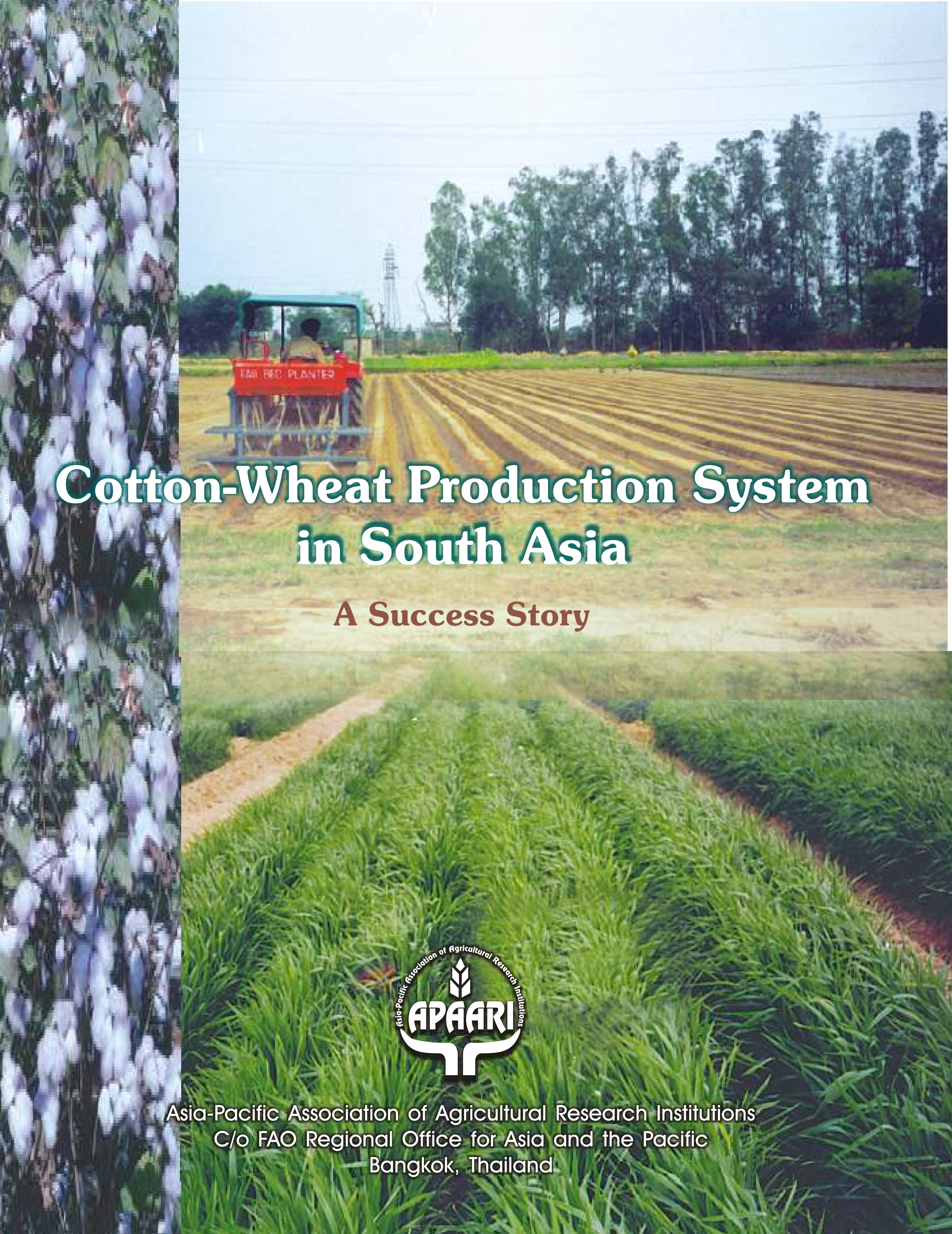

Cotton-Wheat Production System in South Asia

A Success Story

APAARI
Asia-Pacific Association of Agricultural Research Institutions
C/o FAO Regional Office for Asia and the Pacific
Bangkok, Thailand

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Foreword

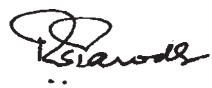
Cotton-wheat is a long established crop production system of north-western plains of India and Pakistan, and it occupies an important place in the agricultural economy of both these countries. While cotton is a cash crop, wheat provides the necessary food security. Accordingly, this crop rotation has brought rich dividends to the farmers. In recent years, there has been a substantial increase in both production and productivity of these crops in the Cotton-Wheat Production System (CWPS). It is currently the next prominent cropping system after rice-wheat in both countries.

