Scaling-up: how to reach a billion resource-poor farmers in developing countries

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Abstract
Crop science research has made tremendous contributions over the second half of the twentieth century and provided enormous economic, social and environmental benefits to the global community. It not only helped in attaining food security through path-breaking new technologies but also ensured enough food at much lower prices, since world food prices have declined in real terms by over 70 percent during the last three decades. All this was made possible by breakthroughs in crop improvement work that received wide adoption by millions of resource-poor farmers in China, India, Indonesia and other developing countries. The key to these successes had been the faster adoption of new crops, modern varieties and hybrids. Research as conducted both independently by the developing country National Agricultural Research Systems (NARS) and in partnership with International Agricultural Research Centers (IARCs) and Advanced Research Institutions (ARIs), backed appropriately by the right policies and the innovative mechanisms for technology transfer were the catalytic factors for these successes. This paper highlights some major success stories that have made significant impacts and which underline the importance of research for international public goods to meet the challenges relating to poverty reduction, food security and sustainability. In order to address these concerns, it would require scaling up of technologies using new science and more dynamic systems for technology transfer. Crop scientists would also have to promote good science practices through an inter-disciplinary and inter-institutional approach for improving productivity and would also require a paradigm shift in their research approach for affecting change in the farming practices necessary to attain sustainability.

Media summary
Successes in crop science research have made a real difference for millions of resource-poor farmers around the world, through both increased production and income.

Key Words
Green Revolution, technology adoption, poverty alleviation, hybrid technology, biotechnology, enabling policy environment.

Introduction

The scientific developments in the field of crop science, especially during the second half of the twentieth century, have led to spectacular growth in food production globally. Household food security could be achieved even in the most populated food insecure countries. Thanks to cutting edge science, new high yielding varieties (HYVs) were developed in important food crops such as wheat, rice and maize, resulting in the "Green Revolution". Such spectacular progress in science and technology ranks first among major accomplishments during the nineties. The benefits reached many of the world's poorest people.

In spite of the doubling of population in most developing countries since 1960, overall food availability increased from 1,950 to 2,475 calories per capita per day, thus meeting the minimum calorie requirement. In absolute terms, global production of rice and wheat increased by almost 2.8 and 2.6 fold, respectively (Figure 1). As a result, the proportion of people in developing countries suffering from hunger and malnutrition (around one billion) dropped by almost 20 percent in the last forty years. A most impressive gain was witnessed in terms of decline in real terms by over 70 percent in world food prices, thus benefiting the poorest of the poor. Credit must go to the plant breeders and geneticists as they continued increasing productivity gains both in wheat and rice by almost 1 percent per year that enabled the world to produce more food with relatively less land. In the absence of these gains, we would have otherwise needed two times more additional land to produce the same quantity of wheat (Figure 2), with absolutely no option for horizontal expansion any more.

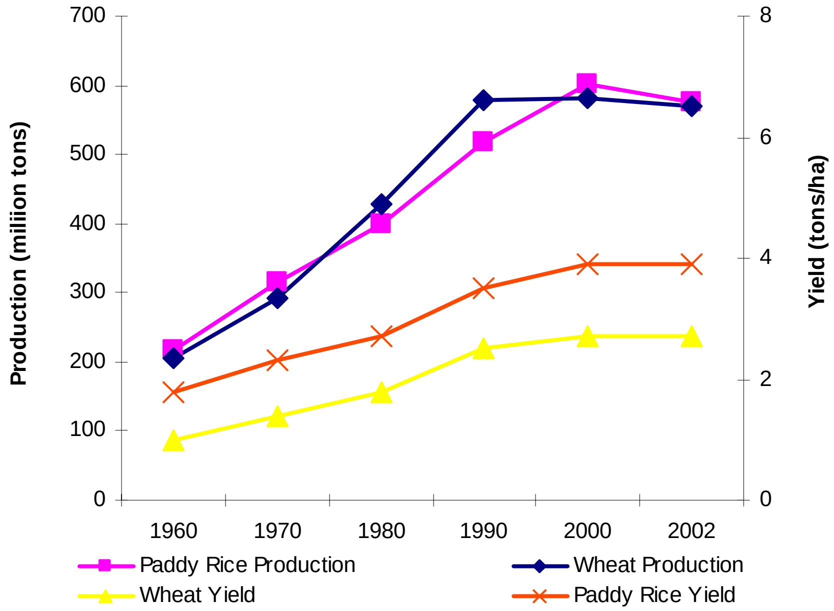

Figure 1. Global rice and wheat yield and production trends.
Source: FAO statistical database. 2003. Available from: http://faostat.fao.org/faostat/collections?subset=agriculture [Accessed on 7 January 2004].

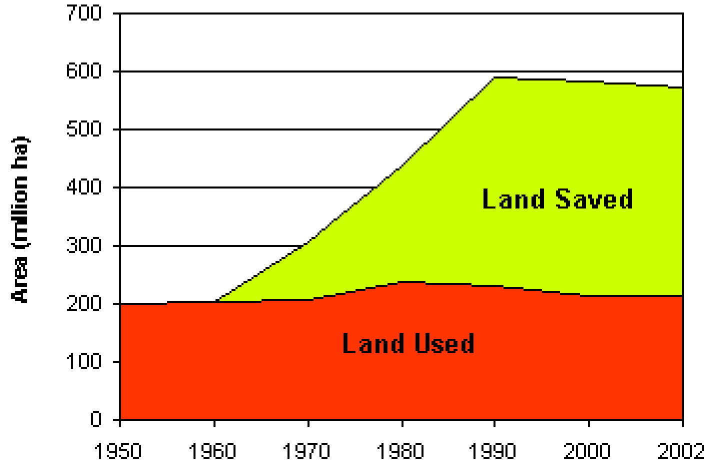

Figure 2. Saving land with modern wheat varieties, global trend.
Source: FAO statistical database. 2003. Available from: http://faostat.fao.org/faostat/collections?subset=agriculture [Accessed on 7 January 2004].

It must be acknowledged that all these achievements would have not been in place, had millions of resource-poor farmers living mostly in the developing world not adopted new crops, varieties/hybrids, cropping systems and innovative production technologies. Thus, the secret of success lies in wide scale adoption of improved technologies by millions of small and marginal farmers. This paper underscores some of the successes accomplished in the field of crop science in Asia, with a major focus on India – the country which was considered a "begging bowl" around four decades ago and which has since then made great strides.

Reaching the resource-poor farmers
The highest concentration of resource poor-farmers is presently in Asia. The most populated countries namely China, India and Indonesia alone constitute the largest population of around 1.5 billion (Table 1) that is mainly dependent on agriculture. In all these countries, the average farm holding is small (around 1 to 2 ha). The majority of these people still live on less than a dollar a day. It is this group of farmers who

have made the best possible use of "Green Revolution" technologies and produced enough foodgrains to attain household food security in a number of countries that otherwise faced acute food shortages during the mid-nineties. Success in the future will largely depend on effective mechanisms for technology dissemination to these resource-poor farmers especially in the developing world.

Table 1. Dynamics of total and agricultural population in Asia (million people).

