanded in the future because the land that can be reclaimed for rice growing is very limited and requires heavy investment. Therefore, Vietnam must carefully preserve rice land and concentrate intensification on narrowing the yield gaps in all the rice ecosystems. This would help to increase the rice yield from the present level of 4 t/ha to 5 t/ha by 2010 corresponding to an increase in rice production from 30 million to 37-38 million tonnes.

Table 1. Production of Major Crops in Vietnam (1997)

Crop	Area planted (thousand ha)	Yield (t/ha)	Production (million tonnes)
Rice	7091	3.90	27.6
Maize	659	2.49	1.6
Soybean	100	1.02	0.103
Peanut	251	1.40	0.353
Sweet potato	267	6.14	1.6
Cassava	239	8.31	2.0
Sugarcane	251	45.5	11.4
Tobacco	28	1.00	0.28
Cotton	15	0.75	0.14
Coffee	270	1.48	0.400

Source: General Statistical Office (1998)

Table 2. Trends in Rice Production, Area and Yield in Vietnam (1988-1998)

	1988	1994	1995	1996	1997	1998	Increase % per Year (1988-98)
Harvested area (million ha)	5.7	6.6	6.7	7.0	7.1	7.5	3.0
Yield (tonnes/ha)	2.90	3.56	3.69	3.77	3.90	4.0	3.5
Production (million tonnes)	17.0	23.5	25.0	26.4	27.6	30.0	5.3

Source: General Statistical Office (1998)

Table 3. Rice Export from Vietnam (1989-1998)

Year	Quantity Exported (million tonnes)	Value (thousand US$)	Average Price (US$/tonne)	Quality of Exported Rice (%)		
				High	Medium	Low
1989	1.372	310	226	0	2.5	97.5
1990	1.478	275	186	14.3	8.7	77.0
1991	1.016	229	225	35.0	10.0	55.0
1992	1.953	405	207	40.3	15.2	44.5
1993	1.649	335	203	51.2	21.4	27.4
1994	1.962	420	214	51.2	21.4	27.4
1995	2.025	538	266	70.0	13.0	17.0
1996	3.047	868	285	54.8	22.7	22.5
1997	3.680	900	242	44.0	8.0	38.0
1998	3.793	1006	266	53.0	11.0	36.0

Source: Ministry of Commerce, Vietnam

Table 4. Area and Average Yield (t/ha) in Different Rice Crops in Vietnam (1994-1997)

Crop	Area (thousand ha)				Yield (t/ha)			
	1994	1995	1996	1997	1994	1995	1996	1997
Spring Rice	2381	2421	2541	2682	4.41	4.43	4.80	4.96
Summer Rice	1577	1742	1984	1866	3.57	3.73	3.47	3.51
Autumn Rice	2640	2601	2478	2542	2.80	2.97	2.95	3.06

Table 5. Popular High yielding Rice Varieties in the Mekong Delta of Vietnam (1998)

Variety Name	Origin	Duration (days)	% Harvested Area of 2.5 million ha
IR50404-57	IRRI	95	15
OMCS94	IR59606-119 (IRRI)	95	14
OM1490	OM606/IR44592	90	12
OM1706	OM90-9/OM33-1	95	8
IR64	IRRI	105	10
OM1723	OM554/IR50401	95	10
IR56279	IRRI	95	5
IR66707	IRRI	105	5
OM997	OM554/IR50401	95	8
IR9729-67	IRRI	95	3
IR62032-189	IRRI	105	1
OMFi1	MRC19399 (Philippines)	105	0.9
OM1633	NN6A/IR32843	95	0.7
OM1271	OM89/IR68	95	0.7

Table 6. Improved High-yielding Rice Varieties in the Red River Delta (1998)

Variety Name
U14, U17, U20, P1, Xuan 11, CR103 (IR8423), C70, C71, TK90, X20, NR11, X21, CR01, X33, VN10, DH6, DT10, DT11, DT13, DT33, D271, CM1

Table 7. Hybrid Rice Production in Vietnam, 1992/96

Years	Area (ha)	Yield (t/ha)	Production (tonnes)
1992	11,340	6.60	75,52
1993	34,828	6,71	233,69
1994	60,007	5,84	350,44
1995	73,503	6,14	463.40
1996	102,800	6.58	677,40

YIELD, PROFIT, AND KNOWLEDGE GAPS IN RICE FARMING: CAUSES AND DEVELOPMENT OF MITIGATION MEASURES

V. Balasubramanian, M. Bell, and M. Sombilla *

1. INTRODUCTION

More than 250 million farm families cultivate rice in Asia (Hossain and Pingali 1998). In the past three decades, they produced 2.5 percent more rice each year to meet the growing food demand (Hossain and Fischer, 1995). This tremendous achievement was possible due to the development and use of high yielding rice varieties, provision of assured water supply, liberal application of fertilizers and pesticides, and focused institutional and policy support for rice crop intensification. According to Hossain (IRRI, 1998-1999), making cheap rice available to millions of poor consumers is the single most important contribution that IRRI has made in the Asia-Pacific Region.

However, it appears that we have exhausted the potential of the 'green revolution' strategies, as we witness declining rice productivity in many countries. In the next 3 decades, farmers need new approaches and technologies to produce 50 to 60 percent more rice on existing or less land and water with limiting and/or expensive inputs. The three factors that could contribute to increased rice productivity are: (a) developing new rice varieties including hybrids with higher yield potential; (b) minimizing the yield gap between what is currently harvested by farmers and the achievable highest on-farm yield of varieties they grow; and (c) reducing the post-harvest losses and improving grain quality to enhance profitability. This paper elaborates on rice yield, profit and knowledge gaps, with brief discussion on yield ceiling to provide a complete scenario.

2. DEVELOPING RICE VARIETIES WITH HIGHER YIELD POTENTIAL

The potential yield is 10 t ha^{-1} for presently available semi-dwarf *indica* rice varieties. An additional 10 to 15 percent increase in rice yields can be expected with the development of tropical rice hybrids (Virmani et al., 1991) which are currently being introduced to many Asian countries. New Plant Type (NPT) lines are being developed to further increase the potential yield of rice varieties.

2.1 New Plant Types

IRRI-developed NPT lines, popularly termed by the media as 'super rice', are expected to yield 12.5 t ha^{-1}. Development of hybrids using NPT could increase the yield further to 14-15 t ha^{-1}. Research is ongoing to incorporate resistance/tolerance to major insect pests and diseases and to improve grain quality. Fully developed NPT lines will become available for testing in farmers' fields by the year 2001-2002.

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2.2 Hybrid Rice Technology

Hybrid rice technology is complex in terms of production of quality seed and crop management. Virmani and Sharma (1994) have developed a manual for producing hybrid seeds in the tropics. The Directorate of Rice Research, Hyderabad, India, has developed a production package for hybrid rice (DRR, 1998): nursery seeding rate of 10-20 g m^{-2}; 1-2 seedlings per hill; herbicide + one hand weeding; 150 kg N ha^{-1} with adequate P, K, Zn, and S; continuous (5 cm water depth) or cyclic submergence; and adequate plant protection.

Proper choice and improvement of parental lines for resistance to pests and diseases as well as better grain quality, development of 2-line hybrids, maintenance of genetic purity of parental lines of popular hybrids, and refinement of a seed production package may enhance the spread of hybrid rice in tropical Asia (Paroda, 1998). Hybrid rice technology should only be promoted in areas best suited for its cultivation. Private sector seed companies have a critical role to play in the supply of quality hybrid seeds to farmers at affordable prices.

3. TYPES OF RICE YIELD GAPS

There are different types of yield gaps: gap between genetic potential and biologically attainable yields, variability in rice yields in different regions, gap between research station and farmers' yields, and yield differences among farmers in a given homogenous environment.

3.1 Gap between Potential and Attainable Yields

As discussed above, the potential yield of semi-dwarf *indica* varieties is 10 t ha^{-1}. However, under the best management conditions, farmers can reap 80 to 85 percent of the potential yield of varieties. The difference between genetic potential yield at the experiment station and the highest attainable yield in farmers' fields is the yield gap due to environmental differences and non-transferable technology, and thus it cannot be bridged. If the potential yield of rice varieties is increased beyond 10 t ha^{-1} by developing hybrids and New Plant Types, farmers can attain correspondingly higher yields when they use those varieties. This is the reason why rice breeders are trying to increase the potential yields.

3.2 Variability in Rice Yields in Different Countries and Regions

High variability exists in rice yields across countries and regions as shown in Table 1. This type of yield gap is due to differences in biophysical (climate, length of growing season, soil, water, pest pressure, etc.) and socio-economic factors, crop management, and access to and use of knowledge and technologies. For example, the high rice yield in Australia is due to:

- Favourable climate: high solar radiation, cloudless long growing season (150-180 days), optimum temperature.

- Precision crop management (crop rotation, single rice crop per year, smooth and level soil surface, use of registered pure seed every season, precise control of water level, high plant density, need-based/timely/balanced fertilizer application, high quality post-harvest management.

- Enlightened farmers and excellent technical support (Beecher, 1999).

The generally high yields obtained in temperate regions (record yields can go up to 14-15 t ha^{-1}) is mainly due to low night temperature, especially at the reproductive stage. We cannot modify the climatic regime and certain biophysical factors, but we can certainly improve the crop management of and technical support to rice farmers to improve rice productivity in Asia, Latin America and Africa.

The national mean, irrigated, and potential rice yields of selected countries of Asia are given in Table 2 (Pingali et al., 1997). The gaps between the potential and irrigated yields are small compared with gaps between the potential and the national average yields. Low yields of rainfed lowland and upland rice ecosystems bring down the national average yields. In such cases, the yields of rainfed lowland rice have to be improved by developing location-specific varieties and production technologies. The major targets for creating impact in rainfed lowland rice systems are: (a) developing varietal resistance to abiotic stress related to uncertain water supply, (b) improving dry seeding methods, (c) maintaining natural resilience of ecosystem to pests, and (d) incorporating micronutrients in rice (Fischer and Cordova, 1998).

Table 1. Mean Rice Yields (t ha^{-1}) in Different Countries and Regions (1994)

Country/Region	Area '000 ha	HYV coverage %	Yield t ha^{-1}	Yield gap %
Countries				
Australia	122	100	8.3	--
Egypt	579	--	7.9	4.8
USA	1,366	100	6.7	19.3
Japan	2,212	100	6.8	18.1
Spain	63	100	6.2	25.3
S. Korea	1,160	100	6.1	26.5
China	30,373	100	5.9	28.9
Regions				
Europe	612	100	5.2	37.3
Asia	134,560	2-91	3.8	54.2
Latin America and Caribbean	5,723	47-100	3.2	61.4
Africa	7,929	--	2.2	73.5
World	150,305	--	3.7	55.4

Table 2. The National Mean, Irrigated, and Potential Rice Yields of Selected Countries (Adapted from: Pingali et al., 1997)

Country	National Mean Yield, t ha^{-1}	Irrigated Rice Yield, t ha^{-1}	Potential Rice Yield, t ha^{-1}	Gap Between Potential and Irrigated Rice Yield, %	Gap Between Potential and National Mean Yield, %
Bangladesh	2.6	4.6	5.4	14.8	51.9
China	5.7	5.9	7.6	22.4	25.0
India	2.6	3.6	5.9	39.0	55.9
Indonesia	4.4	5.3	6.4	17.2	31.3
Nepal	2.5	4.2	5.0	16.0	50.0
Myanmar	2.7	4.2	5.1	17.6	47.1
Philippines	2.8	3.4	6.3	46.0	55.6
Thailand	2.0	4.0	5.3	24.5	62.3
Vietnam	3.1	4.3	6.1	29.5	49.2

3.3 Gaps between Maximum Attainable and Economically Exploitable Yields

Rice yields of experimental plots represent the maximum attainable yields with no physical, biological and economic constraints. They also reflect the knowledge frontier and best known management practices at any given point in time (Pingali et al., 1997). When the target is to maximize profits, the yields obtained are lower than maximum attainable yields (Herdt, 1988). This is termed as the economically exploitable yields. Farmers tend to maximize profits, but consistent with high economically exploitable yields. Exploitable yields are slightly higher in research plots than in farmers' fields as observed in the Philippines (Otai, 1997) - Table 3. The gap in exploitable yields between on-farm research plots and farmer cooperators' fields is less than 6 percent in both seasons. This means that farmer cooperators have learned the improved farming techniques by continuous interaction with researchers and observations of the crop management activities and yield superiority in research plots located in their own fields. On the contrary, the yield gap between on-farm research plots and non-cooperators is 14 percent during the wet season and as high as 39 percent in the dry season. This signifies that farmer non-cooperators operate at low efficiency, for they have yet to learn more about the improved crop management practices either from their neighbours or from research/extension staff.

Table 3. Mean Fertilizer Inputs and Rice Yields in On-farm Research Trials, Farmer Cooperators' Fields, and Non-cooperators' Fields, Maligaya, Central Luzon, Philippines, 1996-97

Particulars	No. of Farms	Mean N-P-K, kg ha^{-1}	Mean Yield, t ha^{-1}	Yield gap, %
1996 Wet Season (July to October)				
On-farm trials	17	61-20-26	4.16 (1.01)*	--
Farmer cooperators	28	102-16-23	3.96 (1.31)	4.8
Farmer non cooperators	39	117-7-11	3.56 (0.83)	14.4
1997 Dry Season (January-April)				
On-farm trials	17	94-12-31	6.92 (0.90)	--
Farmer cooperators	28	130-11-27	6.52 (1.02)	5.8
Farmer non-cooperators	39	145-7-13	4.25 (1.23)	38.6

Source: Otai, 1997.
* Figures in brackets are standard deviation of the mean.

A reverse case from Guyana is illustrated in Table 4. Some progressive farmers obtain much higher yields in their fields than those harvested at the research station in Guyana. The mean rice yield in research (breeding) plots is 31.9 percent lower than that of progressive farmers for the same variety Rustic during the spring season of 1999 (Shrivastava et al., 1999). The main limiting factor appears to be the level of N fertilizer application (Figure 1). The variety Rustic is highly susceptible to blast, and its potential yield is not realized even in the research station due to low N application. Other blast-resistant varieties have now been developed (e.g. Diwani) that give high yields using high N levels (Table 4).