During the last one decade, concerted research efforts with an integrated approach have led to notable achievements in CWPS - the development of early maturing varieties and more recently the Bt-cotton hybrids, which now cover large areas of cotton-wheat production system; better agronomic and crop-management approach with adoption of new techniques such as zero tillage; integrated nutrient management; efficient water use; irrigation management; improved IPM etc. Such focussed R&D initiatives have further increased the potential of CWPS and strengthened its sustainability.

The Asia-Pacific Association of Agricultural Research Institutions (APAARI), as its on-going activity, periodically brings out some agricultural case studies carried out by national programs with achievable results impacting agricultural growth and development in order to disseminate such information for the use of NARS in the Asia-Pacific region. APAARI has so far published over 30 success stories covering diverse topics. These included the rice-wheat system in the Indo-Gangetic Plains and on production trends in wheat and cotton in India and Pakistan. In this context, the present success story on 'Cotton-Wheat Production System in South Asia' adds much to the earlier publications and this well synthesized information will be of great use to member NARS, where both these crops are grown. Successes apart, there are several emerging concerns to be addressed *vis-a-vis* adoption of new technologies. It is envisaged that much headway will be made through participatory approach and public-private-partnership, including inter-regional collaboration such as of INCANA.

The genesis of this success story lies in the decision taken in the Second Meeting of INCANA, which was organised by PFU-CGIAR (then headed by me) and ICARDA-CAC Regional Office, Tashkent under the umbrella of CACAARI and sponsored by Global Forum on Agricultural Research (GFAR), AARINENA, APAARI and CACAARI. The meeting was held at Tashkent (Uzbekistan) from 6-8 September 2004. In the Round Table discussion on current topics of interests for INCANA member countries, Cotton-Wheat rotation was introduced by Dr. C.D. Mayee. It was then decided that the success story on Cotton-Wheat production system, so well established in India and Pakistan, should be documented for the benefit of all member countries as well as some Central Asian countries. I am happy that both the decisions have been implemented. The expert team from Central Asian countries visited India in 2005, whereas this success story is now ready for publication.

APAARI acknowledges the efforts of Dr. C.D. Mayee and the co-authors in synthesizing the research results as presented in this success story. It is felt that wider distribution of this publication will be found useful to concerned member NARS in the Asia-Pacific region.



(R.S. PARODA)

Executive Secretary

Contents

Acronyms

AARINENA	Association of Agricultural Research Institutions in the Near East and North Africa
AICCIP	All India Coordinated Cotton Improvement Project
AICWIP	All India Coordinated Wheat Improvement Project
APAARI	Asia-Pacific Association of Agricultural Research Institutions
Bt	*Bacillus thuringiensis*
CAB	Cotton Advisory Board
CAC	Central Asia and Caucasus
CACAARI	Central Asia and the Caucasus Association of Agricultural Research Institutions
CGIAR	Consultative Group on International Agricultural Research
CICR	Central Institute for Cotton Research
CIMMYT	International Maize and Wheat Improvement Center
CLCuV	Cotton Leaf Curl Virus
CPE	Climatological system based on Pan Evaporation
CRI	Crown Root Initiation
CW	Cotton-Wheat
CWCR	Cotton-Wheat Crop Rotation
CWPS	Cotton-Wheat Production System
DRC	Domestic Resource Cost
ERP	Effective Rate of Protection
FAO	Food and Agriculture Organization
FIRB	Furrow Irrigated Raised Bed
FLD	Field Level Demonstration
FYD	Farm Yard Manure
GE	Genetic Engineering
GEAC	Genetic Engineering Approval Committee

GFAR	Global Forum on Agricultural Research
GFM	Genetically Fully Modified
GM	Genetically Modified
IARI	Indian Agricultural Research Institute
ICAC	International Cotton Advisory Committee
IDM	Integrated Disease Management
ICARDA	International Center for Agricultural Research in the Dry Areas
INCANA	Inter-regional Network on Cotton in Asia and North Africa
INM	Integrated Nutrient Management
INR	Indian Rupees
IPM	Integrated Pest Management
IRM	Insecticide Resistance Management
ISAAA	International Service for the Acquisition of Agri-Biotech Applications
ITK	Indigenous Technology Knowledge
LT	Late Tillering
MDGs	Millennium Development Goals
MSP	Minimum Support Price
NARS	National Agricultural Research System
NIBGE	National Institute of Biotechnology and Genetic Engineering
PFU	Program Facilitation Unit
PKR	Pakistani Rupees
R&D	Research and Development
RWCS	Rice-Wheat Cropping System
SSI	Social Science Institute
WTO	World Trade Organization