Year	China Total Population	Agricultural	India Total Population	Agricultural	Indonesia Total Population	Agricultural	Total Agricultural Population
1950	557	491	358	269	80	60	820
1960	661	547	442	312	96	69	928
1970	835	651	555	375	120	75	1101
1980	1004	742	689	442	150	81	1265
1990	1161	835	845	492	182	93	1420
2000	1282	854	1008	541	212	94	1489
2001	1292	853	1025	545	215	93	1491

Source: FAO statistical database. 2003. Available from: http://faostat.fao.org/faostat/collections?subset=agriculture [Accessed on 7 January 2004].

Green Revolution in India

The Green Revolution is one of the most striking success stories of post-independence India. The impact of it was so dramatic that India became a role model for many developing nations. This massive transformation was possible due to scientific breakthroughs and technological inputs that were made available to all the farmers big or small alike.

Attaining food security had been the major objective before the entire Indian nation since independence. During the mid-sixties, India was importing around 5-10 million tons of food annually. Its food security was called "Ship to Mouth", and was based on reports in newspapers as to which ship had landed in which port and had distributed foodgrains to which part of the country.

Thanks to the cutting edge of science, strong political will coupled with appropriate policy interventions and the hard labour of Indian farmers, the country in the last fifty years has achieved a four-fold increase (from 50 – 200 mt) in foodgrain production against a three-fold increase in population (from 330 – 1000 million). It was the foresight and commitment of the leaders and policy makers that India could build required infrastructure, one of the strongest national agricultural research systems (NARS) in the world, and the competent human resource (around 35,000 scientists) that enabled the nation to usher in the "Green Revolution". It not only gave required success on the food front but also provided much needed self-confidence as well as self-respect to a country, which otherwise was predicted to be a hopeless case during the mid-sixties.

India during 2000 had a record harvest of 206 million tons and its buffer stock figure had crossed an all time high of 40 million tons. Today, India has also become one of the largest producers of milk (88 mt), and the second largest producer of rice (90 mt), wheat (75 mt), fruits (40 mt) and vegetables (90 mt) in the world. All these accomplishments would not have been possible but for the fastest adoption of new technologies by the millions of resource-poor farmers, an appropriate scientific and institutional base, backed by the right policies and development strategies aimed at accelerated growth in agriculture.

Enabling policy environment

Appropriate policy support for capital investment in agriculture including creation of required infrastructure, building of a strong agricultural research and education system coupled with an extensive extension system has helped in achieving food security as well as the required national confidence to meet the food demands despite a population growing at the rate of 1.8 percent (17 million people equivalent to one Australia are added each year). Had there not been major agrarian reforms such as fixation of ceiling and consolidation of holdings, creation of infrastructure like roads, markets, major irrigation systems, production and ready availability of inputs like seeds, fertilizers, pesticides, availability of credit, fixation of minimum support price, buffer stocking of foodgrains, public distribution systems, food for work programs, etc. backed by strong agricultural research, education and extension system, these achievements on the national front would have not been possible. The first Prime Minister

Pandit Jawaharlal Nehru stated, "Everything else can wait but not agriculture" – which testifies the commitment at the highest level to provide an enabling policy environment for triggering the process of change. Hence, these building blocks were the most critical for attaining overall agricultural growth and food security in India. It is because of the lack of these basic elements that the Green Revolution is not yet a reality in many developing countries around the world although better technologies and options for increased productivity are available now more than ever before.

Funding for agricultural R & D

It is now an established fact that only those nations which made substantial investments in R&D have progressed faster in the agricultural sector. This especially happened in the Asia Pacific region where investments on agricultural research almost doubled from 0.26 to 0.55 percent of agricultural GDP during the period 1971-75 to 1991-95. Compared to the developed countries investing around 1.0 to 2.5 percent, this investment is rather low. Yet, an increasing trend of R&D investment is indeed a positive sign indicating commitment as well as appreciation by the policy makers about the important role of agricultural R&D. It is now critical that developing countries having dependence on agriculture, accord higher allocations of at least 1-2 percent of their agricultural GDP for research in future, in order to meet the emerging challenges successfully. Unfortunately, many least developing countries (LDCs) are still unable to spend even 0.5 percent and hence have not moved faster in the field of agriculture. Failure to significantly invest in agricultural research in developing countries will make food security, poverty alleviation and environmental protection goals elusive. Lack of foresight today will obviously prove costly in future. We, therefore, need to activate and convince the policy makers and donor community to put upfront the agenda of agricultural R&D so as to ensure a safe future for our younger generation.

Role of NARES for technology transfer

One of the most important elements of success, beside technology, was an efficient Technology Transfer (TT) Program launched by the Government of India to ensure faster adoption of technologies without much dissemination loss. The Ministry of Agriculture during 1970s had launched an ambitious training and visit (T&V) program funded by the World Bank. This Program was popularly known as the National Agricultural Extension Project (NAEP), involving extension personnel (around 150 thousand) at the state, district and village level. The emphasis was given to weekly training of farmers by the District Agricultural Officers, who had received technical orientation from the experts at the State Agricultural Universities (SAUs). Also this thrust was based on the timely supply of inputs such as seeds, fertilizers, pesticides etc.

In order to provide critical frontline extension support, the Indian Council of Agricultural Research (ICAR), an apex research and education organization, also initiated a number of innovative TT programs involving scientists and teachers working at the National Research Institutes and State Agricultural Universities (SAUs). These programs were: National Demonstration (ND) Program, Operational Research Project (ORP), Lab-to-Land Program, Krishi Vigyan Kendra (KVK), also known as Agricultural Technology Centers (around 350), and the Institute Village Linkage Program (IVLP) involving 70 research institutions/SAUs and around 70,000 farm families. Direct linkage of scientists with farmers and availability of seed of new varieties built the much needed confidence among resource-poor farmers to test and adopt new technologies and take the risk to invest in order to earn more income.

Success stories

Often, an impression goes around that major breakthroughs in agricultural production, such as the Green Revolution, became possible due to the active role and support of the International Agricultural Research Centers (IARCs), such as CIMMYT for wheat and IRRI for rice. While this is true, and for which these Centers received all the credit, the world has perhaps ignored a number of equally important scientific successes in different crops that silently happened mainly through the national efforts by respective NARS in the developing world. Some of the successes of this kind that took place in India, China, and Indonesia are enumerated here.

Varietal improvement

Wheat

Wheat is the second most important crop in India and currently it accounts for one-third of the total food grain production. Wheat is synonymous with national food security. Spectacular growth in wheat production and yield has taken place since the mid-sixties when dwarf Mexican wheats were first tested on a large scale and released for cultivation. Since then, wheat production has risen from 6.46 mt in 1950 to 76 mt in 2000 with an increase in average yield from 663 to 2778 kg/ha (almost 4 times). This was possible due to the availability of HYV of dwarf wheats bred under the leadership of Dr. Norman E. Borlaug (the only agricultural scientist who has received the Nobel Peace Prize) at CIMMYT, Mexico and their proper assessment and genetic improvement by wheat scientists under the leadership of Dr. M.S. Swaminathan (the first World Food Prize winner). A strong institutional and human resource base developed by the Indian NARS, coupled with good support for supply of inputs and appropriate policies of the Government resulted in the wheat revolution.