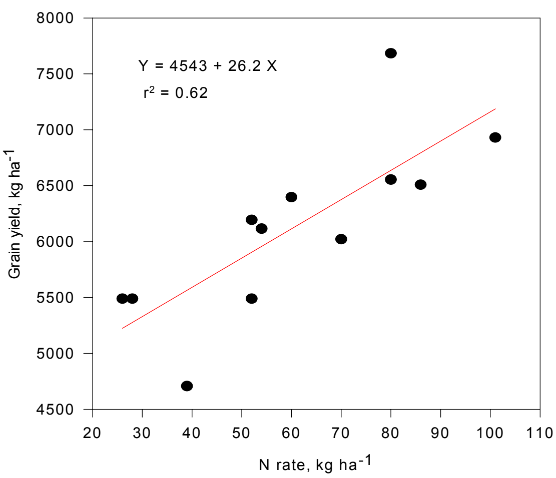

Figure 1. Relationship between grain yield and rate of N application in rice by progressive farmers of Guyana,

Table 4. Mean Yields of Current Commercial Rice Varieties in Breeding Experiments and on Farmers' Fields, Guyana, Spring 1999 (adapted from Shrivastava et al., 1999)

Farmer/Research Station	Area, ha	Variety	N-P-K, kg ha^{-1}	Yield, t ha^{-1}	Yield Gap, %
S. Yaap	2.0	BR 240	80-16-0	6.55	
P. Lall	2.4	G 95-4	86-17-0	6.51	
B. Ramnarine	3.8	Rustic	54-8-0	6.12	
A. Aiyad	2.0	Rustic	70-16-0	6.02	
Heeralal	1.0	Rustic	52-12-0	6.19	
S. Seecharan	5.2	Rustic	101-10-0	6.93	
Chaitram	5.2	Rustic	60-21-0	6.40	
Sesnarine	2.0	Rustic	80-16-0	7.68	
P. Buddhoo	2.0	Rustic	52-12-0	5.49	
A. Mohammed	1.5	BR 444	26-12-0	5.49	
C. Singh	81.2	BR 240	28-5-8	5.49	
I. Alladin	24.2	F7-10	39-6-0	4.71	
Farmers' mean	**21.2**	**Rustic**	**67-14-0**	**6.45**	**--**
Breeding	**Small plot**	**Rustic**		**4.39**	**31.9**
Breeding	-- do --	BR 444		5.71	
Breeding	-- do --	Diwani		6.37	
Breeding	-- do --	F7-10		5.22	

3.4 Rice Yield Differences among Farmers in a Homogenous Region

All farmers do not operate at the same efficiency level. In a survey of rice farmers in Maligaya, Central Luzon, Philippines, Otai (1997) found that there were significant differences in rice yields of on-farm trials, farmer cooperators, and non-cooperators during the 1996 wet season and the 1997 dry season (Table 3). PhilRice has estimated that only 40 percent of the farmers are as efficient as the best farmers and obtain high yields. About 50 percent of the farmers obtain 3.0 t ha^{-1} or less and 70 percent of the farmers 4 t ha^{-1} or less. The average national rice yield is 3.3 t ha^{-1}. This average yield can be increased to 5.0 t ha^{-1} with currently available technologies. Additional data in Table 4 demonstrate the differences in rice yields among farmers in Guyana. Significant yield differences among rice farmers do exist in other countries as well.

Certain factors (Figure 2) are responsible for yield gaps among farmers: biological (soil, water, seed quality, pests); socioeconomic (social/economic status, family size, household income/expenses/investment); farmer knowledge (education level) and experience; farmers' management skills; farmers' decision making (attitude, objectives, capability, behavior); and institutional/policy support (rural development & infrastructure, land tenure, irrigation, price, tax, crop insurance, etc.). All these factors should be addressed to reduce the yield gaps among farmers.

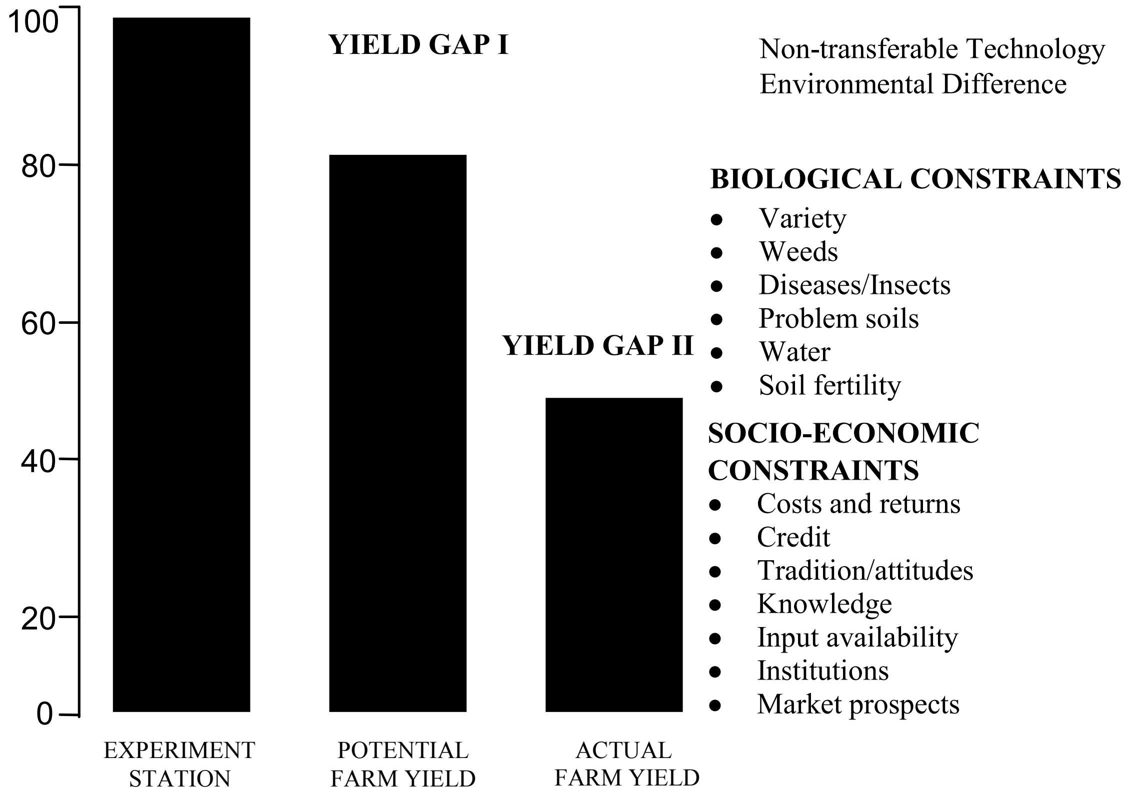

Figure 2. Yield gaps and constraint research model (Source: De Datta et al 1978)

Progressive farmers differ from other farmers in adapting the knowledge and technologies to their own conditions to attain high yields in their region. We have to identify the set of best farmers' practices that can be transferred to other farmers so as to improve their efficiency in farming.

4. CROP MANAGEMENT TECHNOLOGY OPTIONS FOR REDUCING YIELD GAP

Rice production is coming under increasing pressure in Asia due to population growth and changing socio-economic factors. Land, water and labor resources are increasingly less available for rice production, while at the same time, the demand for rice and for improved grain quality is increasing. To meet the challenges, technologies within the production and post-production chains are changing (Table 5). The extent of the relevance of technological options depends in large part on the scales of production and the availability of resources. Improved technology options available for rice farmers are listed below:

- Land Preparation and Leveling: laser-aided precision leveling; herbicide-based minimum tillage; dry shallow tillage prior to puddling; shallow tillage soon after harvest to incorporate crop residues and improve soil N supply; hydrotiller, hand tractor, 4-wheel tractor.

- Crop Establishment: transplanting machine; seedling broadcast; drum seeder, tiller-seeder-planking attachment for hand-tractor, and seed-cum-fertilizer drill.

- Water Harvesting and Management: farm pond; dry seeding; drought-tolerant varieties; improved irrigation & drainage channels; saturated water condition for wet-seeded rice; cyclic/intermittent irrigation (wetting and drying).

- Integrated Nutrient Management (INM): organic + chemical fertilizers; balanced, field-specific fertilizer recommendation; K in two splits; soil-test based S, Zn; real time N management with chlorophyll meter & leaf color chart; deep placement of urea briquette; coated controlled release urea.

- Integrated Weed Management (IWM): cultural practices to minimize weed problem; row seeding + cono weeder package; timely and judicious herbicide use.

- Integrated Pest Management (IPM): no early spraying against leaf folders and thrips; pheromone traps for yellow stem borer; active barrier system for rat control; deployment of pest-resistant varieties; silica application for blast control; timely and judicious use of bio and/or chemical pesticides.

- Post-harvest Technologies: improved serrated sickle; reaper; thresher; stripper harvester; combine; dryer; cleaner; improved mills; micro rice mill.

- By-products Utilization: rice hull stove, rice hull briquette; rice bran oil extractor; rice hull ash + cement for hollow blocks; rice hull mulch for cut flower gardens and mushroom culture; rice puff machine; rice wine making.

Table 5. Shifts in Factors and Technologies and their Implications

Factors	Shift	Implications	
Production Factors		**Positive**	**Needs & Concerns**
Land preparation	Manual and hand tractor to 4 wheel tractor	Improved land preparation, Timeliness	Mobility and improved drainage required
Variety	Traditional to modern HYVs	Higher yield potential	Meeting grain quality and demands of markets
Seed quality	Poor/ordinary seed to improved, quality seed	Increased yield, reduced seed-borne pests, less weeds	Farmer training on benefits and production of quality seeds; source, storage conditions, seedling vigor
Crop establishment	Manual transplanting to machine trans-planting and direct seeding (wet & dry)	Reduced labor, less drudgery, improved timeliness	DSR: Weed pressures (red rice); need for better land leveling & improved water management
Pest management Weeds Insects Diseases Birds Rats Snails	From manual to chemical From calendar based application to integrated pest management (IPM)	IPM utilizes benefits of different forms of control and reduces reliance on chemicals.	With chemical control – selection of quality product, use of correct dose, uniformity of application; safety for the user and the environment, quality of products
Water management	Less available water- Better maintenance of irrigation & drainage structure; Shifts to low water levels, cyclic irrigation	Less water use, more area irrigated, higher water use efficiency	Cost of maintenance, community decision making in sharing water, pricing water, and weed problems
Nutrient management	Shift from blanket to site-specific, need-based nutrient management (chlorophyll meter, color chart); balanced NPK and other nutrients, INM	Less fertilizer cost, same or higher yields, less pests/diseases, less lodging, better quality water and soil.	Labor for adoption of certain techniques, cost of tools, quality assurance in decision tools, fertilizer quality

Factor	Shift	Implications	
Post-production Factors		**Positive**	**Needs and Concerns**
Harvesting and threshing	Manual to reaper/thresher to combine	Low labour requirement timely harvest and therefore better quality grain	Mobility - water management and field layouts required for larger equipment
Drying	Sun-drying to mechanical dryers	Timely drying, less spoilage and better quality grain	Cost of dryers, energy source and cost, utilization time, market incentive for dry grains
Cleaning	No or little cleaning (e.g., winnowing) to mechanical	Reduced pest and debris load; higher quality grain, less spoilage in storage	Cost of grain cleaners, power sources, market incentive for clean grains
Storage	Bag to bulk	Centralized, modern storage facilities; maintenance of better grain quality	Moisture content management, Spoilage from discoloration and insects, if not adequately treated and/or dried; not farm level
Milling	Hand pounding to steel huller to modified steel huller to rubber roll	Better quality grain' Higher head rice yields	Adequate moisture content, maintenance of parts
Grain quality	Quantity to quality	Higher price and profitability	Production and post production management
Socio-economic Factors			
Marketing	Subsistence to cooperative to commercial	Farmers obtain higher incomes through direct marketing	Organization and management skills; procurement of facilities
Credit	From money lenders to cooperatives and banks	Credit at low interest, inputs, and technical advice	Organization, collateral requirement, delay in credit delivery
Knowledge transfer	Alternate partners: NGOs, Cooperatives, Private sector	More choice and may be better and timely service; client-oriented	Profit motive of POs; less technical knowledge of NGOs

5. PROFIT GAPS DUE TO POST-HARVEST LOSSES

About 20 to 25 percent of the harvested rice is lost before it reaches the consumers' table. The post-harvest losses in both quantity and quality lead to substantial profit gaps among farmers. Improved processing, storage, and direct marketing will help farmers to increase their profits. Effective farmer organizations such as cooperatives can assist farmers in post-harvest processing and marketing.

For better grain quality and higher head-rice yield, production and post-production practices have to be improved. Harvesting, threshing, cleaning, drying, and parboiling/drying are labour intensive operations in developing Asian countries. These operations must be carried out at the right time to minimize losses and to ensure good grain quality. Improvement and appropriate mechanization of these operations will depend on the market demand and price incentive for quality rice. The level of processing, i.e., at farm, village or mill level, will determine the type of equipment needed. Most post-harvest equipment will require some minimum economy of scale for their profitable operation. Organization of user groups is vital to successfully introduce such equipment (D. de Padua, Consultant to IRRI AED, IRRI, Philippines, 1998, personal communication).

Harvesting

Farmers must harvest the crop at optimum maturity when 80 to 85 percent of the grains are straw-coloured and the grain moisture content (MC) is 20 to 25 percent. A good indicator is that the grains will be firm but not brittle at optimum maturity. Harvested crops will dry at 1 to 2 percent moisture per day. Harvesting of very dry crops will increase shattering losses and breakage of grains at threshing and milling. Machines available for harvesting and cleaning are: reaper harvester, stripper gatherer, thresher, combine harvester, and cleaner.

Threshing

Harvested crops should be threshed soon; otherwise, the grain quality will deteriorate with longer waiting between harvesting and threshing. Machine threshing is normally done immediately after harvesting when the grain MC is 20 to 25 percent. If the grain MC is < 20 percent or > 25 percent, grain damage will occur at machine threshing. Hand threshing is normally done one to two days of field drying after harvest, when the grains reach 20 percent MC. If the grain MC is > 25 percent, it will be difficult to thresh and separate the grains from panicles by manual threshing.

Drying

Rice grains are dried to 14 percent MC before storage. Sun drying is the most common method used by farmers in Asia. If properly done, the moisture will be reduced from 20 to 14 percent in one day. Grain damage by rains, wind, or by birds is common in open drying floors. Different types of dryers are available for drying wet rice: low cost in-store dryer (SRR) (1-2 tonnes/ 60-70 h), flat bed dryer (4-6 tonnes/ 8 h), columnar batch recirculating dryer (1-2 tonnes/ 6-8 h), etc. The grain quality is good and the germination percent is high with machine-dried rice.

Milling and Grain Quality

In rural areas, small mills (0.25 to 0.50 tph) are common. Grain quality is poor in these mills due to the use of Engleberg type steel hullers for dehusking and polishing in one pass. Small-scale commercial mills with 1-2 tph capacity use rubber rollers to improve grain quality.

Millers and traders maintain high grain quality for export rice. The quality criteria differ for different markets and types of rice. The private rice industry has developed many post-harvest procedures to meet the quality standards of various markets. They are mostly kept as trade secrets. For example, the processing of quality long grain rice involves:

- Dry to 13 percent moisture just before milling.
- Use cream coloured, soft rubber rollers for dehusking, with both rollers adjusted exactly parallel to each other.
- Adopt 4-5 passes for polishing, tempering the grains for 6-8 hours between passes.
- Use water polishing for shiny grains.
- Adopt lens grading for removal of smalls and brokens.

6. BRIDGING KNOWLEDGE GAPS BETWEEN RESEARCHERS, EXTENSION STAFF AND FARMERS

There are considerable knowledge gaps between researchers, extension agents, and farmers. We need to train the (government, non-government, private sector) extension staff and equip them with adequate tools so that they can educate their farmer-clients. Farmers need adequate training and technical support to improve their decision-making capacity.

6.1 Farmers' Knowledge vs. Researchers' Insights

Farmers' experience or indigenous knowledge (IK) is accumulated over generations. Scientists' technical knowledge is synthesized from years of research. These two systems of knowledge should be integrated for the benefit of both and to enhance mutual learning to reduce knowledge gaps between farmers and researchers.

6.2 Knowledge gap between researchers and extension staff

The new knowledge and technologies are not reaching most of the farmers due to poor extension efforts in this area. The extension service in many countries is very poorly trained and equipped to handle delivery of new knowledge from researchers to farmers. This lacuna should be urgently addressed.