Despite the severe constraint of wheat rusts, especially brown rust in northern India, the major wheat belt, wheat breeders have continued with an aggressive genetic improvement program, also using CIMMYT breeding materials. This has enabled them to realize an annual genetic gain in productivity of almost 1.0 percent, comparable to what CIMMYT has achieved in their own program.

Strong support for varietal testing and release under the All India coordinated wheat improvement project, involving more than 400 wheat scientists representing different disciplines, backed by a well organized quality seed production program, and timely availability of critical inputs such as fertilizers, water, electricity, farm machinery etc. resulted in these spectacular gains.

From a ‘basket case’, India has now emerged to be the second largest wheat producer in the world (Table 2). It possibly may occupy first position in the next two decades if a similar pace continues. It has left behind USA, having almost the same acreage (around 25 million ha) under wheat. Compared to the scenario of bulk imports in the mid-sixties, India now maintains a buffer stock of around 20 mt annually and has emerged as an important exporter of wheat. In a true sense, wheat has provided the required resilience in agriculture as well as the much-needed self-confidence to the nation to feed its ever-growing population. Today, good wheat production means household food security for the people in India. No doubt, crop scientists have made all this difference!

Table 2. World major wheat producers.

Countries	1961	1970	1980	1990	2000	2003	%
				(million tons)			
China	14.3	29.2	55.2	98.2	99.6	86.1	602
India	10.9	20.0	31.8	49.8	76.4	65.1	597
USA	33.5	36.8	64.8	74.3	60.8	63.6	190
Russian Federation*	56.7	91.3	92.2	101.2	34.5	34.0	60
France	9.6	12.6	23.7	33.4	37.4	30.6	318
Australia	6.7	7.9	10.9	15.0	22.1	24.9	372

* Before 1990 the numbers are given as for the USSR.
Source: FAO statistical database. 2004. Available from: http://faostat.fao.org/faostat/collections?subset=agriculture [Accessed on 30 July 2004].

Sugarcane
Nobilization of cane is another success story of a science-based revolution in agricultural production in India. Today, India stands first in the world both in sugar and sugarcane production, in addition to being the second largest agro-based industry providing employment potential and economic benefits for poverty alleviation in the rural areas.

Before the twentieth century, sugarcane production was mainly confined to the Peninsular (tropical) zone in southern India. No one could expect to grow it in sub-temperate conditions of northern India because of higher incidence of red rot, a shorter growing period and above all, occurrence of cold temperature and water stresses.

Thanks to the successful inter-generic hybridization work that started in 1916 at the Sugarcane Breeding Institute (SBI), Coimbatore in Tamil Nadu, the first commercial hybrid Co 205 was released in 1926 in the Punjab Province in the north, as a result of hybridization between *S. officinarum Vellai* x *S. spontaneum* – Coimbatore type.

Since most of the sugarcane species flower only under Coimbatore conditions, SBI played an important role towards sugarcane breeding work. At Cannanore in Kerala State, it maintains the world's largest germplasm collection of over 4000, including the spontaneum collections (around 500 clones) from the north-eastern states of India, the region where sugarcane originated. SBI also provided an opportunity for sugarcane breeders from all over the country to attempt crosses and made available seed for their subsequent testing under varying agro-climatic conditions. Also mutation breeding proved successful for resistance against red rot and other diseases. Sugar rich varieties from Queensland were used in the breeding program. The first high sugared variety CoC 671 was released in the south and CoJ 64, an early maturing high sugared variety, recently revolutionized high sugar recovery in the north.

Thanks again to a well coordinated effort of sugarcane breeders, supported by the two national institutes – one in the South (SBI, Coimbatore) and another in the North (Indian Institute of Sugarcane Research (IISR), Lucknow –a large number of improved varieties were developed and released (around 200 – representing early, medium and late maturity). At the same time, appropriate production technologies were evolved. Today, not only are Co canes grown throughout India, but they have also become popular in more than 25 countries around the world. Along with the introduction of sugarcane, a migration of sugarcane farmers also took place from South India to countries such as Malaysia, Indonesia, Fiji, South Africa etc. to ensure its successful cultivation.

The impact of sugarcane varietal improvement during the past 5 decades is shown in Table 3. Average cane yield almost doubled from 36.4 tons/ha in 1945-1946 to 71.1 tons/ha in 1994-95. Though the average sugar recovery over these years remained at around 10 percent, a breakthrough was achieved by breeding early maturing high sugar content varieties, which are now quite popular. Sugarcane production was also backed by the sugar industry through procurement of cane at the minimum support price announced by the Government. Thanks to these successes, growing of sugarcane today means economic stability to the farmers in India.

Table 3. Impact of varietal improvement in sugarcane on sugar production and recovery.

Year	Area (million ha)	Cane production (million tons)	Yield (tons/ha)	Number of factories	Crushing days	Recovery (%)	Sugar production (million tons)
1945-46	1.3	47.3	36.4	145	93	10.09	0.96
1950-51	1.7	54.8	32.1	139	101	9.99	1.1
1955-56	1.8	58.4	31.6	143	145	9.83	1.8
1960-61	2.4	110.0	45.5	174	166	9.76	2.7
1965-66	2.8	124.0	43.7	200	159	9.7	3.5
1970-71	2.6	126.4	48.3	215	139	9.79	3.7
1975-76	2.8	140.6	50.9	252	116	10.18	4.3
1980-81	2.7	154.2	57.8	315	104	9.98	5.1
1985-86	2.8	170.6	59.9	342	116	10.23	7.0
1990-91	3.7	241.0	65.4	385	166	9.84	12.0
1995-96	3.8	271.2	71.1	408	159	9.92	14.6
1996-2001	4.3	299.2	69.7	450	160	10.0	18.2
Increase 1946-2001 (%)	230	533	91.4	210.3	72.0	0.0	1,798

Source: Sugarcane and Sugar Statistics: Indian Sugar, Sugarcane Breeding Institute, Coimbatore, India.

Potato

Potato, a crop introduced from Europe during the British period, has emerged as one of the most popular vegetable crops in India. From an area of 1.4 million ha, the present potato production in India has increased to 25 million tons, with an average yield of 17.0 t/ha (Table 4). In 1949-50, the year of establishment of the Central Potato Research Institute (CPRI), the production was only 1.54 million tons from 0.23 million ha with an average yield of 6.59 t/ha (Figure 3). Hence, during the last five decades, the area has increased by almost five fold, with 2.5 fold increase in yield. These giant strides were made possible because of enormous efforts made by the scientists at CPRI to develop potato varieties and production technologies suited for Indian conditions including the short growing period of only 70-80 days.

Table 4. World major potato producers in 2002.

Countries	Area (million ha)	Yield (tons/ha)	Production (million tons)
China	4.5	14.8	66.6
Russian Federation	3.1	11.6	36.0
India	1.3	17.3	22.5
USA	0.5	41.1	20.5
Ukraine	1.6	11.6	18.6

Source: FAO statistical database. 2004. Available from: http://faostat.fao.org/faostat/collections?subset=agriculture [Accessed on 30 July 2004].

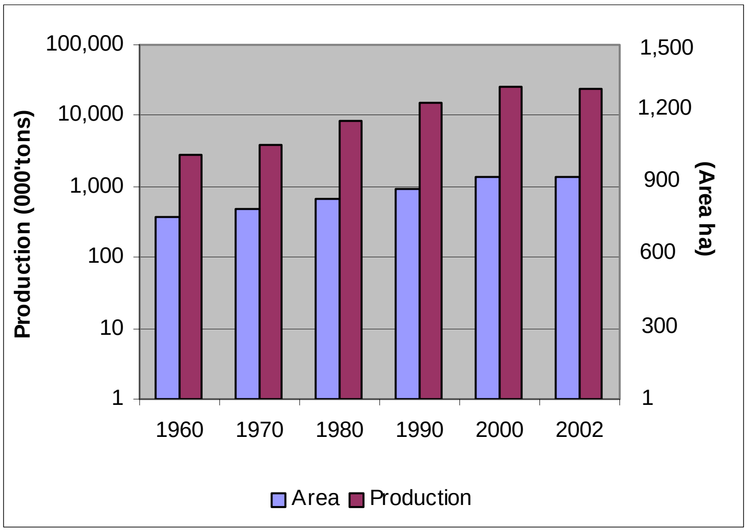

Figure 3. Potato production in India. Note logarithmic scale for the left-hand y-axis.
Source: "Sustaining our Food Security" (Paroda RS, 2003).

An ambitious hybridization program was launched using a high elevation location at Kufri, in Himachal Pradesh, suitable for flowering and crossing work, which yielded promising results. Since 1958, more than 34 high yielding varieties were bred and released for different agro-climatic regions and possessing resistance to diseases and pests. The major achievements had been to develop disease resistant high yielding varieties with 70-80 days maturity as against those taking 140-180 days in Europe. Thanks to these varieties, today India has registered very high productivity growth rates for potato (5.7%) compared to those of the major potato growing countries in the world.

Though the seed produced in hills did meet quality standards, it was not possible to plant the main crop in the plains because of dormancy problems. Hence, a major breakthrough in potato seed production was achieved with the development of the "Seed Plot Technique", which involves growing of a seed crop during the low aphid incidence period in the North Indian plains. Thanks to this technique, growing of healthy seed in the plains region has become possible to meet the large seed demand. It was also found that the farmers could maintain their own seed for 4-5years without losing productivity.

Being a labour-intensive crop, potato also significantly contributes towards employment generation, including post-harvest operations and storage. Being a short duration crop, it fits extremely well in different major cropping systems and helps resource-poor farmers to generate additional income.

Soybean

Despite being a relatively new crop in India, soybean has shown a phenomenal growth both in area and productivity during the last two decades. There is no other parallel to soybean as a new crop, from hardly any acreage in 1975, it has now become the largest oil seed crop in India with production of about 6.0 mt, surpassing even groundnut and rape seed mustard. India now ranks 5^{th} in the world both in soybean area and production after USA, Brazil, Argentina and China (Table 5). The crop found its niche in central India where it revolutionized the entire rural economy due to the prosperity of soybean farmers.

Table 5.World major soybean producers in 2001.

Country	Area (million ha)	Yield t/ha	Production (million tons)
USA	26.3	2.2	57.9
Brazil	18.5	2.8	51.8
Argentina	12.4	2.8	34.7
China	9.5	1.7	16.2
India	6.5	1.1	7.2

Source: FAO statistical database. 2004. Available from: http://faostat.fao.org/faostat/collections?subset=agriculture [Accessed on 30 July 2004].

Its large scale cultivation in India (Figure 4) became possible only after the introduction of yellow seeded high yielding varieties like Bragg, Alle etc. from USA in the mid-sixties. Specific support for research under the All India Coordinated Soybean Project and subsequent establishment of an Institute (National Research Center for Soybean) by the ICAR in 1987 at Indore in Madhya Pradesh led to the development of high yielding disease resistant varieties and also efficient soybean production technologies.

The significant changes in soybean production in India mainly occurred due to: i) appropriate research and development support, ii) establishment of soybean oil extraction plants in central India, iii) the availability of fallow land during the rainy season, and iv) export potential of soymeal as feed. The annual export of soymeal cake is presently of the order of US$ 1 billion per annum, in addition to production of around 1 million ton of soybean oil for local consumption. The installed capacity of soybean processing plants in India is also of the order of 15 million tons, which is almost twice that of current production potential.

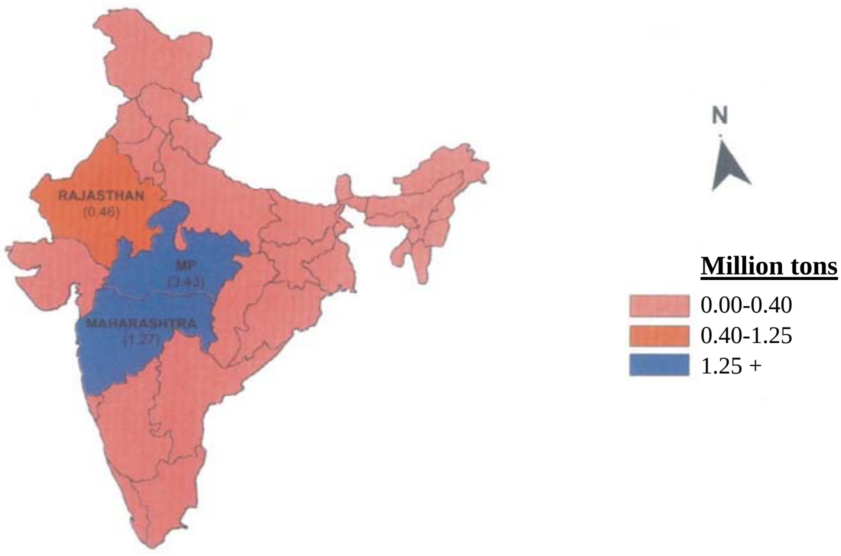

Figure 4. Soybean production area in India in 2001.
Source: Map reproduced from Agricultural Statistics at a Glance (2002) Agricultural Statistics Division. Ministry of Agriculture, Government of India, New Delhi.

It is projected that soybean in India would have a coverage of around 10 million ha by 2010 and India may emerge to be the second largest producer in the world after the U.S.A. Provided yield potential per hectare is enhanced to a level of 2 tons, equivalent to the global average, this is a realistic projection. Soybean, though it originated in China, became an important crop in the USA mainly on account of genetic breakthroughs in productivity. Today, it covers a large area of 25 million ha. The soybean-maize cropping systems of the US have today become the most popular example of a sustainable system in the world.

Hybrid technology

Hxybrid rice in China

Hybrid rice technology in China is another spectacular success story. The first hybrid was released in 1976 and since then coverage under hybrids has continued to increase rapidly. Today, hybrid rice occupies an area of 15 million ha in China, which is almost 53 percent of the total paddy area and it contributes almost 59 percent of the production (Table 6).

The road to success was not all that smooth. A source of Cytoplasmic Male Sterility (CMS) had to be improved and seed production technology (almost 3 t/ha) was perfected to make it economically feasible. Improvement in rice quality, being a limitation in the past, has also been accomplished. All these achievements were possible because of almost 20 years of consistent efforts by the 'Father' of Hybrid Rice in China Dr. Yuan Longping and his team backed by appropriate policies of the Government to promote hybrid rice technology. Obviously, these have paid rich dividends and today China harvests almost 1.5 t/ha extra paddy rice resulting in an additional 25 million tons just through the adoption of hybrid rice technology.