The technology delivery system should be re-oriented to handle changing circumstances and to deliver complex, knowledge-intensive technologies to farmers. We need to explore private sector extension agencies in commercial farming areas and other service-oriented agencies (NGOs) in food crop areas to extend new knowledge and technologies to farmers. All of them should be properly trained and equipped to promote new technologies. The effectiveness of different combinations of public, private, cooperative and NGO extension agencies is being evaluated.

6.3 Farmer Education

Continuous farmer education is necessary to make them understand scientific principles of crop and resource management; adjust various inputs to temporal and spatial variability of rice fields; adopt integrated nutrient, water, weed, and pest management; and increase farm income through efficient post-harvest processing and utilization of byproducts. For example, we are adapting simple decision tools such as the chlorophyll meter and leaf colour chart (LCC) to enhance their knowledge in need-based N management of rice crops.

We can use different ways to transfer the knowledge to farmers: farmer field school (FFS), farmer participatory research (FPR), private advisory groups, etc. FFS imparts systematic experience learning to farmers so that they can effectively adapt and use the technologies. Through appropriate FPR, we can equip farmers with scientific principles of crop and resource management that they can use to adapt/refine new technologies to their own circumstances and needs. The new knowledge should be couched in farmers' familiar terms and allow them to experiment and evaluate it in their own way till they get convinced. This will facilitate the incorporation of new knowledge into farmers' own knowledge base.

6.4 Communication Strategies

Successfully evaluated technologies should be disseminated to farmers in a large area to have a wider impact. We are evaluating effective communication technologies such as radio and television (mostly one-way, large audience, time lag); two-way radio and telephone (two-way, timely, need-based, interactive); and internet/web-based communication (distance learning/ teaching) for disseminating knowledge and technologies. We can use the GIS, crop models, and systems approaches to replicate successful outcomes in space and time.

6.5 Institutional/Policy Support

Adequate rural infrastructure such as farmer training institutions, various groups of extension/technology delivery agencies, farm credit organizations, inputs/machinery suppliers, marketing outlets and traders, road, transport and communication networks and product quality and grading centres should be present to encourage farmers to produce food efficiently. Policy support in terms of pricing of inputs and outputs, incentives for farmers to encourage food production, land tenure, tax, crop insurance, etc., will optimize farmers' productivity.

6.6 Crop and Resource Management Network (CREMNET)

Field evaluation and delivery of the new knowledge and technologies to farmers are vital to achieve impact on productivity. We at IRRI, have developed a network to deal with the diffusion of information, knowledge, and technologies to rice farmers. This is called CREMNET, the Crop and Resource Management Network.

This network acts as a bridge between two groups of R and D partners: those who generate new research findings and technologies at the one end and those who evaluate, adapt, and promote the technologies for use by farmers at the other end. CREMNET encourages the two-way flow of information and feedback between these two groups to improve the efficiency of both.

In the network mode of operation, we serve as a catalyst to national R and D organizations to promote the applied, adaptive, and farmer participatory research on potential crop and resource management technologies suitable for their regions. In this process, we also help in strengthening the national R and D institutions through sharing of information, knowledge, techniques, tools, and methods, as well as by training collaborators. Our ultimate aim is to bridge the knowledge systems gaps of rice scientists and farmers to maximize mutual benefits.

7. CONCLUSIONS

There is high variability in rice yields among countries and regions as well as among farmers even in homogeneous domains. Profit gaps arise due to post-harvest losses in quantity and quality of rice grain. Biophysical, socio-economic, management, institutional, and policy factors are responsible for yield and profit gaps. Identification of problems/causes for such gaps and development of possible mitigation measures can only be considered the first of a two step process. The second and equally important step is to minimize the knowledge gap between researchers, extension staff and farmers by developing and using viable mechanisms to transfer new knowledge and techniques from researchers to farmers and collect feedback to re-orient research on issues critical to farmers.

An integrated crop management approach (water, soil fertility/nutrients, weeds/pests/diseases, and post-harvest processing) is vital to maximize the productivity and profitability of rice farmers. All technologies and practices should be used synergistically to help farmers increase and/or maintain grain yields at the same or reduced cost. Improving the quality of milled rice and increasing the recovery of head-rice will enhance farmers' profitability.

We need to train the (government, non-government, private sector) extension staff and equip them with adequate tools so that they can educate their farmer-clients on modern rice farming. Farmers need adequate training and technical support to improve their decision-making capacity and properly utilize the new techniques.

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WATER MANAGEMENT IN RICE IN ASIA: SOME ISSUES FOR THE FUTURE

Thierry Facon*

1. INTRODUCTION

In most of Asia, rice is not only the staple food, but also constitutes the major economic activity and a key source of employment and income for the rural population. Water is the single most important component for sustainable rice production, especially in the traditional rice growing areas of the Region. Reduced investments in irrigation infrastructure, increased competition for water and large water withdrawals from underground water lower the sustainability of rice production. However, despite the constraints of water scarcity, rice production must rise dramatically over the next generation to meet the food needs of Asia's poor. Producing more rice with less water is therefore a formidable challenge for the food, economic, social and water security of the Region.

This paper reviews the water resources and uses of the Region, the status of irrigation development with a particular focus in irrigated rice production, trends in the irrigation sub-sector but also in the water sector as a whole and in socio-economic development as they affect the sub-sector. The paper then examines water management practices for irrigated rice production and options and pre-set approaches to improve the water efficiency and productivity of rice production at the farm, and system level. These options must be considered in a basin-wide perspective and their adoption will require policy, economic and institutional reforms, as well as proper incentives, empowerment and irrigation services for farmers to adopt. Finally, the paper briefly describes the efforts and interventions needed to meet the challenge for producing more rice with less water.

2. IRRIGATION AND RICE PRODUCTION IN ASIA: AN OVERVIEW

2.1 Water Resources and Use**

Water resources: The large range of climates encountered in the Region generates a variety of hydrological regimes. The Region is host to some of the most humid climates giving rise to major rivers, while in other parts it has a very arid climate, with closed hydrologic systems. As a result, the Region shows a very uneven distribution of its water resources and of its water use conditions. In the humid areas, water management concerns have mostly been dominated by considerations related to flood control. The hydrology of the Region is dominated by the typical monsoon climate which induces large inter-seasonal variations of river flows. In this situation, average annual values of river flows are a poor indicator of the

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amount of water resources available for use. In the absence of flow regulation, most of the water flows during a short season when it is usually needed less. As a first approximation, the amount of water readily available for use is between 10 and 20 percent of the total renewable water resources (Table 1) in the absence of storage. Runoff in the countries of Southeast Asia and the islands is not significantly affected by withdrawals, while the difference between natural and actual flow may be much more important in the arid regions (mostly China).

Overall, the Region is relatively well endowed with water resources. However, the amount of water resources per inhabitant is only slightly above half the world's average. In terms of water resources per person, the groups of the Indian subcontinent, Eastern Asia and the Far East show the lowest figures while Southeast Asia has much more water resources per person than the world average. The figure of 2,000 m3/inhabitant/year is usually used as an indicator of water scarcity: India and China are reaching this limit, while the Republic of Korea is already below it, at 1,538 m3/inhabitant/year.

Table 1. Renewable Water Resources in Asia

Country	Population (1996)	Precipitation (mm)	Annual Renewable Water Resources					Dependency Ratio %
			Internal		External	Total		
			million m^3	m^3 per inhab. 1996	million m^3	million m^3	m^3 per inhab. 1996	
	(1)	(2)	(3)	(4)=(3)*10^6/(1)	(5)	(6)=(3)+(5)	(7)=(6)*10^6/(1)	(8)
Bangladesh	120,073,000	2,320	105,000	874	1,105,644	1,210,644	10,083	91.3
Bhutan	1,812,000	4,000	95,000	52,428	0	95,000	52,428	0.0
Brunei	300,000	2,654	8,500	28,333	0	8,500	28,333	0.0
Cambodia	10,273,000	1,463	120,570	11,737	355,540	476,110	46,346	74.7
China	1,238,274,000	648	2,812,400	2,271	17,169	2,829,569	2,285	0.6
India	944,580,000	1,170	1,260,540	1,334	647,220	1,907,760	2,020	33.9
Indonesia	200,453,000	2,700	2,838,000	14,158	0	2,838,000	14,158	0.0
Japan	125,351,000	1,728	430,000	3.430	0	430,000	3,430	0.0
Korea,DPR	22,466,000	1,054	67,000	2,982	10,135	77,135	3,433	13.1
Korea, Rep.	45,314,920	1,274	64,000	1,431	4,850	69,700	1,538	7.0
Lao PDR	5,035,000	1,600	190,420	37,782	143,130	331,550	66,181	42.9
Malaysia	20,581,000	3,000	580,000	28,183	0	580,000	28,183	0.0
Maldives	263,000	1,883	30	114	0	30	114	0.0
Mongolia	2,515,000	251	34,800	13,837	0	34,800	13,837	0.0
Myanmar	45,922,000	2,341	880,600	19,176	165,001	1,045,601	22,769	15.8
Nepal	22,021,000	1,500	198,200	9,000	12,000	210,200	9,545	5.7
Papua New Guinea	4,400,000	3,500	801,000	182,045	0	801,000	182,045	0.0
Philippines	69,283,000	2,373	479,000	6,914	0	479,000	6,914	0.0
Sri Lanka	18,100,000	2,000	50,000	2,762	0	50,000	2,762	0.0
Thailand	68,703,000	1,485	210,000	3,577	199,944	409,944	6,983	48.8
Vietnam	75,181,000	1,960	366,500	4,875	524,710	891,210	11,854	58.9
Total	3,030,900,920	1,194	11,592,410	3,825				

Water withdrawal: Table 2 shows the distribution of water withdrawal between the three major sectors of water use: agriculture (irrigation and livestock), communities (domestic water supply) and industry. Water requirements for energy (hydropower), navigation, fisheries, mining, environment and recreation, although they may represent a significant part of the water resources, have a negligible net consumption rate.

Table 2. Water Withdrawal in Asia

Country	Year	Annual Water Withdrawal								% of intern. renewable water res.	% of total renewable water res.
		Agricultural		Domestic		Industrial		Total			
		million m^3	% of total	million m^3	% of total	million m^3	% of total	million m^3	m^3 per inhab. (1996)		
		(1)	(2)=(1)*100/(7)	(3)	(4)	(5)	(6)	(7)=(1)+(3)+(5)	(8)=(7)*100/(1) of T.1	(9)=(7)*100/(3) of T. 1	(10)=(7)*100/(6) of T.1
Bangladesh	1990	12,600.00	86	1,704.32	12	332.16	2	14,636.48	122	13.94	1.21
Bhutan	1987	10.80	54	7.20	36	2.00	10	20.00	11	0.02	0.02
Brunei	1994	-	-	-	-	-	-	91.60	305	1.08	1.08
Cambodia	1987	489.00	94	26.00	5	5.00	1	520.00	51	0.43	0.11
China	1993	407,774.00	77	25,165.00	5	92,550.00	18	525,459.00	424	18.68	18.57
India	1990	460,000.00	82	25,000.00	5	15,000.00	3	500,000.00	529	39.67	26.21
Indonesia	1990	69,241.00	93	4,729.00	6	376.00	1	74,346.00	371	2.62	2.62
Japan	1992	58,600.00	64	17,000.00	19	15,800.00	17	91,400.00	729	21.26	21.26
Korea, DPR	1987	10,336.00	73	1,557.60	11	2,265.60	16	14,160.00	630	21.13	18.36
Korea, Rep.	1994	14,877.00	63	6,209.00	26	2,582.00	11	23,668.00	522	36.50	33.96
Lao PDR	1987	812.00	82	79.00	8	99.00	10	990.00	196	0.52	0.30
Malaysia	1995	9,750.00	77	1,342.00	10	1,641.00	13	12,733.00	619	2.20	2.20
Maldives	1987	0.00	0	3.32	98	0.05	2	3.37	13	11.23	11.23
Mongolia	1993	227.04	53	85.36	20	115.72	27	428.12	170	1.23	1.23
Myanmar	1987	3,564.00	90	277.20	7	118.80	3	3,960.00	86	0.45	0.38
Nepal	1994	28,702.00	99	246.00	1	5.00	0	28,953.00	1,315	14.61	13.77
Papua New Guinea	1987	49.00	49	29.00	29	22.00	22	100.00	23	0.01	0.01
Philippines	1995	48,857.00	88	4,269.00	8	2,296.00	4	55,422.00	780	11.57	11.57
Sri Lanka	1990	9,380.00	96	195.00	2	195.00	2	9,770.00	540	19.54	19.54
Thailand	1990	30,200.00	91	1,496.00	5	1,436.00	4	33,132.00	564	15.78	8.08
Vietnam	1990	47,000.00	86	2,000.00	4	5,330.00	10	54,330.00	723	14.82	6.10
Total		1,212,469.64	84	91,420.00	6	140,171.33	10	1,444,152.97	476	12.46	

In Asia, almost 84 percent of the water withdrawal is used for agricultural purposes, compared to 71 percent for the world. The Indian subcontinent and Eastern Asia have the highest level of water withdrawal for agriculture with 92 and 77 percent, respectively. The two regions together represent about 82 percent of the total irrigated area in Asia. With a major regional emphasis on flooded rice irrigation, it is particularly difficult to assess agricultural water use. The gross average for the Region is 8,900 m3/ha/year. Figures for China and India, which represent 72 percent of the Region's agricultural water withdrawal, are relatively similar: 7,500 and 9,200 m3/ha of irrigated land, respectively. However, other countries show much higher values, as is the case for the Philippines, Malaysia, Japan, Republic of Korea, Nepal and Sri Lanka, where agricultural water withdrawal is between 15,000 and 31,500 m3/ha/year. More research is needed to obtain homogenous information on agricultural water use among countries.

Water withdrawal expressed as a percentage of Total Renewable Water Resources, which takes into account the incoming or border flows and the existing agreements, is a good indicator of the pressure on water resources. Roughly, it can be considered that pressure on water resources is high when this value is above 25 percent, as is the case for India and the Republic of Korea with 34 and 26 percent respectively. China, Japan, DPR Korea and Sri Lanka also have high values with 18.57, 21.26, 18.36 and 19.54 percent, respectively.

2.2 Irrigation

Irrigation potential: The irrigation potential for the Region was estimated at 235 million ha. India and China account for about 76 percent of this total. However, figures presented here should be used cautiously. In India, for example, the irrigation potential, which is 113.5 million ha, corresponds to the gross area which could theoretically be irrigated in a year on the basis of the assumed design cropping pattern and a rainfall probability of 75 percent, and represents 2.27 times the area under irrigation in 1993. This figure is a theoretical maximum. Indeed, it is considered that development of irrigation in India is about to reach its limits and that no major extension of irrigated lands is to be expected after the beginning of the twenty-first century. In China, the figure for irrigation potential is 64 million ha and corresponds to the total area which could be brought under irrigation in the first half of the next century. As much of the additional land proposed for irrigation is located in the arid and semi-arid zones, reaching such a level would require a viable long-term strategy as to how to provide the amount of water necessary to irrigate these lands.

Irrigation development: Asia represents the bulk of irrigation in the world. High population density combined with the tradition of irrigated rice cultivation in all the tropical part of the Region are the main factors explaining the importance of irrigation in Asia. While irrigation development dates back several centuries, the twentieth century, and particularly its second half, has seen a rapid increase in what could be called modern irrigation development and a majority of the countries have achieved self-sufficiency in cereal crops, mostly rice.