Table 6. Comparison of hybrid with conventional rice in China.

	Area (million ha)	Production (million tons)	Yield (t/ha)
Total rice	28	176	6.2
Conventional rice	13	73	5.6
Hybrid rice	15	103	6.9
Hybrid rice (% of total rice)	53	59	111

Source: S.S. Virmani, IRRI, 2003 (Personal communication).

Taking advantage of hybrid rice work at IRRI, and learning from the experiences in China, R&D efforts on hybrid rice were accelerated during the past decade in Vietnam, India, Philippines and Indonesia (Table 7). Vietnam earlier adopted a number of hybrids from China in the northern region through FAO support and later strengthened its own research program. Hybrid rice there presently covers an area of 550,000 ha. In India, more than a dozen rice hybrids have been released and during the last five years, the area coverage has increased to 280,000 ha. Similarly, Philippines is moving forward and has now more than 100,000 ha under hybrid rice. In Bangladesh, the coverage of hybrid rice varieties is over 10,000 ha.

Table 7. Status of hybrid rice in Asia in 2003.

Countries	Area (million ha)	Yield (t/ha)	Yield advantage over inbred (%)
China	15.0	6.9	26
Vietnam	0.55	6.5	20-25
India	0.28	6.0	15-20
Philippines	0.10	6.2	30

Source: S.S. Virmani, IRRI, 2003. (Personal communication).

All these developments reveal that initially national efforts can also benefit other countries in the region, with the much needed facilitation role of an international center like IRRI.

Hybrid cotton in India

Cotton is one of the most important industrial crops in India. Today, it covers an area of 9.0 million ha and produces 15 million bales of short, medium, long and extra long staple cotton. In addition to a more than 3-fold increase in production resulting in self-sufficiency, hybrid cotton has become an important income-generating crop for small and marginal farmers in rainfed areas.

Dr. C.T. Patel, the 'Father' of hybrid cotton in India, produced the first Hybrid H-4 in 1970, an intra-hirsutum cotton, based on more than two decades of continuous research efforts. H4 became highly successful in Central India giving more than twice the yield compared to the parent varieties G.67. Despite hand emasculation and pollination, hybrid seed production proved to be remunerative to the hybrid seed producers and provided, on an average, a net income of over US$ 600 per ha. It also generated considerable employment opportunities especially for women farmers and youth. Subsequently, a large number of inter-specific hybrids (G. hirsutum and G. barbadense) with excellent fibre quality (length of 30 – 33 mm and spinning potential of 80s counts) were also released under the All India Cotton Improvement Program, thus resulting in a fibre revolution in India.

The advent of hybrids in the seventies brought a sea change both in terms of the quantity and quality of cotton produced in India. Hybrids gave almost twice the yield of varieties and better quality, especially long/ extra long staples. In the 20 year period 1972 to1992, the proportion of high quality cotton produced doubled from 24 percent to almost 54 percent resulting in an increasing trend for export ranging between 2 to 4 million bales.

The most significant impact of hybrid cotton seed production technology appeared in the form of employment generation of about a 25 million labour force (women being around 23 million). In the recent past, hybrids have also become successful in North India, with better yield and early maturity characteristics, having a yield potential of more than 4 tons under irrigated conditions. All these successes were made possible through excellent Government support for research and development of hybrid cotton, a well organized public and private seed industry in different cotton growing states, extensive transfer of technologies and field demonstration programs, cheap and well trained labour for seed production, a minimum support price and above all, the high yield potential of hybrids even under rainfed conditions. Today, hybrid cotton in India is grown over more than 3.0 million ha (50 percent of total area under cotton) and produces more than 60 percent of cotton mainly in Central and South India.

IPM

Rice in Indonesia

The success story of Integrated Pest Management (IPM) in rice in Indonesia provides an interesting case of research and development efforts that were well planned, coordinated and executed at the national level involving rice researchers, extension workers and farmers in a participatory approach. The IPM program in Indonesia reflects a cost-effective model, wherein complex methodologies have been institutionalized on a large scale at the level of the farmers' field, resulting in tangible benefits.

For most Indonesians, rice is the major staple crop. Starting in the mid-1960s, their Government provided the highest priority to its rice production program. Strong commitment by the national leaders, a good scientific base and the hard work of rice farmers led the nation to self-sufficiency in rice by 1984 (Figure 5). However, these gains were not without negative impact on the environment due to increased use of agro-chemicals (pesticides, herbicides and fertilizers). Also the use of pesticides had not been economically feasible for almost half of the 21 million farm households, cultivating less than 0.5 hectare of land. At the same time, under the rice self-sufficiency program, started under the BIMAS (Mass Guidance) scheme in 1963/64, support was extended by the Government to provide inputs such as seeds, fertilizers and pesticides at subsidized rates (Figure 6).

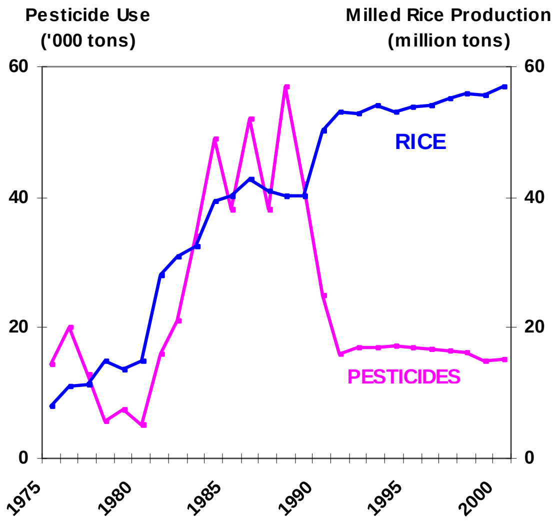

Figure 5. Pesticide use and rice production in Indonesia (1973-2000).
Source: J.Soejitno. 1999. Integrated pest management in rice in Indonesia. A success story. APAARI Publication. 2:15.

In order to save the rice crop against the ravages of diseases such as Brown Plant Hopper (BPH), Rice Tungro Virus (RTV), Stemborer and also the extensive damage by rats, pesticide subsidies were increased to a level of 80 percent during the period 1975-1987, reaching an annual figure of around US$ 150 million. In the process, pesticide use increased dramatically by almost three fold (from 20 to 60,000. tons) (Figure 5), whilst banned pesticides also continued to be used. The government had to intervene to remedy this problem, especially when in 1986 there was a major devastation of 75,000 ha of rice due to a BPH outbreak in central Java, the major rice producing region. A Presidential Decree was promulgated banning the use of 57 broad-spectrum pesticides formulations, reducing also the subsidies from 80 to 40 percent with a subsequent total subsidy ban by 1989. This triggered the IPM strategy involving the Ministries of Agriculture, Home Affairs, and Environment, scientists, extension agencies and farmers in large numbers through the Farmer Field School (FFS) approach.