The assessment of land under irrigation in the countries of the Region is made particularly difficult by the different approaches used in the countries to compute irrigation. For some countries (Bangladesh, Bhutan) paddy fields, cultivated mainly during the wet season, are not considered as irrigated land. For the other countries where paddy rice cultivation is practiced, all paddy fields are considered irrigated land. In most cases, schemes are designed primarily to secure rice cultivation in the main cropping season, although the need for intensification has progressively led some countries to design new irrigation schemes for year-round irrigation, e.g. Thailand, while Vietnam has three rice crops a year. In total, 37 percent of the land under cultivation in the Region is irrigated.

While most wet season rice irrigation is fully gravity irrigation (cascades from plot to plot), dry season cropping may require pumping in places. In the tropical zone, wet season irrigation is almost only paddy rice. It is usually considered as supplementary irrigation to an already abundant precipitation. During the dry season, a much larger diversity of crops are grown on irrigated fields. In Cambodia, Indonesia, Malaysia and Mongolia, a kind of flood control irrigation is practiced with flood water being used to inundate paddy fields which are then cultivated with rice. In total, such practice concerns an area of about 1.2 percent of the total irrigated land in the Region. Surface irrigation is by far the most widespread irrigation technique in the Region and all rice is irrigated by surface methods. Surface water is the major source of irrigation water in the Region, except for Bangladesh, China, India and Pakistan where groundwater is widely used. The percentage of power irrigated area is more important in Bangladesh, China and India, with 83, 54 and 53 percent, respectively.

Irrigated crops: Rice represents about 45 percent of all irrigated crop areas in the Region and 59 percent of the rice is irrigated. However, its regional distribution shows major trends: in the countries of the Far East, Southeast Asia and the Islands, rice represents systematically more than 90 percent of irrigated crops, as is also the case for Bhutan, Nepal and Sri Lanka. By contrast, India, China and DPR Korea have a much more balanced distribution of irrigated crops with rice representing only about one-third to one half of the total irrigated crop area. This reflects the cold or arid context of large parts of these countries. In India, the percentage of land under irrigated wheat is slightly higher than that under irrigated rice (31 percent as against 30 percent). In China, it can be estimated that it is shared evenly between rice, wheat and other crops; rice being the single most important irrigated crop. However, in India only 47 percent of the total harvested area for paddy rice is irrigated, while more that 92 percent of the harvested paddy rice in China is irrigated.

Cropping intensity varies from 72 percent in Bhutan, to 132 percent in India and Malaysia with an average of 127 percent. Care should be taken, however, when comparing figures for different countries. In Bangladesh (84 percent), irrigation is considered only for dry season cropping. The average irrigated cropping intensity for ten countries where data are available is 127 percent.

There are approximately 28 million hectares under intense irrigation, producing two to three crops per year. Average yields are 4-6 t/ha per crop, and on a yearly basis 10-15 t/ha are common. Maintaining and improving the high annual output from these areas is essential for food security. However, there are signs of declining productivity in the intensively cropped, irrigated system, both on long-term research plots and farmers' fields. Reasons for this phenomenon are not understood yet, but are thought to be linked to the prolonged submergence of soils, puddling and their effects on soil chemical and biological processes, including anaerobic decomposition of organic matter, and near-continuous soil reduction. Finding solutions to arrest declining productivity will therefore most certainly require changes in flooding practices.

2.2.1 Drainage, flood control and environmental issues

In most of Asia, drainage is closely linked to irrigation. In traditional terraced paddy cultivation, water flows from one plot to another and no distinction can be made between irrigation and drainage. In several humid countries of the Region, large segments of lowland or wetland are used for paddy cultivation. In such cases, the main purpose of water control is to ensure appropriate control of water level and drainage. Bangladesh and Cambodia use the terms controlled flooding or inundation, which are typical of paddy cultivation in the major deltas (Brahmaputra, Mekong). Lao PDR prefers to use lowland flooded rice. In these areas, drainage and flood control are also very much related. In Bangladesh, on average, 22 percent of the country is flooded every year and 50 percent of water development expenditures are spent on flood control and drainage. In Myanmar, in the Ayeyarwady Delta, drainage and flood control structures are also linked. Drainage covers 1 million ha in north and central Vietnam, mostly in the Red River Delta. Flood protected areas in China represent 32.69 million ha. The extreme case of agriculture under flood conditions is floating rice in Cambodia.

Drainage infrastructure associated with irrigation in arid and semi-arid areas concern mostly northern China, India and Mongolia. In China as a whole, it was estimated in 1996 that 24.58 million ha were subject to waterlogging, of which 20.28 million ha were equipped with drainage. In India, drainage works have been undertaken on about 5.8 million ha, but investment in drainage works associated with irrigation schemes has been widely neglected and drainage systems are usually in very poorly maintained condition.

Although total water withdrawal remains limited compared to water resources in Southeast Asia (about 5 percent), the large amounts of water diverted, mostly for agriculture, in those countries, have an environmental impact which may assume important proportions locally. Intrusion of saltwater in deltas is a concern in Myanmar, Vietnam and parts of India. Excessive groundwater exploitation around Bangkok, Thailand creates land subsidence and exacerbates already existing flood problems.

2.2.2 Trends in irrigation and drainage

Overall, growth in irrigated areas in Asian countries has declined from 2.1 percent per year in period 1961-1980 to 1.3 percent per year in 1980-1995. This decline is most acute in industrialized East Asia, followed by China. Most of the growth has come form tube-well development, especially in India, Pakistan and Bangladesh. However this groundwater development is not sustainable in many regions where groundwater draw-down has reached alarming levels, with very severe ecological impacts. A large proportion of new areas are not planted with rice but with other crops. Declining prices of rice, higher marginal development costs, environmental concerns, and poor performance of existing schemes are among the main factors for the decline in irrigation growth and investment both by governments and farmers in the Region.

However, the proportion of rice area that is irrigated is increasing, rising from just 35 percent of the total rice area to 44 percent over the last twenty years. Rice irrigated areas have expanded by 600 000 hectares per year while upland and deep water rice ecosystems decreased by 25 percent.

While irrigation has been instrumental in achieving self-sufficiency in staple crop production in recent decades in most countries of the Region, some countries such as Indonesia and the Philippines still indicate self-sufficiency as a major target of their irrigation development programmes; this is mainly to keep pace with rising populations. In Malaysia, however, the national policy is to decrease self-sufficiency in rice from 80 to 65 percent in 2010, due to the high cost of rice production. In Japan, rice irrigation has been on a downward trend for the last 20 years due to overproduction in the 1970's.

Increased competition for water between sectors already affects agriculture in China, India, Malaysia, Thailand and the Republic of Korea and the trend is towards an intensification of the problem due mainly to the rapid growth of the domestic and industrial sectors in these countries. Major interbasin transfer programmes are reported in China and Thailand. Water scarcity and the interdependency between water use sectors are pushing countries to develop integrated water resources management programmes. Water quality and the increased importance of water conservation and protection are also major growing concerns.

The failure to develop adequate operation and maintenance (O and M) mechanisms to ensure the sustainability of the irrigation schemes (mostly large, public schemes) has led to irrigation management transfer or increased participation of users in the management of the schemes. This is achieved through the development or improvement of water users associations (WUAs).

Most of the countries have undergone deep societal and socio-economic transformations, characterized by: fast economic growth (until recently at least), especially in the industrial and services sectors; liberal macro-economic policies, development of trade reforms and privatization in the public sector and institutions; development of the civil society; and growing awareness of environmental issues and problems. In general, it is estimated that these profound changes in the environment, dominated by the need to adapt to water scarcity chiefly by the adoption of demand management strategies, call for a deep transformation of the irrigation sub-sector by the adoption of the following measures. First and foremost to consume less water, to modify water demands and maximize efficiency in water use and to improve of it's economic, technical, and environmental performance, together with diversification of produce and cropping patterns, changes in management systems and structures, and financial and fiscal sustainability.

On the other hand, improved levels of education and of technological environment, more dynamic markets and diversified financing systems, more efficient and decentralized administration, and new management models, constitute many favourable conditions for an improvement of the performance of the irrigation sub-sectors and modernization of irrigation schemes.

As the older public schemes reach the age of 30-40 years in most countries, the issue of rehabilitation, which is related to operation and maintenance and modernization, is becoming increasingly important. While for some countries (such as Lao PDR, Myanmar, Philippines, Vietnam and parts of India) the extension of irrigated land still represents an important part of irrigation programmes, in most countries rehabilitation programmes are taking on increasing importance. The increased land and water scarcity and low expected return of future expansion of irrigation in these countries are often factors explaining the growing importance of rehabilitation in irrigation programmes.

Modernization of irrigation schemes as a part of a broader transformation of the water and agricultural sectors, responds to a complex set of institutional, technical, operational and economic issues, and would consist of a complex set of institutional, technical, operational and agricultural changes, generally associated with changes in water pricing and cost recovery. There is a general agreement on the specific objectives of the improvement of the performance of irrigation systems, in terms of delivering water to farmers in a more efficient, flexible, reliable and equitable manner. However, progress in the Region is rather slow when compared with other regions, and particularly with countries like Mexico or Turkey. Concepts related to service-oriented irrigation are not yet widespread or understood.

3. SCENARIOS FOR 2025

In World Water Demand and Supply, 1990 to 2025: Scenarios and Issues (IWMI Research Report 19, Seckler, Amarasinghe, Molden, de Silva and Barker, 1998), IWMI projects growth in water demand with two scenarios for the irrigation sector. In the first scenario, the 1990 level of irrigation efficiency remains constant through 2025. In the second scenario, higher efficiencies are attained (70 percent except for rice growing countries where 60 percent is projected, or a doubling of present efficiency, whichever is lower). The assumptions are that the per capita amount of food production from irrigated agriculture will remain constant. No allowance is made for additional irrigated area or irrigation water to meet increased per capita food demand; increased per capita consumption is met by increased yields; and the proportion of food supplied by irrigated areas and rainfed areas remains constant. These assumptions may underestimate the severity of the problem as cereal yields are stagnating, remaining rainfed land in the Region is very limited or can be developed only at high environmental and economic costs, and irrigation land is being lost to urbanization, water logging and sanitation at a fast pace.

Table 3 presents 1990 per capita withdrawals of water for the domestic, industrial and irrigation sectors and projected withdrawals by these sectors in 2025 for Asian countries. For countries currently below 20 m^3 per capita for satisfaction of basic domestic water needs, 20 m^3 per capita are projected in 2025. For countries currently above that level, estimates of withdrawal for domestic and industrial sectors are based on projected per capita GNP for both the domestic and industrial sectors. Environmental needs (minimum flows, water demand of ecosystems, etc.) are not taken into account. The model does not take into account shifts in production patterns, the role of trade in meeting national food balances, the trans-boundary nature of water resources and changes in food consumption patterns which usually follow socio-economic development. In this respect about 2,200 m^3 of water are required to feed one person for a year with a diet rich in meat. A diet low in meat requires about half as much water.

For the Region as a whole, in the first scenario total water withdrawal from all sectors would increase by 62 percent as against 18 percent in the second scenario, or a total saving of 691KM3 per year. Still additional withdrawals of 315 KM^3 per year over the present withdrawal of 1,555 KM^3 per year would be required and, globally at the regional level, potential water savings derived from increases in irrigation efficiency could not compensate for the growth in food and other demands. Additional water resources would need to be developed and there could be no net transfer of water resources from irrigation to the other sectors.

At the country level, countries can be grouped according to the nature and degree of their projected water scarcity by 2025 under the second scenario:

Group 1: absolute water scarcity[***] (Pakistan, Afghanistan and Singapore, total population 333 million). Singapore is a very particular case and must be treated separately as there is no irrigation in this City State. They do not have sufficient water resources to meet reasonable per capita water needs and will certainly have to reduce the amount of water used in irrigated agriculture and transfer it to other sectors, importing more food instead. This will place an additional burden on their economies as they are already suffering large deficit accounts. Being so large and diverse, China and India must be treated separately at a sub-national level. North China as well as West and South India are very dry and around one third of the population of these two countries will live in regions of absolute water scarcity (381 and 280 million people, respectively from a total of 661 million people).

Therefore, at the level of the Region, approximately 1 billion people would live in regions of absolute water scarcity. The other groups would have sufficient resources to meet future water demand and can be categorized by economic water scarcity, as many of these would have to embark on massive water development programmes.

Countries in Group 3 (Nepal, Australia, Cambodia, Myanmar, Malaysia) also need to increase water development by between 25 and 100 percent. They represent a total population of close to 500 million people and their capacity to make the necessary investments is very diverse. Countries in Group 4 (Philippines, Vietnam, Bangladesh) would have only modest requirements for additional water resources development while countries in Group 5 (Republic of Korea, DPR Korea, Japan, Thailand and Sri Lanka) would have zero or negative needs for water development.

The model has the merit of comparing two scenarios: business as usual and substantial (perhaps over-optimistic under any circumstances) increases in irrigation sector water use efficiency, in the context of projected growth of the water demand of all sectors; and of taking into account not only the availability of water resources but also an estimation for their required further development. The overall picture for the Region may be described as the following: because of the projected increases in population and therefore food demand, irrigated food production will need to increase significantly. Demand from other sectors will also increase because of both projected economic development and increase in population.

[***] *If annual withdrawals are higher than 50% of annual available resources.*

Table 3. Water Supply and Demand in Asia in 2025

Country		1990 Data: Population 1990 (millions)	Population Growth 1990-2025 %	Population 2025 (millions)	Annual Water Resou. (AWR) KM^3	Total With-drawals (=DWR) KM^3	Per capita WITH Dom. M^3	Per capita WITH Ind. M^3	Per capita WITH Irr. M^3	1990 Irrigation: Net irrigated area (NIA) (1000ha)	Total Irr WITH KM^3	Annual irr int.	WITH gross irr. area M/ha/Year	NET gross irr. area M/ha/Year	Effec eff. %	2025 Irrigation Scenerios (S1 and S2): Assum effec eff. 70% %	S1 tot irr WITH KM^3	S2 tot irr WITH KM^3	S2 % chan from 1990 %	S2/S1 %	S1-S2 KM^3	2025 Domestic and Industrial: Per capita Dom. M^3	Per capita Ind. M^3	Total D&I WITH KM^3	% chan. from 1990 %	2025 Total: S2 2025 Total WITH KM^3	S2 Add'l WITH in 2025 KM^3	Indicators: IRWR Per Cap (Stand-dard) M^3	IWMI 2025 WITH (S1) % chan from 1990 %	IWMI 2025 WITH (S2) % chan from 1990 %	(S2) % of AWR %
		1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
World		5,285	160%	8456	47,196	3,410				245,067																		5,581			
Asia		2930	152%	4460	17931	1555				138396	1330						2135	1444	9%	68%	691			391		1835	315	4,021	62%	18%	10%
China		1,155	132%	1526	2,800	533	28	32	401	47,965	463	184%	0.53	0.21	39%	60%	612	399	-14%	65%	213	46	38	128	84%	527	0	1,835	39%	-1%	19%
% of Total		24%			7%	18%	6%	7%	87%	22%	22%						18%	16%			23%			11%		15%					
India		851	164%	1392	2,085	518	18	24	569	45,144	484	145%	0.74	0.29	40%	60%	792	525	8%	66%	267	28	24	73	100%	598	80	1,498	67%	15%	29%
% of Total		17%			5%	18%	3%	4%	93%	20%	23%						23%	22%			28%			6%		16%					
Group 1																															
Afghanistan(1)	1	15.0	301%	45	65.0	25.6	102	34	1566	3,000	23.6	84%	0.94	0.66	70%	70%	70.9	70.9	201%	100%	0.0	102	1	4.7	128%	75.5	49.9	1,436	195%	195%	116%
Singapore	1	2.7	124%	3	0.6	0.2	41	43	0	-	-	NS	NS	NS	NS	NA	0.0	0.0	-	NA	0.0	82	86	0.6	148%	0.6	0.3	179	148%	148%	94%
Pakistan(1)	1	121.9	234%	285	418.3	155.7	26	26	1226	16,940	149	116%	0.76	0.37	49%	60%	349.2	282.7	89%	81%	66.4	26	26	14.5	134%	297.3	141.6	1,469	134%	91%	71%
Total Group 1		139.7		333	483.9	181.5				19,940.0	173.0						420.0	353.6			66.4			19.8		373.4	191.9				
Group 2																															
Group 3																															
Nepal	3	19.3	211%	41	170.0	2.9	6	2	143	900	2.7	109%	0.28	0.16	58%	70%	5.8	4.8	75%	83%	1.0	12	3	0.6	323%	5.4	2.5	4,178	122%	87%	3%
Australia	3	16.9	146%	25	343.0	15.8	606	19	308	1,832	5.2	101%	0.28	0.19	68%	70%	7.6	7.4	41%	97%	0.2	606	37	15.9	50%	23.2	7.5	13,905	49%	47%	7%
Cambodia	3	8.8	223%	20	498.1	0.6	3	1	60	160	0.5	122%	0.27	0.11	40%	70%	1.2	0.7	28%	58%	0.5	6	1	0.2	345%	0.8	0.3	25,302	136%	47%	0%
Indonesia	3	182.8	151%	276	2530.0	17.5	12	11	73	4,410	13.3	137%	0.22	0.08	34%	60%	20.1	11.5	-13%	57%	8.6	25	21	12.7	202%	24.2	6.7	9,180	87%	38%	1%
Malaysia	3	17.9	251%	45	2531.0	13.7	177	230	361	335	6.5	200%	0.96	0.08	8%	16%	16.2	8.1	25%	50%	8.1	177	230	18.3	151%	26.4	12.6	56,417	151%	92%	1%
Myanmar	3	41.8	181%	76	2532.0	4.2	7	3	91	1,005	3.8	118%	0.32	0.12	39%	70%	6.9	3.8	1%	56%	3.0	14	6	1.5	261%	5.4	1.1	33,508	99%	27%	0%
Total Group 3		287.5		481.1	8,604.1	54.7				8,642.0	32.1						57.7	36.3			21.4			49.1		85.4	30.7				
Group 4																															
Philippines	4	60.8	172%	105	323.0	41.7	123	144	418	1,560	25.4	200%	0.82	0.14	18%	35%	43.7	21.9	-14%	50%	21.9	123	144	28.0	72%	49.8	8.1	3,090	72%	20%	15%
Vietnam	4	66.7	177%	118	376.0	27.6	54	37	323	1,840	21.5	183%	0.64	0.21	32%	60%	38.2	20.4	-5%	54%	17.7	54	37	10.8	77%	31.2	3.6	3,182	77%	13%	8%
Bangladesh	4	108.1	181%	196	2357.0	23.8	7	2	211	2,936	22.8	161%	0.48	0.15	30%	60%	41.4	20.8	-9%	50%	20.7	13	4	3.5	263%	24.2	0.4	12,018	89%	2%	1%
Total Group 4		235.6		419	3,056.0	93.1				6,336.0	69.8						123.3	63.1			60.3			42.2		105.2	12.1				
Group 5																															
South Korea	5	42.9	127%	54	66.1	27.1	120	221	291	1,345	12.5	100%	0.93	0.15	16%	33%	15.8	7.9	-37%	50%	7.9	126	221	18.9	29%	26.8	0.0	1,215	28%	-1%	41%
North Korea	5	21.8	153%	33	67.0	15.0	76	110	502	1,420	10.9	100%	0.77	0.12	15%	31%	16.7	8.4	-23%	50%	8.4	76	110	6.2	53%	14.6	0.0	2,007	53%	-3%	22%
Sri Lanka	5	17.2	145%	25	43.2	8.7	10	10	483	520	8.3	178%	0.90	0.33	36%	60%	12.1	7.3	-12%	61%	4.8	20	20	1.0	191%	8.3	0.0	1,726	51%	-4%	19%
Thailand	5	55.6	132%	74	179.0	33.5	24	36	542	4,238	30.1	143%	0.50	0.16	31%	60%	39.9	20.9	-31%	52%	19.0	48	72	8.9	165%	29.7	0.0	2,433	46%	-11%	17%
Japan	5	123.5	98%	122	547.0	90.8	125	243	368	2,846	45.4	200%	0.80	0.03	4%	7%	44.7	22.3	-51%	50%	22.3	125	243	44.7	-2%	67.0	0.0	4,499	-2%	-26%	12%
Total Group 5		261		308	902	175				10369	107						129	67			62			80		146	0				

Many countries in the Region (Group 4 and Group 5) would be able to meet total societal water demand for their socio-economic development at the cost of relatively limited further water development (and therefore limited environmental impact) and/or with their available water resources, provided that they embark on significant and far-reaching improvement programmes of water use efficiency in the irrigation sector. The potential benefits or problems averted would be greater for those countries with limited investment capacity such as Vietnam or Bangladesh, which otherwise would need to almost double their developed water supplies.

Countries in Group 3 would need to invest massively in both water development and improvement of their national irrigation systems in order to avoid water becoming an overriding constraint in socio-economic development and to meet food security objectives, but they have a varied capacity to do so.

However, approximately one billion persons or about a quarter of the Region's population would live in countries or regions of absolute water scarcity with severe consequences for their rural (and urban) population and substantial impact on the agricultural sector, for which Governments would need to prepare the populations and assist them in finding employment and income generating activities in other economic sectors, and develop other sectors to be able to meet their food import bills in order to achieve food security. This situation may be mitigated to a certain extent by inter-basin transfers within China or India.

As many of the regions concerned are major production areas for vital cereal food production, it is foreseen by many experts that the need for these regions to import cereals could have severe consequences for the poor segments of the population in other countries, by raising their prices on the international markets. A major factor of poverty eradication in the past has been the reduction of food commodity prices thanks to the (irrigated) "green revolution". In theory, a shift in global production patterns for crops with a high virtual water content from water-scarce regions to well water-endowed regions and countries could ensure the satisfaction of demand, but whether this will happen is far from certain.

What seems to be certain is that nearly all countries in the Region will need to invest considerable efforts and resources in a mixture of improved demand management of the water sector and interventions on the supply side. In addition to the required economic investments on the supply side, considerable investments entailed by an irrigation water management improvement programme or the institutional and social capacity of the countries in implementing the necessary reforms in the water sector as a whole or in the irrigation sub-sector would be required to achieve the very considerable improvements in water use efficiency postulated in the second scenario. These rising costs will be borne increasingly by the water users through a combination of pricing and cost recovery, pushing the prices of food commodities up, impacting in particular on the Region's poor.

4. RICE WATER MANAGEMENT

Total water requirements and specific water use (m^3/ha) for rice production under different ecologies can be roughly estimated on average (evapotranspiration 550-950 mm/crop, which is the water actually consumed by the plant) at:

- rainfed upland rice: 5500 m^3/ha (evapotranspiration only) for 1.25 t/ha specific water use: 6.5 m^3/kg
- rainfed lowland rice: 10,000 m^3/ha (evapotranspiration + impounded rainwater) for 2.5 t/ha specific water use: 4.0 m^3/kg
- irrigated upland rice: 10,000 m^3/ha (evapotranspiration + supplementary irrigation) for 2.5 t/ha specific water use: 4.0 m^3/kg
- irrigated lowland/deepwater rice: 16,500 m^3/ha (evapotranspiration and full irrigation) for 4.5 t/ha specific water use: 3.7 m^3/kg

Irrigated lowland is at the same time the dominant ecosystem, the most productive in terms of yields and specific water use (the most water productive), but also the least efficient if one considers water use per cultivated ha or the amount of water required for evapotranspiration divided by the amount of water diverted into the system.

Research, with some reason, has concentrated in the past on this ecology where the greatest potential gains could be achieved per ha and globally. Early research focused on ways to improve water productivity by developing improved varieties and improving agronomic management, then more recently on improving water use efficiency, and finally on improving water productivity (which considers yields or income per m^3 of water consumed) at all levels.

Irrigation inflow requirements (the amount of water diverted into the system) can be subdivided into crop evapotranspiration **(T)**, evaporation **(E)**, seepage and percolation losses **(S and P)**, and surface run off **(SRO)**. Because quantities of water required for land preparation and soaking as well as for maintaining water level in the paddy fields and soil saturation are high, **T** may represent only a small portion of irrigation inflow requirements and therefore overall (system) irrigation efficiency or (farm) water use efficiency are typically quite low (in the range of 30 to 40 percent).

Typically, parts of seepage and percolation losses as well as surface runoff can be re-used, i.e., recycled within the system **(RCL)**. Attention has focused more recently on the fate of seepage and percolation and runoff. If this water is reused within the system (recycling drainage water or with conjunctive use) for agriculture or other uses, or returned to the hydrological cycle for further use downstream for productive use, then this water cannot be considered as lost. In the upstream part of the river basin, reducing these "losses" might only result in dry or paper savings and in disturbing the established hydrological regime (reducing groundwater re-charge, affecting downstream users etc.). Further downstream, wherever this water flows into sinks (i.e., cannot be reused), flows into the sea or is too polluted or salinized to be reused, then, attempts at reducing these losses or recycling them within the system would result in real or wet water savings. Indeed, it may be argued that paddy fields perform similar hydrological functions to wetlands for groundwater re-charge, flood control and trapping silt, which could be valued. Some authors have even suggested that farmers might be subsidized to practice inefficient irrigation practices for groundwater re-charge.

In any case, it is now widely accepted that:

- A river basin perspective should be adopted with much more attention being paid to defining the boundaries of intervention (farm, system, basin). Substantial progress has been made in defining concepts and methodologies (water accounting, modeling, etc.) but available data, which are already woefully inadequate to assess the merit of interventions at the farm or system level, water abstraction and even cultivated and irrigated areas, are even more lacking for the adoption of integrated river basin approaches.

- More attention must be paid to water quality issues and particularly the release of pollutants (fertilizers and other agro-chemicals) and salt concentration.

Nevertheless, practices which minimize irrigation inflow are of a direct interest to farmers, who see their water supply rationed and have to pay an increasing share of its cost; to managers and developers, who also face rationing because of degradation of water resources, dam siltation, transfer to other sectors, etc. and therefore have an interest in minimizing pumping costs, and operation and maintenance as well as development costs; and also to water resources managers who need to plan future irrigation developments with minimum environmental impact from withdrawals or reservoirs. In addition, many major rice growing areas are located in coastal plains. Furthermore, water saving practices, which require greater water control, typically are associated with or part of packages to improve agronomic practices and the efficiency of use of other inputs, and therefore play an important role in total factor productivity.

They therefore contribute to increasing not only water use or irrigation efficiency but also to improving or sustaining water productivity. Indeed, water management methods which improve water use efficiency have been developed with a view to maintaining crop yields and actually, when implemented properly, lead to yield increases (in the range of 15-20 percent in China for intermittent flooding and other methods). It follows that, although it is correct and necessary to use rigorous concepts for efficiency and performance at system and basin levels, and to determine under various conditions the optimum combination of improved technologies and water management practices that can meet water demand with least water consumed and managing return flows to ensure system and basin level efficiency, in practice it is difficult to find water management techniques proposed for adoption at the farm level which do not simultaneously raise irrigation efficiency and water productivity.

The range of possible strategies and their effect on various components of irrigation inflow requirements can be summarized in the following Table 4.

These various practices and strategies are presented and discussed in detail in SWIM Paper 5 (Guerra, Bhuiyan, Tuong, Barker, 1998) as well as in Barker, Dawe, Tuong, Bhuiyan and Guerra, 1998 and Klemm, 1998 from which the above table is drawn and will be summarized or commented on in the following section.

Table 4. Practices and Strategies to Improve Rice Water Productivity

Practices	T	E	S and P	SRO	RCL
Developing improved varieties	x				
Improving agronomic management	x				
Changing schedules to reduce evaporation		x			
Reducing water for land preparation		x	x	X	
Changing rice planting practices		x	x	X	
Reducing crop growth water		x	x	X	
Making more effective use of rainfall			x	X	
Water distribution strategies		x	x	X	
Water recycling and conjunctive use					x

4.1 Increasing Water Productivity

Developing improved varieties: High yielding varieties (HYVs) have more than doubled rice water productivity (against **T**) over the last decades. Hybrid rice has successfully been introduced in transplanted systems. However, the direct seeding method which is gaining increased acceptance is limiting the adoption rate of the hybrid rice technology since the process requires the use of much more of the costly seeds of hybrid rice per hectare than does the alternative method of transplanting rice. Direct seeding of hybrid rice is not economical with current hybrid seed production technologies. The New Plant Type (NPT) has been developed by IRRI scientists with the goal of raising the yield potential of conventional rice varieties to about 12-15 t/ha. NPTs are targeted for direct seeding conditions in an irrigated ecology. Biotechnology could amend many abiotic and biotic constraints to sustainable rice production including drought stress and tolerance to adverse soils and cold temperature.

Improving agronomic management: Improving pest control and nutrient management and other technologies that enhance yields increase output per unit of water (T). It should be noted that IPM techniques were developed in the context of large schemes where water supply was considered a constraint. Efforts are currently under way to integrate on-farm water management, IPM, nutrient management with the improvement of crop management (Pilot projects of FAO's Special Programme for food Security in Sri Lanka, Cambodia, Nepal, Bangladesh, and Pakistan).

***Changing the crop planting date and making more effective use of rainfall*:** Both these strategies require changes in water resources or reservoirs and farm management strategies and good cooperation between system operators and farmers.

***Reducing water use for land preparation*:** Practices include land leveling (which contributes to better utilization of variable rainfall early in the season, reducing weeds, reducing S and P, improving fertilization application efficiencies and improving the timeliness of land preparation etc.), reducing the land preparation period, puddling, management of cracked soils (losses can be reduced by measures that minimize crack development during the soil drying period through straw mulching and dry shallow surface tillage on crack formation during the fallow period , or by impeding the flow of water through these cracks), and dry tillage.

***Changing rice planting practices*:** Wet seeding of rice uses about 20-25 percent less water than in traditional transplanted rice methods and drastically reduces labor for establishing the crop from 30-person days per ha for transplanting to 1-2 person days. Improved water management practices during crop establishment (the first 2 weeks from planting) are crucial to enhance the weed-suppressing advantages that can be achieved by early flooding of wet seeded rice. Expansion of employment opportunities and crop intensification have resulted in the replacement of transplanting by direct seeding. Dry seeded rice saves even more water especially during land preparation.