With technical backstopping of FAO, the Rice IPM Program, to begin with, involved 100,000 farmers during 1989-91 and finally around 1,000,000 farmers by 1998. The IPM program ultimately resulted in an increase in rice yields despite considerable reduction in the use of pesticides (Figure 5). It is also significant that the IPM strategy mainly relied on active participation of farmers, as well as trained and competent experts, with access to the best information and knowledge relating to various components of IPM. There were resistant varieties, clean cultivation, timely planting, use of bio-pesticides and bio-control agents according to threshold values for different pests and the need-based use of safe chemical pesticides. Ultimately, the farmer to farmer training program became the basis for such impressive success, which later on many countries including India, Philippines, Malaysia etc. tried to follow.

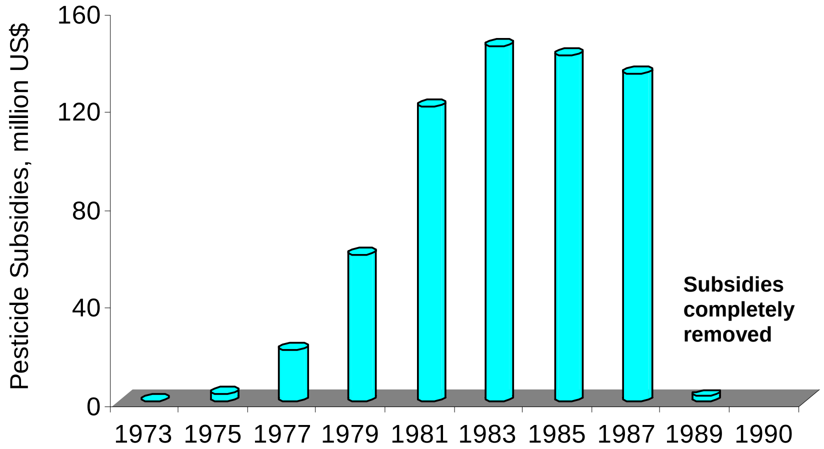

Figure 6. Pesticide subsidies in Indonesia during (1973-1990).
Source: J.Soejitno. 1999. Integrated pest management in rice in Indonesia. A success story. APAARI Publication. 2:21.

Scaling-up: Future vision
Most of the successes, mentioned above, had taken place in an enabling environment of political commitment, policy support for investment in agricultural R&D and the existence of required institutions and well trained human resource. Also capital investment in agriculture was enhanced in view of acute food shortages during the sixties and realization by the developing countries that they had to attain food self sufficiency. At the same time, increased support for higher production through innovative transfer of technology programs linked with availability of critical inputs such as water (irrigation facilities), seeds, fertilizers and pesticides (all at subsidised rates), and promotion of agricultural mechanization catalyzed the process of increased productivity.

As food production increased in most of the developing countries in Asia, by the eighties and nineties, a sense of complacency had crept in which pushed the agricultural research agenda to the back seat. This, obviously, led to less capital investment in agriculture, including reduced support for agricultural research (invariably less than 1 percent of agricultural GDP). Subsidies on critical inputs were slowly withdrawn and costs of inputs became high, often unaffordable by resource-poor farmers, and natural resources (soil and water) also became degraded. On the contrary, the global prices for foodgrains declined in view of the increased overall production and availability of cereals in the world market. Factor productivity decline in many developing countries, on account of the second-generation problems of "Green Revolution", led to the realization that beside genetic enhancement programs (HYV, Hybrids etc.), integrated crop management was equally important for desired successes. Unfortunately, the visible impact of NRM technologies could not match those of miracle seeds evolved earlier by CIMMYT, IRRI and other CG Centers. Therefore, it became clear that unlike faster adoption of HYVs, the natural resource conservation technologies did not enthuse the resource-poor farmers to take the required risk unless they were doubly sure about the expected benefits. Obviously, this demanded a paradigm shift towards innovative approaches for both generation of NRM technologies and the effective transfer of technologies. At the same time, scaling-up of genetic enhancement activities for improved productivity and profitability, using new science and tools, became critical for harnessing required benefits by the resource-poor farmers of the developing world. Hence, a two pronged approach of scaling-up of TT (Technology Transfer) programs and the crop science research appears to be of paramount importance for future successes in agriculture.

Existing Constraints and Required Paradigm Shift in Technology Transfer

Lately, it has become quite clear that the soft options for TT that worked well in the past, are no more valid in the present context. Also it is recognized more now than ever before that with available technologies, significant advancements in agriculture can only be made when these are effectively disseminated to the farmers. The training and visit (T&V) system has outlived its utility. It had mainly relied on "technology generation – technology transfer" model and presumed that all the technologies would have wider acceptance and adoption, whereas it is well understood now that a continuum between "technology generation – assessment - refinement – transfer" is critical for any future success. Hence, there is a need to scale-up TT programs through establishment of linkages between scientists and farmers, and between institutions and villages in order to avoid dissemination losses for technology adoption. To ensure acceptance of new technologies, scientists will have to adopt farmers participatory approaches and use farmers' fields more for validation and refinement of their technologies. Following are some of the innovative approaches for TT:

Concept of Agri-Clinics

It is realized now widely that the public supported system of technology transfer is not the best model for TT. To meet the changing needs, it is essential that we create a new cadre of "Technology Agents", who are better trained, equipped and committed to serve the farming community through the concept of "Agri-Clinics", while generating self-employment for the rural youth. Through this approach, not only technology dissemination losses will be avoided but also appropriate technologies will get disseminated faster. Another advantage of this approach would be that the young graduates in future will become job creators and not job seekers. Obviously, this would demand the institutions and the Agricultural Universities to undertake innovative vocational training programs, needing an obvious shift from the existing formal to an informal education system.

Farmers cooperatives

In future, TT models will demand a shift from approaching an individual farmer to that of addressing communities using new communication technologies (TV, Radio, computer, etc.). Also technologies that can catalyze communities will have better chances for their faster adoption. In this context, lately, the farmers' cooperatives have become an important element of progress in the agricultural economy. In the dairy sector, they have played a powerful role by transforming India into a major milk producer in the world. Through an "Operation Flood" program, initiated in 1970 and hailed as India's most ambitious and highly successful rural development project, milk production went up almost four fold from 20 mt to 88 mt, widely acclaimed as a "White Revolution".

Increased participation of small and landless farmers, who joined hands to form cooperative societies for effective marketing and to eliminate the role of middlemen, has been the key factor for this success. From about 278 thousand members in 1970-71, today there are more than 11 million members who own, manage and control about 103,281 cooperatives. The basic philosophy of the project has been the scientific and professional management of a vertically integrated structure that establishes direct linkages between those who produce the milk and those who consume it. Hence, the integration of production, processing and marketing into a composite matrix provides tangible economic, social and psychological incentives to the small and landless dairy farmers.

Farmers' cooperatives can thus be seen as an innovative and efficient mechanism for faster technology adoption. Such approaches could also be useful for fruits and vegetables, being perishable products need timely post harvest processing and marketing interventions. Hence, ownership of any initiative by the farmers would ensure needed success of new technologies in future. However, all these initiatives will require a strong interface among the research organizations and development departments, and appropriate policies to strengthen farmers' groups in future. Role of Civil Society Organizations (CSOs) such as Farmer's Associations and NGOs in this regard will, indeed, be more important in future.