***Reducing water use during crop growth*:** Intermittent flooding, maintaining the soil in sub-saturated condition, alternate drying and wetting (as developed in various provinces in China) can reduce water applied to the field by more than 40 percent compared with continuous submergence methods without affecting yields. Increases in yields by up to 20 percent are actually reported. Some variants of these water management methods allow for storage and maximum use of rainfall. Optimum use of rainfall during the rainy season can more generally save reservoir water and increase areas irrigated during the dry season.

***Supplementary irrigation of rainfed lowland rice*:** Supplementary irrigation either for crop establishment or at critical growth stages, particularly flowering, can prevent yield depressions of up to 40 percent or even crop failure one year out of five for T. Aman (monsoon season) rice in Bangladesh.

***Water distribution strategies*:** Reducing inequities in water distribution among tertiary canals or within tertiary canal blocks through various systems of rotation should contribute to achieving a more even distribution, reduce losses and provide water to large areas. However, rotation systems are difficult to establish in practice.

***Water recycling and conjunctive use*:** Conjunctive use was developed on the Indian sub-continent principally to compensate for the lack of reliability, inequities in distribution, and rigidity of canal water distribution systems, which constitute many obstacles to the development of productive irrigated production systems. It allows flexibility in availability of irrigation water and secures against failures in water delivery. It enables farmers to reuse seepage and percolation losses from canals and fields. However, conjunctive use and recycling of drainage water were not developed primarily to enhance water productivity or overall system efficiency and are usually not considered in design manuals of most irrigation agencies. Their development in uncontrolled conditions have led in many areas to groundwater draw-down and salinity problems. However, they are standard features of modern design methods. Drainage recycling has been applied very successfully, for instance in the MUDA scheme in Malaysia.

***Alternatives to flooding techniques*:** While Barker, Dawe, Tuong, Bhuiyan and Guerra address the domain of surface irrigation basin on-farm methods, Klemm also discusses pressurized irrigation methods. It should be noted that, indeed, in theory, and also in practice, rice (both upland and lowland) can be irrigated with overhead as well as surface methods, and, among these, not only flooding and related techniques but also furrow and other surface methods. These techniques have been developed mostly in Latin America for upland rice, in the United States of America and in the Mediterranean Region which faces severe water scarcity and, the region in China where large rice areas are under arid to semi-arid climates. With the development of new varieties and the improvement of agro-technical methods and practices, yield obtained under aerobic conditions reach the level of production as under flood irrigation. Good results are also achieved with sprinkler irrigation of lowland rice.

However, growing irrigated rice under aerobic conditions still faces severe constraints:

- Higher inputs for weed control
- Increased susceptibility to diseases
- Imbalance of soil nutrients
- More know-how required in on-farm water management
- Increase of investment and maintenance costs
- Deep ingrained traditions and social customs based on flood irrigation management.

The acceptance by farmers of all the above strategies and practices will of course depend on economic factors. Furthermore, they depend on improved water control management of water at the system level, as well as adequate irrigation (in particular a reticulated irrigation distribution system) and drainage facilities. Their availability in China has allowed farmers to adopt water savings techniques described above. However, typically, at that level, conveyance, field canal and distribution efficiencies are particularly sensitive to the quality of management, communication and technical control. When water supply within the system is unreliable, farmers try to store more water than is needed. In many large irrigation systems, few control structures at any level and poor drainage structures and poor drainage networks contribute to a waste of water.

Being confronted with this rather large number of problems, it is not surprising that farmers are reluctant to shift to more demanding water management techniques than flooding. However, considering the growing water scarcity and pressure on the irrigated sub-sector within the water sector and on agriculture by other sectors of society and overall economic development policies described in previous sections, there is no choice and farmers must be provided both with a conducive environment and a proper production tool, i.e. better performing irrigation services.

It is the responsibility of governments to develop such a conducive environment which can be briefly summarized as follows:

- Legal support at national level for land use and water resources management (establishment of laws);

- Legal support at district and community level for land use and water resources management (integration of customary laws and establishment of regulations and by-laws);
- Technical support in upgrading irrigation systems for efficient water distribution;
- Agricultural support in adapting agricultural practices to modified irrigation methods;
- Financial support to initiate community-managed credit-schemes; and
- Human resources development at district and community level (area-based water resources management and on-farm water management).

In addition, the success of irrigated agriculture hinges on economic factors and the presence of adequate services. Inadequacies of market systems, storage facilities, management of agricultural produce and credit sources have contributed to failures in the past. These constraints must be eliminated through sound government macro-economic policies to permit increases in production and to ensure the economic viability of projects.

4.2 The System Level

Improvements in the operation and maintenance of rice irrigation schemes through rehabilitation of the deteriorated systems, improvement of irrigation infrastructure for surface irrigation, irrigation management transfer, modernization, combining to various degrees institutional, organizational and technical changes, have been attempted in the Region with variable degrees of success. Studies undertaken by the World Bank in recent years have evaluated the impact of irrigation projects.

Jones (1995) evaluated the design of rice project in the humid tropics and concluded, from the strong degree of resistance of farmers to new design standards and the level of anarchy and chaos observed on the schemes, that the more reticulated systems, capable of supporting on-demand water delivery, were not appropriate under these climates.

A more recent study (OED, 1996, Rice, 1997) assessed the agro-economic impacts of investments in gravity-fed irrigation schemes in the paddy lands of Southeast Asia, to determine whether and how the quality of operation and maintenance (O and M) services influences the sustainability of those impacts.

At four of the six sites, the areas supplied by the irrigation systems were significantly less than planned. Cropping intensities were also substantially lower than expected at three sites and falling at a fourth. Only one scheme had attained both its area and intensity targets. Paddy yields varied widely - between schemes and in comparison with expectations - but a weighted average for the wet and dry seasons at all the schemes was about 3.3 tons, or 85 percent of appraisal projections. However, farmers had not diversified out of paddy. Indeed, the concentration on paddy had increased. Output was between 32 and 73 percent of appraisal estimates for five schemes. The returns had also been driven down by the decline of the international price of rice.

Overall, agency and irrigator performance appeared to be substantially better than expected. Farmers cooperated to achieve at least basic O and M objectives regardless of the level of maturity of the formal organization. There were no substantial negative constraints on irrigated production attributable to poor performance in O and M. Those O and M operations that are essential to keep sufficient supplies of water flowing to the great majority of the fields were adequately carried out. The study also noted the dismantling of complex technological control systems installed in the 1980’s in favour of fixed structures that have no adjustments and structures that adjust automatically to changes in water levels; and the rejection by farmers of both rotations and gates. Rotations do occur, but they tend to break down under conditions of shortage, which is when they are needed most.

The main finding was that given that they offered poor economics and low incomes, these paddy irrigation schemes faced an uncertain future. Small holder irrigated paddy could no longer provide the basis for a growing, or even stable household economy, driving younger family members off the farms while older members who stayed behind concentrated on basic subsistence crops. Consequently, social capital would erode and O and M standards were likely to suffer. As economies expanded, irrigated paddy would not be able to compete with the incomes to be had from other employment opportunities. Improved O and M performance would not rescue them. The study made these recommendations:

- Sharpen the response to O and M failures by disaggregating O and M; identifying the poorly performing components; and dealing with disincentives specific to each, such as the tertiary gates that farmers below consider unfriendly.

- Simplify the infrastructure and operations technology by converting to fixed and automatic controls that need less human intervention and by supporting authorities who plan with the farmers to abandon equitable rotations by rationing water during emergencies.

- Promote the transfer of management to farmers and their WUGs judiciously by recognizing that organizing user groups pays off, but also accepting that immature WUGs cannot handle some management responsibilities.

- Improve household earnings by diversifying cropping systems and supporting research, extension, and marketing services keyed to specialty crops and integrated, high value farming.

More recently, the International Programme for Technology and Research in Irrigation and Drainage evaluated the impact on performance of modern water control and management practices in irrigation (IPTRID/World Bank/FAO Water reports 19, 1999) on 16 projects, of which 6 were in Asia (Majalgaon, Dantiwada and Bhakra in India, Kemubu and Muda in Malaysia, and Lam Pao in Thailand – Lam Pao was also one of the sites of the previous study).

Key findings were:

- While 15 of the 16 irrigation projects visited had some aspects of modernization, none of them could qualify as "modernized" irrigation projects.

- The partially modernized projects did not have the chaos and anarchy that has been widely documented in typical (non-modernized) irrigation projects.

- Several projects have been modernized to the point that the water conveyance operations and hardware were able to support functional water user associations, and in turn those water user associations were collecting sufficient water fees to pay for all or most of the O and M expenses.

- Water user associations of some form (parastatal or private sector) provide distinct advantages if they are properly empowered. The "social" WUAs that are developed for the purpose of providing maintenance and collecting water fees were consistently either weak or imaginary. The "business" WUAs that hired staff to distribute water and ran the water distribution similar to a business operation were often quite strong.

- Farmers and managers appeared to be satisfied with a level of water delivery service that simply eliminates anarchy and also provides "sufficient" water to farms. Such criteria are insufficient to support modern field irrigation hardware and management.

- Modernization efforts which emphasized computer programmes for predicting canal gate movements and water deliveries were generally ineffective (or worse).

- Modernization needs were split between hardware, management, and a combination of the two. All projects needed improvements in both hardware and management.

- Successful projects stress improved communications, focus on operational data rather than statistical data, and require a minimum of paperwork for operators.

- Simple hardware and operational changes could give immediate benefits - if people just knew about them. There is a huge lack of awareness of how to design irrigation systems that provide good service. Examples of simple potential improvements were:

    - Re-orienting employees from statistical data collection to operations and focusing on results rather than process.
    - Using weir flow on cross regulators rather than only orifice flow.
    - Modification of turnout operations for improved flow control and measurement, including some physical modifications to the turnouts.
    - Installation of re-circulation systems within the project to easily collect and reuse spill.
    - Improved voice communication and mobility of operators.
    - Remote monitoring of spill points, and subsequent adjustment of the head works for the pertinent canal. This can be done manually with radios or even over a reliable telephone network.
    - More frequent adjustment of flow rates at the source of a project, based on meaningful data from throughout the project.
    - Programmes for improved irrigation scheduling for field irrigation are doomed to failure unless the water delivery service is well controlled, reliable, and flexible -- which means most such programmes are doomed to failure.

- There is a very serious shortage of trainers and consultants who can provide focused and pragmatic training and design which properly incorporates both strategies and details of hardware and management modernization.

- Modernization is a slow and expensive process. Many modernization projects are under-funded with respect to the expectations.

- Overall, there is a lack of understanding of modernization strategies and how to implement them.

Most field (on-farm) irrigation methods in these irrigation projects were relatively simple, and the farmers and irrigation project staff had low expectations of the level of water delivery service needed. The initial focus on modernization was generally on reliability and equity. This is because traditional field irrigation techniques are not sophisticated, and obtaining reliability and equity is essential to avoid anarchy. This will not mean that reliability and equity are less important for future irrigation systems; it means that flexibility and control will be more important than they are at present. Because the study aimed at investigation of the capacity of the systems to provide the level of service required in the future, which will have to be much higher than at present, the capacity of the systems to allow farmers to convert to pressurized irrigation methods was evaluated. Modern field irrigation systems have different service needs, where flexibility plus accurate control/measurement of volumes to fields are more important.

The study concluded the following on appropriate modernization strategies:

- Irrigation project proposals, at the onset, must clearly define:

- The desired service that will be provided at all levels within the system. This requirement needs more than a few sentences in a report. Performance-based design requires that substantial thought and resources be dedicated to this matter.

- The operational procedures which will be used to provide this desired level of service.

- The hardware and irrigation project game plan (strategy) that is needed to implement the proper operation.

Finally, there is a need for a new vision for projects:

- The vision for all modernization programmes must be on the water delivery service that is needed 30 years from now.

- Direct government contributions to O and M activities can realistically be reduced if the projects are first brought up to the point where reasonable water delivery service can be provided.

The findings and conclusions of these three studies seem to be rather pessimistic and contradictory. However, put together, they tend to indicate that present project designs are not capable of supporting both economically and technically the intensified, diversified and more water efficient and productive rice production systems which will be required in the future. They also seem to indicate that purely software solutions or mere improvement of operation and maintenance do not deliver the expected results in terms of improvements in performance and yields. They also reveal that many modernization or improvement efforts have been inappropriate, poorly adapted to local circumstances and the specific character of rice-based production systems, and incomplete or fragmentary.

***The Case of the Indian Sub-continent*:** Irrigation schemes in large parts of India and Pakistan have been built on the design logic of "protective irrigation”. The idea is to reach as many farmers as possible to protect them against crop failure and famine which would occur without irrigation in regions with erratic monsoon rainfall. Water available in rivers or reservoirs is spread thinly over a large area. The amount of water a farmer is entitled to receive is insufficient to cover the full water requirements on all his land for an average rainfall year. Management principles in India (Warabandi, Shejpali, crop sanctioning) all involve the problem of rationing scarce water in a supply based system where the objectives of individual farmers differ from those of the scheme management. Typical irrigation systems have very few control structures. Canals are run at full supply level or have to be closed in order to achieve equal distribution of water to ungated chak outlets and to avoid deposition of silt. Construction costs are low but maintenance costs are high in comparison to the low level of irrigation service. Protective irrigation systems have been able to mitigate the effects of severe droughts and are still the backbone of the agricultural economies in Pakistan and India. However, it is now becoming apparent that the design logic of these systems may no longer be adequate for modern productive irrigated agriculture in an increasingly global economy.

The most pressing problems include: low efficiency in water distribution and use, unreliable water delivery, widespread vandalism of structures, poor maintenance, waterlogging and salinity, and insufficient cost recovery. Farmers could cope with these inefficiencies and make full use of advances of the green revolution in cases were they had access to fresh groundwater. However in areas which are less fortunate, because of saline or insufficient groundwater, yields are stagnating or declining.

The level of service provided to farmers clearly would not allow them to adopt the water saving technologies and management practices for rice production described in previous sections.

Successful irrigation systems feature high yields, service oriented irrigation management and financial autonomy. They may be described as productive irrigation.

FAO's position is that a resolute modernization of irrigation schemes, through a combined strategy of institutional, managerial and technological change with the objective to change from a supply to service oriented mode of operation, building on current economic trends, is the adequate strategic choice to the present economic and social environment.

Other options include maintaining the status quo, with an exacerbation of existing problems, or enforcement of the protective irrigation concept by irrigation authorities which would have to continue to be dependent on state subsidies: levels of irrigation service and agricultural productivity will remain low except where canal water is supplemented by private wells.

This view seems to be supported by the Government of India, which in the 1998 preface to the World Bank Irrigation Sector Report, called for "a total revolution in irrigated agriculture … with much more focus on the improvement of performance of existing irrigated facilities and provision of a client-focused irrigation service … a paradigm shift in emphasis … toward improving the performance of existing irrigated agriculture … a second revolution in irrigated agriculture is required now".

5. CONCLUSIONS

The challenge to produce more rice with less water, economically and in ways that will be adopted by farmers in a context of reformed agricultural and water policies and integrated water resources management appears formidable yet is vital for the food security of the Region. This will require considerable investments in economic as well as human resources.

A range of options are available for increasing the productivity and efficiency of water in surface irrigated rice ecologies. More radical options departing from traditional systems are also available and may be required. Over the past decades, substantial gains have already been achieved and farmers have demonstrated that, provided that they are empowered, have the economic incentives and an adequate production tool and irrigation service, they could quickly adopt substantial changes in their water management practices. However, new institutional and technical approaches have had limited impacts in the field.

The most appropriate strategies to adopt will vary over time and space and will have to be designed carefully with the involvement of the farmers, but will need to be resolutely forward-looking and perhaps revolutionary. Identifying the policies, management practices and technologies needed at farm, system and basin level will require a multi-disciplinary approach, substantial investments in collection and analysis of new and relevant information and research, as well as constant evaluation of present approaches and practices.

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STRATEGIES FOR BRIDGING THE YIELD GAP IN RICE: A REGIONAL PERSPECTIVE

R. C. Chaudhary [*]

1. INTRODUCTION

Rice in the Asia-Pacific Region, where 90 percent of it is produced and consumed, will remain the lifeline of the people. Demand for rice is expected to grow faster than the production in most countries (Swaminathan, 1998) so much so that by 2025 we will need 800 million tons of it annually. How this additional 300 million tons will be produced annually (Hossain, 1997) with less land, water, pesticides and manpower, is the crucial question for the next millennium. A depleted resource base and gradually eroding quality of land, water, and environment pose a threat of another magnitude.

The currency crisis in most Asian countries added another dimension to importing and exporting countries through cost of rice and/or investment in research and production. The yield deceleration, stagnation and decline observed in high-yield environments also gives a danger signal (Papademetriou, 1998). The rice area has already started declining in China, Malaysia, Bangladesh, the Red River delta in Vietnam, and other countries (Table 1).

2. APPROACHES TO BRIDGE DEMAND–PRODUCTION GAP

Approaches to bridge the gap of projected demand to current level of production could be by the expansion of rice area (horizontal expansion), increase of yield (vertical expansion), yield gap bridging, and reduction of yield losses. Horizontal expansion is often followed for additional production but in the Asia-Pacific Region now land area is diminishing (Table 1, Fig. 1). There is hope only from Africa and Latin America as more than 96 percent of the suitable rice land is remaining unutilised (Chaudhary and Tran, 1999). The vertical expansion approach by breaking yield barriers and by the use of already released varieties is the immediate possibility. Further, the New Plant Type (NPT) or Super Rice, hybrid rice, and genetically engineered transgenic rice are the additional possibilities. The yield gap bridging i.e., filling the gap between best experimental yields and those that farmers can achieve is promising. But due to its complexity, there are different views regarding avenues for increasing rice production (Duwayri et al., 1998). Pingali et al., (1997) argued that the yield gaps in favourable rice ecologies are not significant for exploitation for increasing rice production. Under this situation further increase in yield is possible only with the deployment of new technologies, such as hybrid rice. The reasons for the presence of large gaps and levels of technology has to be understood, (Fujisaka, 1994). But the pre and post harvest yield losses, often as much as 49 percent, gives much hope for bridging the yield gaps in most countries.

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Table 1. Rice Production (P), Yield (Y) and Area (A) in 1997, and Growth Rates in P, Y, and A, during 1987-97 in Asia-Pacific (Source: FAO-RAP Publ.1998/21).

Country	Production (P) (000 tons)	Area (A) (000 ha)	Yield (Y) (kg/ha)	Growth Rate (%) in (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	189,000	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
P. N. Guinea	1	-	3,023	-	-	0.1
Philippines	11,269	3,840	2,933	2.7	1.8	1.0
Rep. of Korea	7,100	1,049	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

3. SUPERIORITY OF YIELD GAP BRIDGING

While efforts are being made to raise the yield ceiling, there is even a more pressing need to address the problem of yield gaps (Duwayri et al., 1998). The yield gap reduction can be considered as a local solution to a global problem. It can bring in additional production with the additional incentives of cost reduction, poverty alleviation, and social justice and equity. While no major breakthrough is expected immediately, reducing the yield gap alone can provide an additional 60 percent more rice needed by the year 2025.

4. MEANS AND MODELS TO BRIDGE THE YIELD GAP

4.1 The Model

The narrowing of the yield gap in rice, requires integrated and holistic approaches, including appropriate concept, and policy intervention (Cromwell, 1996). If any one of these components is missing or weak, the yield gap in that area cannot be narrowed (Tran, 1996). Narrowing the yield gaps (Fig. 2) 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 a holistic approaches and action by governments (IRRI, 1998b). An integrated programme approach is obligatorily required. The narrowing of the yield gap is not static but dynamic with the new technological development in rice production, as the gaps tend to enlarge with the improvement of yield potential of rice varieties.

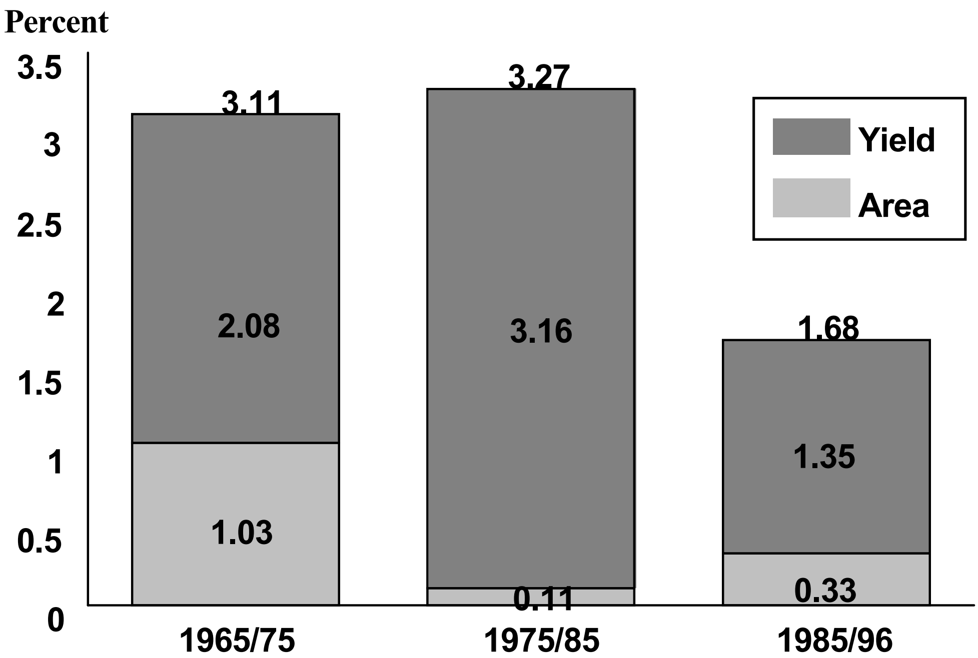

Figure 1. Contribution (%) of area and yield to rice production in Asia, 1965-96. Production figures above the yield (Source: FAOSTAT 1997)

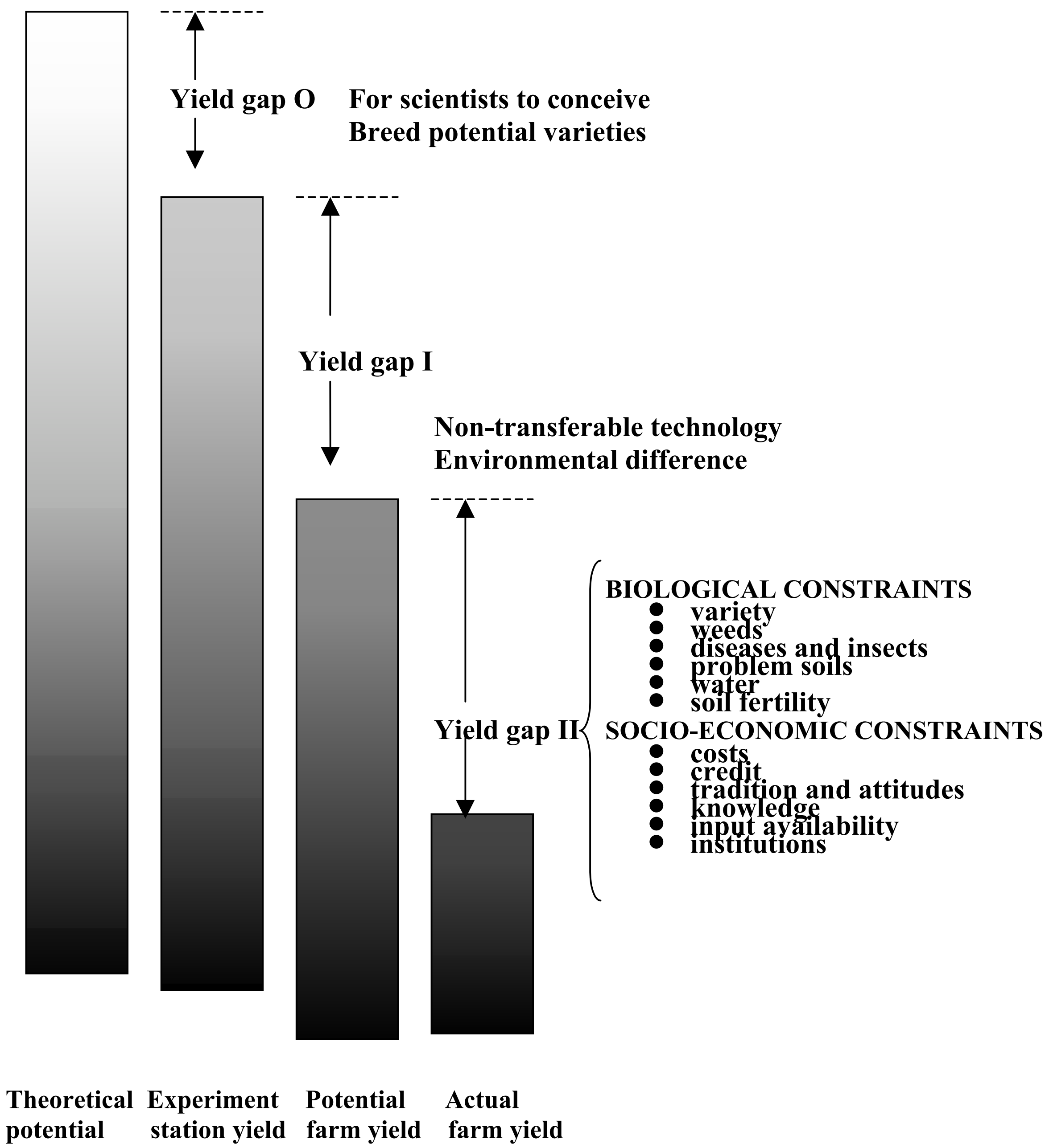

Figure 2. The concept of yield gaps among theoretical potential, experiment station yield, the potential farm yield and the actual farm yield (modified from Gomez, 1977).

4.2 Lessons from Some Countries

In Indonesia, the national rice yield increased by about 4.9 percent per year during 1967-77 and 4.3 percent during 1977-87 through various schemes. Indonesia sets a good example of setting up strong test-transfer centres for technology (Chaudhary, 1998). Vietnam became the 4th largest exporter from a basket case (Le, 1998), highlighting the ownership policy reform, from government to family holdings. Various methods and models of technology transfer have been tried since the era of the "green revolution" that began in India (Chaudhary et al., 1998; Taimni and Verma, 1998). Compact block Front Line Demonstrations (FLD) were started in 1990. Egyptian rice yield increased from 5.8 t/ha in 1987 to 8.5 t/ha in 1997 (Table 2) where technology demonstrations got very intensive and yield gaps reduced (Badawi, 1998). In Australia, the concept of "Ricecheck" reversed the yield decline of 2.4 percent per year in 1967 to the current level of 10 t/ha (Lacy, 1998) due to a very efficient system of technology transfer. In U.S.A. the yield gap is small (David Mackill, personal communication). With no yield gap, the national yield of Greece reached 7.6 t/ha in 1996, setting a good example to be emulated by other countries.

Table 2. Egyptian Rice Yields (ton/ ha) in Demonstration Plots, National Average Gap during 1988-1997 (Source: Badawi, 1998).

Ye	Demonstration Fields	National Avera ge	Yield gap
1988	9.90	6.07	2.83
1989	10.50	6.45	4.05
1990	10.43	7.29	3.14
1991	10.60	7.57	3.03
1992	10.64	7.67	2.97
1993	10.31	7.74	2.57
1994	10.45	7.93	2.52
1995	10.51	8.20	2.31
1996	10.29	8.35	1.94
1997	10.33	8.56	1.77
Mean	**10.40**	**7.58**	**2.82**

5. HANDLING BIOLOGICAL CONSTRAINTS AFFECTING YIELD GAPS

5.1 Stable Performing Varieties

Superior yielding varieties are available (Chaudhary, 1996), which can take farmers' yield to 8.00 t/ha if grown properly. But their performance is variable due to a higher proportion of Genotype X Environment (G X E) interaction (Gauch, 1992; Chaudhary, 1996). While the genetic reasons of stability in the performance of varieties may be difficult to understand, yet there is a need to identify and release stable yielding varieties even on a specific area basis, in contrast to relatively less stable varieties but on wide area basis. There are strong genotypic differences among varieties for this interaction, and methods are available to select more stable ones (Gauch, 1992; McLaren and Chaudhary, 1998). The New Plant Type of rice (also called "Super 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 yields in a more effective and sustainable manner. Hybrid rice has become a reality in China and also in India, Vietnam, Myanmar and the Philippines, and may pose less yield gap problems in the future.

5.2 Weeds

Weeds reduce rice yield by competing for space, nutrients, light, and water, by serving as hosts for pests and diseases, and even due to allelopathic effects. Under farmer's conditions, yield losses (gaps) are heavy due to improper or untimely operations.

5.3 Biotic and Abiotic Stresses

Rice has been under cultivation for thousands of years. As a result it has become a useful host for a number of diseases and insect-pests, 54 in the temperate zone, and about 500 in tropical countries. Of the major diseases and pests, 45 are fungal, 10 bacterial, 15 viral, and 75 insect-pests and nematodes. Realizing the economic losses caused by them, efforts have been directed to understand the genetic basis of resistance. The host-plant interaction and other control measures do reduce losses proportionate to their use, which is one pointer to yield gaps.

5.4 Soil Problems

Rice is grown from 45^{o}S to 50^{o}N of the equator, and from below sea level to 2,500m altitude. The rice soils vary from sand to clay, 5 to 10 pH, organic matter from 1 to 50 percent, and salt content from 0.1 to 1 percent. Other than on normal soils, rice is also grown in marginal and problem soils where plants face nutrient deficiency and toxicity. Improper varieties and improper management results in heavy yield losses and resultant yield gaps. Technologies are developing fast to ameliorate such situations.

5.5 Soil Fertility and Fertilizer

Soil degradation and quality deterioration limit crop yield in many intensive 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, development of a hardpan at shallow depths are some of the major indicators of deteriorating soil quality. Yield gaps can be attributed to knowledge gaps also (Balasubramanian et al., 1998). 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 by regulating the timing of N application based on needs of the plants, thus partly increasing the efficiency of the plant's use of the applied N. The other is to increase the ability of the rice system to fix its own N through nodulin genes and bacterium genes.

5.6 Water and Irrigation

Most studies on constraints to high rice yield indicate water as the main factor for yield gaps and yield variability from experiment station to farms. A recent study conducted by the International Water Management Institute, estimates that by the year 2020 a third of Asian population will face water shortage. Next wars may be fought over water (Gleick, 1993). The growth rate in the development of irrigation has already declined (Barker et al., 1998).