Elevating the role of private sector

The private sector seems to have moved faster in agricultural R&D especially in the developed countries where they have Intellectual Property Rights (IPR) protection and faster adoption of hybrid technology, biotechnology, ICT, etc. It is estimated that their contribution is presently around 10-15 percent of total R&D expenditure in the developed countries, whereas their role is still quite minimal elsewhere. This scenario in future may, however, change with emerging IPR regimes in a number of developing countries and also better appreciation for the private sector's role for agricultural R&D, especially for faster adoption of new approaches and technologies and the supply of technology related inputs at affordable prices to the farmer's door.

Another important role of the private sector, beside supply of inputs such as seed, fertilizer, pesticides etc., will be to act as information providers to the farmers for effective transfer of technologies. This social obligation will have to be shouldered more in future for faster adoption of NRM related approaches aiming at sustainable use, and not abuse, of agricultural inputs. Their role in linking farmers with markets, using ICT and biotechnology, would accelerate the pace of agricultural growth throughout the world.

ICT for knowledge sharing

The "top-down" approach for TT through Government extension agencies neither would be practically feasible nor sufficient to meet the challenge of the so called 'digital divide'. Farmers will demand access to reliable and better knowledge, for which the role of information and communication technologies (ICTs) becomes important. The ICT model adopted in the Union Territory of Pondicherry, South India by the M S Swaminathan Research Foundation (MSSRF) in 1998, is one good example, seen as a 'bottom-up' and 'demand-driven' process. It started with the establishment of an operational center having access to the Internet through two dial-up accounts and functioning as the hub of a local area network for data and voice transmission covering the project villages. Unique to this program is the fact that most information collected and fed in was by the volunteer teams representing the local community. The results of the project have clearly demonstrated that the key benefit of ICTs is the ability to access generic information and render it location specific. It is with this information that rural families, especially poor and marginal farmers, can hope to improve their productivity of labour and inputs and have profitability. Obviously, farmers would benefit greatly if they could have easy access to information relating to new technologies, weather conditions, inputs availability, various development related programs, prevailing prices, marketing opportunities etc. As stated earlier, the private sector could certainly play a prominent role in this regard through the development of portals or kiosks. Similarly, international organizations such as FAO, CGIAR, GFAR, CABI could play a significant role by developing relevant technology oriented information modules /compendia/ CDs or websites to suit the needs of developing countries lagging behind in knowledge sharing.

Technology Up-scaling Using a Twin Pillar Strategy

Sustainable agriculture is a reflection of continued productivity while conserving natural resources. Hence, technologies for sustainable farming systems with least dependence on costly inputs, including chemicals, will have to be promoted. Improving input use efficiency would also be a key factor for attaining sustainable agriculture. A paradigm shift in our research agenda, focusing more on a systems' approach rather than commodity-oriented research, will be critical for agricultural sustainability. In future, a twin pillar strategy centered around: first, genetic enhancement for improved productivity involving genes that can ensure responsiveness to low inputs and also biotic and abiotic stresses, and second, efficient production management through agronomy and agri-engineering practices would be critical to sustainable agriculture.

Integrated crop management

The emphasis will have to be laid more in future on integrated crop management in a systems' mode addressing precision farming, conservation tillage, use of stress tolerant genotypes, input use efficiency and blending of farmers' rich traditional knowledge with that of modern science. Recent research efforts on conservation tillage, including zero tillage in rice-wheat production systems in South Asia, have shown great promise to make this intensive cropping system more sustainable in future. The Rice-Wheat Consortium of Indo-Gangetic Plains, involving CG Centers and NARS of South Asia has clearly revealed that the zero till area for planting wheat immediately after rice to reduce planting time as well as input costs for field preparation has benefited small farmers. The technology in the last three years has covered more than 1.0 million ha benefiting more than 258 thousand farmers (Figure 7). Such efforts will have to be further intensified and replicated elsewhere.

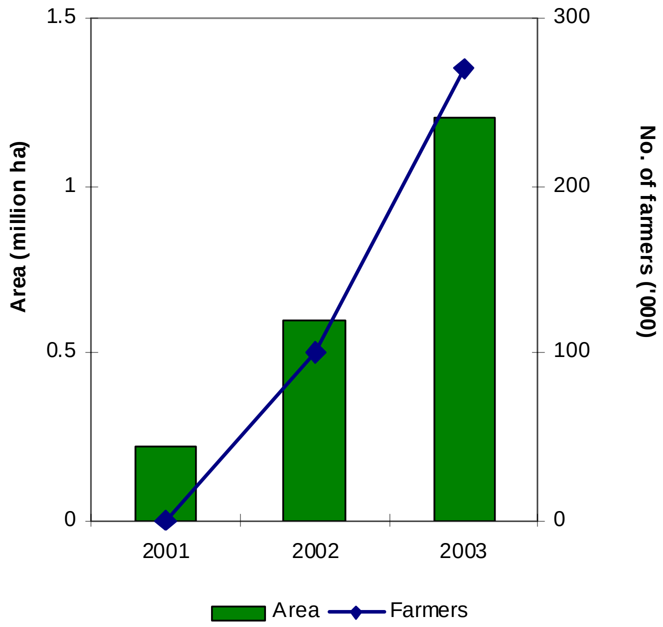

Figure 7. Expansion of area under zero till technology and number of benefiting farmers in the Indo-Gangetic Plain.

Source: Rice-Wheat Consortium for the Indo-Gangetic Plains, Highlights 2003-2004.

Improving productivity

In future, research in crop science will demand innovative approaches that can help in attaining both productivity gains and sustainability of production systems while ensuring increased income to the resource-poor farmers. In other words, technologies that can help reduce the cost of inputs and provide better yields both under irrigated and rainfed farming, especially under abiotic stresses such as drought and salinity would be required. In this context, use of biotechnology offers great promise, whilst approaches such as participatory plant breeding (PPB), seed production of hybrids and vegetatively propagated materials such as sugarcane, potato etc., using tissue culture technology, would offer both efficient and affordable options to resource-poor farmers. These approaches are described here briefly as scaling-up options:

Participatory plant breeding (PPB)

Decentralized selection combined with farmer participation from the initial stages in any breeding process is a powerful methodology to fit crops to specific biophysical and socio-economic contexts, and to respond to farmers' needs and knowledge. Earlier, the conventional plant breeding approach was a centralized, top-down approach that paid little attention to the actual conditions being faced by farmers, with the result, many varieties did not perform well after their release in the farmers' fields. Hence, active participation of the farmers right from the beginning would avoid the risk of useful lines being discarded on experimental stations.

A new partnership with farmers in PPB research would enable them to be active recipients of technologies, seeds and information. In future, more breeding efforts *in situ* – on farms and in communities – with farmers, especially women, would ensure complementing each other's knowledge, skills and experience and accelerate the process of varietal release and adoption under farmers' specific agro-climatic conditions.

Harnessing hybrid technology

Among various technological options available for the improvement of productivity, heterosis breeding offers greatest potential, since this technology has already been exploited extensively in several crop plants the world over. In the Asia-Pacific region, hybrid technology has successfully been used on an extensive scale in crops, such as rice, maize, sorghum and pearl millet.