5.7 Integrated Crop Management (Prescription Farming)

Based on the extensive and critical testing of rice varieties and crop management technologies, it is possible to develop "prescription rice farming" for individual farmers and individual situations. The concept was tested on a limited scale in Indonesia during 1996-1997. Integrated Weed Management practice and IPM increase yield and decrease cost of pesticides, cost of production, and risk to health and the environment. Other knowledge based techniques will also help (Price and Balasubramanian, 1998). Narrowing the yield gaps by improvement of crop management practices of small farmers in developing countries is often not an easy task. It is essential, therefore, that these practices should not be applied in isolation but be holistically integrated in Integrated Crop Management Packages (ICMPs) with flexibility to adjust to prevailing environmental, socio-economic and market conditions.

5.8 Post-Harvest Problems

The introduction of more efficient technologies for handling, drying, storage and milling rice at the village level is essential to reduce post-production losses. The present impressions are that post-production activities are labour intensive, as the operations involve hand harvesting, sun-drying before threshing, threshing by trampling, and wind winnowing. This results in poor quality of milled rice including grain discoloration. The physical losses are more in wet season harvests due to problems of 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 should therefore be given the opportunity to define their post-production needs and be consulted in the selection of appropriate technologies.

6. HANDLING SOCIO-ECONOMIC CONSTRAINTS

6.1 Risk, Cost and Return

Rice is a totally risky crop in ecosystems like rainfed, upland, and flood-prone lands. Even in irrigated ecosystems, it is prone to risks of pests, diseases and floods. This affects farmers who apply costly inputs like seed and fertilizers. Even economists, not the farmers alone, advocate diversification and maximizing income from sources not strongly connected to rice farming. The only technology that can give confidence to farmers to use inputs, and can encourage them to reduce yield gaps, is the availability of stress resistant rice varieties.

6.2 Credit

Availability of credit for the development of infrastructure, capital costs or even crop loans in sufficient amount and on time is a big constraint. Not only the lack of collateral but also the interest rates pose a problem to farmers' access to credit. This also affects farmers' input applying capacity and profit margin. Government policy, institutional framework and policy affect the credit availability to farmers (Cromwell, 1996). A proper policy intervention is a must to make farmers credit-worthy and get enough and on time to buy inputs on an annual basis. The example of crop insurance in India is a praiseworthy policy support system.

6.3. Tradition and Attitude

The current level of factor productivity, which is still declining, cannot sustain the food need of the growing populace. Thus, sustainability must be at an increasing productivity level. The major reasons for instability in productivity are weather aberrations, crop management practices, and the severity of the pests. Although varieties tolerant to environmental stresses, higher stability and superior pest resistance have helped stabilize production, yet there is sufficient scope for improvement in these aspects. The issue to ensure that there is no degradation of the resource base in terms of soil and water, as well as the biodiversity of rice types requires the setting of an index of productivity.

6.4 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. 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. 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 loans, housing loans, joint loans and general loans (Dadhich, 1995). 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 stand, freedom from weeds and seed borne diseases. It is recognized in general, that quality seed ensures 10 to 15 percent higher yields under the same set of crop management practices.

6.5 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 technologies (Price and Balasubramanian, 1998). The government and private institutions associated with credit, input and pricing influence directly the adoption and level of their use, and thereby the yield level.

7. PLANNING TO BRIDGE THE GAP

CGIAR Centres like IRRI, CIAT, WARDA have changed gears and decided to come out of their ivory towers to listen to farmers (IRRI, 1996), and plan farmer-relevant research with their cooperation. Hopefully, future collaborative projects could involve collaborating institutions, training of local researchers on basics of yield gap bridging, strategic planning with local counterparts, development of operational plans, introduction of selected technologies, and extension success cases. Such a blueprint plan is long overdue.

7.1 Project components

The project components are shown below. However, rapid appraisal studies are undertaken initially where such information does not exist.

- **Survey, analysis and prescription: -** Systems perspective and system requirements - a consideration of all key factors and players to identify key intervention points.
- **Technology resourcing: -** Existing technologies from international, national and provincial institutions, including modern progressive farmers.
- **Institutional arrangements: -** Linkages including integration of activities with other disciplines, and to establish IO-GO-NGO-PO linkages.
- **Communication: -** Communicating the technology and knowledge-based practices.
- **Critical research: -** Bottleneck technologies and practices to explore opportunities for improvement.

7.1.1 Survey, analysis and prescription

The yield gap analysis has to be performed considering the uniqueness of the individual situation. Another interesting area of inquiry would be to study the relative magnitude of yield gaps in different yield-potential groups of rice, say within TV, HYV, hybrid rice, NPT rice. This is based on the hypothesis that it should be the minimum in hybrid rice, as the seed cost is high and the farmers take relatively better crop care including application of fertilizer, weeding and irrigation. This is where the methodology proposed by De Datta et al., (1978) needs to be examined critically and modified to answer the following:

- Characterization - yield gap (estimating potential yield levels in different production environments). Also stratification of relative magnitude of yield gaps in various yield potential groups, within TV, HYV, hybrid rice, NPT rice etc.
- Partition total yield gap into individual components of management, biological and socio-economic groups.
- Analysis - systematic approach to understand decision process and management practices
- Intervention points/measures - improve management efficiency and alleviate working conditions of farmers, especially women farmers.
- Decision-support systems and communication systems developed for bringing information-intensive technologies to farmers. Development of guidelines for potential extrapolation to larger groups and other areas.

7.1.2 Technology resourcing

The process of technology resourcing has to be done on a specific area and situation basis to come up with prescription farming.

- Technology resourcing (assessment of requirements, evaluation of available technologies, assistance in pilot programmes)
- Information and knowledge (database, training)
- Development of decision support systems.

7.1.3 Reaching to farmers-models of technology transfer

Communication issues have been haunting development agencies in transferring the technologies to farmers and devising methods on how to communicate to farmers with knowledge-intensive technologies. More efforts are needed to increase impact through identification of appropriate ways for high potential rice production and utilization interventions and to promote their adoption through development and application of improved dissemination strategies.

7.1.3.1 Government (GO) schemes

The positive aspects of government extension services lie in early successes with simple seed-based technologies and promotion of objectives of the State. They are relatively well resourced and staffed, but they have negative points like staff responsibility for non extension activities, slow bureaucratic response, weak links with research, tendency to favour more advantaged farmers, and top-down focus.

7.1.3.2 Non-Government Organisation (NGO)

The positive aspects of non-government Organisations are strength in decentralized systems, less bureaucratic/more flexible, people and poor centred, articulate the needs of disadvantaged groups, community focus, and effective in community mobilization/motivation, and active where the State and market are absent. The negative points of NGOs are their small/restricted impact, distance from policy decisions, professional and technical limitations, infrastructure, coordination, accountability, and limited resources.

7.1.3.3 Private Organizations (PO)

The positive aspects of the private sector organizations are strength in centralized systems, resources and management skills, technical competence, less bureaucratic, more flexible and innovative, and clear objectives. There are a number of strong negative points that focus on non-profit development, market manipulation, questionable technologies, favour mostly large and resource advantaged farmers.

7.1.3.4 Participatory (GO-NGO-PO)

The government organizations (GO), non-government organizations (NGO) and private organizations (PO) and farmers may join hands to resource-test-demonstrate-adopt models. Given appropriate roles and a decision making process, this may be the most effective broad-based and sustainable approach. IRRI has put such proposals into practice recently (IRRI 1998a, 1998b). But we must consider the new agents of change positively, which lie in the partnership of NGO, PO, and GO. The question remains as to who are the most appropriate ones?

- Difficult to answer.
- Dependent on circumstances and technology.
- Still not well understood.

Currently, the general trend is to move away from traditional GOs towards new agents of change (POs and NGOs). But partnership in itself is an experiment in development and technology transfer. There are issues needing to be understood such as:

- Are these new agents of change more effective in promoting the impact of research results?
- Under what kind of circumstances and for what kinds of technologies?
- What are the most appropriate roles, responsibilities, and linkage mechanisms?

Recognition of comparative advantages and maximization of resources to achieve common objectives must answer the following questions:

- Is it feasible?
- What can be done to encourage partnership formation?
- Under what kind of circumstances and for what kinds of technologies?
- What are the most appropriate roles, responsibilities, and linkage mechanisms?

Still other questions can be asked as to what can be done to address the weaknesses and capitalize on strengths? How can we put the relative strengths of the agencies together?

- GO + NGO +PO Partnerships
- Research +NGO/PO partnerships
- Hybrid diffusion system
- Utilizing new tools.

7.1.3.5 Farmer to farmer links

Learning from successful farmers shows the relative importance of biophysical and socio-economic constraints. The hypothesis in this case is that farmers with least yield gap have used sets of technologies and knowledge adapted to their locations in a dynamic decision-making process that is uniquely different from farmers with high yield gaps. Tapping the knowledge of successful farmers is considered very effective in resourcing and spreading location specific and superior technologies. Appropriate national agencies must learn all this gamut of technologies, knowledge and experience to transfer to the bulk of other farmers.

7.2 Policy Support

Government policies provide the environment for research investment, improve productivity, alleviate poverty, ensure systems' sustainability, protect the environment, and provide food security. Various types of policy interventions are needed which influence investments in research, assure availability of inputs and credit, and introduce a crop insurance policy to encourage the use of inputs and reduce risks. It is therefore imperative that through appropriate policies, socio-economic adjustments should be affected in terms of input-output pricing, institutional support, and to redress the needs of rice farmers in order to complement the technological gains.

7.3 Linkages

Linkages within and outside the country are important aspects of the project, for which the following list may be relevant:

- Linkage with the efforts of NARS in the Asia-Pacific Region
- Linkage of GO-NGO-PO-Farmers
- Linkage with IRRI's projects RE4, CREMNET and RTDP.
- Linkage with FAO's projects in this area.
- Linkage with other IARCs on a case by case basis.
- Linkage for funding support with donor consortiums.

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CONCLUSIONS AND RECOMMENDATIONS

The expert consultation recognized that rice is the staple food of most people in Asia and hence food security means rice security. Rice is closely linked with the social harmony and political stability of many countries. However, recent trends of declining farmers' productivity and profitability are discouraging many farmers from pursuing rice farming. It is therefore recommended that the governments should take appropriate action to improve rice farmers' productivity and income while ensuring national food security.

Of the various strategies to achieve the minimum required production growth to raise and sustain the present level of sufficiency in rice, consolidation of already gained genetic yield is widely recognized as the most practical short-term strategy. This requires precise assessment of the yield gap, identification of key technological, institutional, socio-economic and policy level constraints, and finding appropriate remedies.

Yield Gaps in Rice Ecosystems

- The expert consultation recognized the existence of sizable yield gaps between attainable and farm level yields across ecologies, regions within ecologies, and crop seasons in all rice growing countries in the Asia-Pacific region.

- The practical yield gap that can be addressed is the difference between the maximum attainable yield and the farm level yield as defined below:

    a. Maximum attainable yield: is the rice yields of experimental/on-farm plots with no physical, biological and economic constraints and with the best-known management practices at a given time and ecology.

    b. Farm level yield: is the average farmers' yield in a given target area at a given time and ecology.

- The consultation observed that the yield gap ranges from 10 to 60 percent between attainable and economically exploitable yields depending on the ecosystem and countries. The adverse environments (rainfed and flood-prone) have the highest yield gaps.

- The consultation discussed the various factors currently contributing to the yield gap in different countries. These include biophysical, technical/management, socio-economic, institutional/policy, technology transfer and adoption/linkage problems.

- It was also recognized that only a part of the yield gap can be remedied by currently available technologies. Policy environment and interventions were considered a very vital component of the strategy to bridge the yield gap. Likewise, technology transfer to farmers and research-extension-farmer linkages play an equally important role.

- The consultation recognized that developing new varieties with higher yield potential and stability is complementary to bridging the yield gap.

- The expert consultation felt that the goodwill and cooperation of governments is essential to initiate an effective yield gap-narrowing regional programme.

Factors Contributing to the Yield Gap

The consultation identified the following key constraints contributing to the yield gap.

a) Biophysical: climate/weather, soils, water, pest pressure, weeds.
b) Technical/management: tillage, variety/seed selection, water, nutrient, weeds, pests and post-harvest management.
c) Socio-economic: social/economic status, farmers' traditions and knowledge, family size, household income/expenses/investment
d) Institutional/Policy: government policy, rice price, credit, input supply, land tenure, market, Research, Development and Extension (RD and E).
e) Technology transfer and linkages: Competence and equipment of extension staff, RD and E integration, farmers' cognitive blocks, knowledge and skills, weak linkage among public, private, and NGO extension staff.

The specific constraints affecting rice productivity in different ecosystems of selected Asian countries were identified as listed below:

Irrigated Rice Ecosystem
(*priority concerns)

* - Declining soil productivity and inappropriate/imbalanced nutrient use
* - Increasing severity of pest and disease pressure
* - Poor water management resulting in low Water Use Efficiency (WUE) and soil salinity/alkalinity problems
- Varietal appropriateness, availability, adoption problems
- Planting time and plant density problems
- Timely availability and quality of inputs (seed, fertilizer, pesticide)
- Post-harvest losses
* - Declining profit
* - Inadequate research and extension support to farmers.

Rainfed Lowland Ecosystem

(*priority concerns)

* - Low soil fertility and fertilizer use
- Problem soils (salinity, acidity, alkalinity, iron toxicity)
- Drought/flood problems
* - Inadequate research (Lack of location-specific varieties and production technologies)
* - Poor weed management

- Timely availability and quality of inputs (seed, fertilizer, pesticide)
- Post-harvest losses
- * - Low profit
- * - Inadequate/ineffective extension support to farmers and slow adoption of recommended technologies
- * - Poor rural infrastructure.

<u>Upland Rice</u>
(*priority concerns)

- * - Drought
- Very low soil fertility and fertilizer use
- * - Weed infestation
- Lack of location-specific varieties (blast resistant and drought tolerant) and production technologies
- * - Inadequate research and extension support service
- * - Low profit

The expert consultation recommended the development of a uniform system on a continuous basis for precisely assessing the levels of yield gaps and apportioning the relative contribution of various factors to the yield gaps and productivity growth.

Mechanisms of Programmes to Reduce Yield Gaps

The different countries presented common and unique activities, programmes, and strategies to reduce the yield gap. The expert consultation recognized that the narrowing of the yield gap of rice requires concerted efforts of all concerned parties both national and international (GO, NGO, PO, IARC, UN agencies). Sensitization of policy and decision-makers is an important activity in bridging the yield gap.

The consultation agreed on the deployment of a holistic and participatory approach to address the yield gap problems. Key points of this strategy are as follows:

- Development of location-specific varieties and technologies, i.e. integrated crop management approach like the “Ricecheck System” used in Australia (“Tropical rice check” for targeted areas).
- Incorporation of yield stabilizing traits through conventional and innovative approaches (resistance to biotic and abiotic stresses).
- Development and adoption of technologies with higher yield potential such as hybrid rice, New Plant Type, etc.
- Intensified technology transfer activities using successful models such as contiguous area demonstration to promote yield enhancing technologies, i.e., land preparation, improved variety and seed, pest management, nutrient management, water management, and post-harvest management.
- Improve working relationship and interaction of research, development and extension services.
- Policy intervention to provide incentives to high production, i.e. pricing, credit, input supplies, marketing etc.

Regional Project to Bridge Yield Gap

The consultation agreed to the development of a regional project that will focus on priority technical and management constraints and improvement of technology transfer and linkages. The specific institutional and policy interventions required to complement the effective implementation of the regional project will be forwarded to the respective governments for consideration and favourable action.

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