As stated earlier, China had the distinction of commercially exploiting heterosis for the first time in rice in 1976. Similarly, India was the first to release a grain pearl millet hybrid in the mid-sixties. Extensive efforts in the region have also been made to commercially exploit both maize and sorghum hybrids. Experience of more than two decades of growing maize, pearl millet, sorghum, cotton, sunflower and castor hybrids has amply demonstrated the distinct advantage of hybrids under rainfed farming in a number of countries. As such, this technology has reached the remotest areas and proved to be a friendly technology for the resource-poor farmers. Hence, scaling-up of hybrid technology would help in improving productivity. Some specific examples are:

Single cross maize hybrids

The most successful scaling-up program for hybrid technology was the corn hybrid program of U.S.A., which started with open pollinated varieties and moved to double-cross hybrids, to three-way hybrids and then to the single-cross hybrids, with consistent genetic advances each year. The increase in productivity of maize was indeed spectacular after the adoption of single-cross hybrid technology during the early sixties (Figure 8). Productivity of maize almost doubled (from about 3.5 t/ha to 7.0 t/ha), demonstrating the distinct advantage of hybrid technology. Similar advances also later took place in China and Republic of Korea using the single-cross maize hybrids. India, Philippines and Thailand are also moving ahead in this direction, but need a concentrated effort to make a difference in their maize productivity.

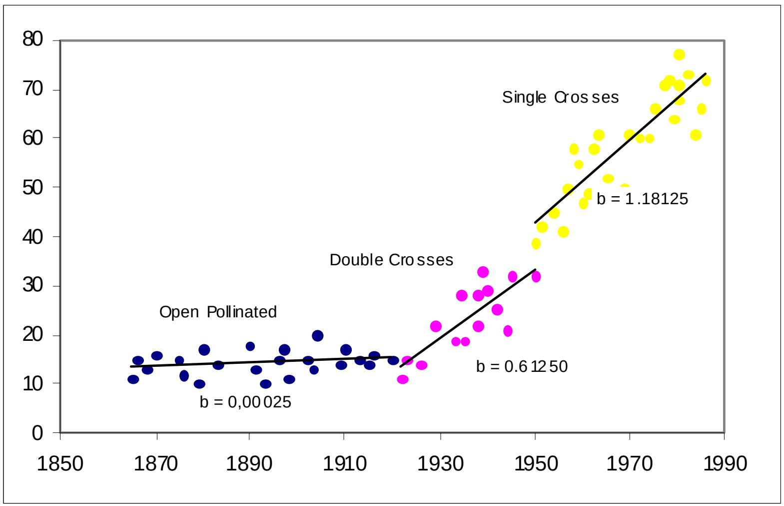

Figure 8. Rate of maize production in U.S. A. as related to the US hybrid technology.
Source: Figure reproduced from "Sustaining our Food Security" (Paroda RS, 2003).

CMS based cotton hybrids

Seed production in cotton can be made more cost effective through the use of cytoplasmic genetic male sterility (CMS) as against the use of hand emasculation and pollination techniques, which are labour intensive. It has been seen that new hybrids of cotton in India based on the CMS technique, can reduce the cost of 1 kg hybrid seed production by almost half (from US$ 3 to US$ 1.5). Though many hybrids are now based on the CMS system, the technique has not been extensively used to provide needed benefits to farmers despite its scientific feasibility and demonstrated gains. This alternative methodology could be exploited now in many cotton producing countries.

Two line hybrid in rice

The classical three-line approach involving CMS, maintainer and restorer lines is expected to remain effective in future. However, since this procedure is quite complicated, simpler systems, such as two line (using thermo-sensitive genetic male sterile (TGMS) or photo-sensitive (PGMS) materials) or one line (using apomixis, which has the ability to set seeds without fertilization), once perfected, would be highly rewarding. The use of simpler systems would provide quicker development of new hybrids and allow the use of less-skilled personnel. Also seed production costs would be reduced considerably. Hence, concerted efforts to use particularly, thermo-sensitive genetic male sterile lines, would be of immense benefit to rice farmers.

Biotechnology revolution

Biotechnology will be the science of the 21st century. Genetic engineering holds vast potential both for increasing productivity and conserving our natural resources. Support to both public and private sector initiatives in biotechnology is crucial at this juncture. Countries such as China, India, Philippines, Indonesia and Vietnam are laying greater emphasis on both research and human resource development to make their public system strong. Considering options and opportunities that this new science offers, we need to move aggressively to reap the likely benefits. For this, forging linkages between the public and private sectors will be critical and demand innovative partnership models to be developed based on mutual trust and understanding. Also the role of international centers to be proactive in generating international public goods using new science appears to be most crucial at this juncture. Through functional genomic research, IARCs and some of the ARIs can complement the national efforts especially in view of the fact that these centers hold a large genetic resource base. However, the application of biotechnology must address concerns for biosafety and protect the interests of resource-poor farmers. The research agenda must clearly address both the benefits and the concerns. Though biotechnology is likely to encompass wide areas of agriculture, what is needed presently is to up-scale those technologies that have great potential in helping the resource-poor farmers in the developing world. Some of these are enumerated here to just illustrate this point:

Bt cotton

The major cost of cotton cultivation is presently the use of pesticides. In India, fifty percent of pesticides used annually are used on cotton alone (30,000 tons of active ingredient). Farmers often spray cotton crops at quick intervals to control cotton pests, especially the boll worm. Commercial use of Bt cotton both in China and India in the recent past has helped in reducing the use of pesticides while ensuring a healthy crop, with less pollution in the environment. This technology has great potential and its up-scaling using new “Bt” genes in improved local varieties would benefit most of the cotton producers in Asia.

Micro-propagation in sugarcane

The major cost of sugarcane cultivation is the bulk seed requirement. Also, faster seed multiplication of newly released varieties is presently a major constraint. To overcome this, micro-propagation techniques in sugarcane have lately been exploited on a commercial scale. Multiplication through tissue culture can also help in eliminating various seed borne diseases. This technique has good potential for further exploitation provided micro-propagation is made cheaper through scaling up of available technology.

True Potato Seed (TPS)

A major constraint in increasing area and production of potato is the availability of good quality seed needed in large quantities and its cost, including transportation to mountain areas. Hence, this bulk requirement of potato seed needs scaling up of technologies. The Indian potato program, in collaboration with International Potato Center (CIP) made a significant advance in the development of True Potato Seed (TPS) technology for raising commercial crops of potato by using botanical seed. Instead of 2.5-3.0 tons of tuber seed required per hectare, only 150 g of TPS would be sufficient to raise a good crop of potato. In order to cut costs on the bulk seed requirement of potato, the micro-propagation of potato using tissue culture technique for the development of both micro-tubers and mini-tubers using the true potato seed (TPS) technology or for that matter use of any standard potato variety could be commercially exploited.

Epilogue

It is well known that spectacular achievements in crop science research during the twentieth century had helped in overcoming major food shortages all over the world. Science has always been the vanguard of past successes. In order to meet future challenges, we shall need to harness new science. This would require us to have the right institutions and competent human resources in place, supported by right policies, and enabling environment for excellence in science. New partnerships will also have to be built and the scientific knowledge, both new and traditional, will have to be blended and harnessed. Past accomplishments on the food front have given us needed confidence to face the emerging challenges aimed at household food, nutrition and environmental security. It is our firm conviction that through scaling-up of technologies in the field of crop science, we shall continue meeting the increasing expectations of our resource-poor farmers, and ensuring needed benefits to our society.

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