Introduction

In South Asia, cotton as a crop as well as a commodity, plays an important role in the agrarian and industrial activities of India and Pakistan and has a unique place in the economy of these countries. Cotton popularly known as “White Gold” is grown mainly for fibre. In addition to this, cotton seed is the second important source of edible oil. India has been a traditional home of cottons and cotton textiles. India is the only country where all the four cultivated species of cotton are grown. The economy of the regions where it is cultivated is consistently influenced by its production and processing sectors, and by generating direct and indirect employment to more than 8 million people.

Cotton-wheat is a long established crop production system of north-western plains of the Indian sub-continent and this rotation occupies prestigious place in the agricultural growth of India and Pakistan, the leading wheat producing nations of the world. These crops contribute largely to improve the economic conditions of a large number of people engaged in farming, processing trade, and textile industry. Cotton is also the most important foreign exchange earner through export of raw cotton, readymade garments, clothes and cotton seed byproducts in the form of edible oil and oil cake. With the advent of short duration, early-maturing varieties, and development of assured irrigation facilities in the cotton growing belts of northern India and adjoining regions of Pakistan, these crops are being cultivated in cotton-wheat sequential cropping system. This cropping system has now become the second most important crop sequence after rice-wheat in the north-western plains, and is practised on a vast area. In north-western India, especially in Punjab, Haryana and Rajasthan, more than 95% of the cotton grown in *kharif* is under assured irrigation, and wheat is the principal *rabi* crop in the rotation. On an average, productivity of 18 q/ha of seed cotton and 32 q/ha of wheat grain can be realized. With the availability of new varieties, matching production technology and increased use of farm power and machinery for timely field operations, the productivity of cotton-wheat production system (CWPS) has improved significantly over the years.

There was a decline in the cotton productivity in the Indian cotton growing states and fluctuations in area for almost a decade during late nineties. Then the sustainability of production became a major issue. However, the introduction of Bt-cotton hybrids in 2005-06 in north India led to considerable rise in area and productivity and restored the cotton-wheat production system from a short period of slow growth. In

South Asia, India and Pakistan are the two major countries where CWPS is followed but there are few other areas where it is practised in small pockets. Similarly in India beyond the north-western plains, cotton is a predominant crop in rainy season in seven other key states accounting for more than 5.7 mha area. There are pockets of this cropping system in Madhya Pradesh, Gujarat and Maharashtra. However, the cotton grown in CWPS is different in many respects from rest of the country particularly for genotype, duration, time of sowing, nutrient, water and pest management, time of harvest, quality of cotton and mechanization in cultivation. The uniqueness of the CWPS system is its double cropping, i.e. cotton followed mainly by wheat which has come to be known as on the pattern of Rice-Wheat Cropping System (RWCS). While RWCS is a grain production system and was started around 1960 with introduction of dwarf wheat varieties (Prasad, 2005), CWPS is a grain plus cash cropping system which improves the economy of farmers through cultivation of cotton as an industrial commodity and wheat as a component of food security. Overall, thus, the Cotton-Wheat Production System (CWPS) is of immense practical significance as it fits well within the existing cropping systems. Being a cash and grain cropping system it is highly remunerative with assured returns.

Earlier, APAARI has published the success story on the rice-wheat system of the Indo-Gangetic plains apart from the success stories on cotton and wheat production in India and Pakistan. This success story in similar context focusses on CWPS. It is felt that the information provided on the successes achieved will be helpful to the concerned NARS of this region where both these crops are grown; particularly in sharing research and development initiatives undertaken and technologies developed/ adopted.

Cotton-Wheat Production System

Cotton-Wheat Production System (CWPS) in the Indian sub-continent particularly in north India and adjoining parts of Pakistan is a fairly well established cropping system since the last 50 years. The system got further impetus with the introduction of dwarf wheats from CIMMYT, Mexico, which required lower temperature for good germination than that required for traditional tall Indian wheats. The sowing pattern, therefore, slightly shifted from mid-October to mid-November, providing extra period for the preceding rainy season crops like cotton, rice etc. This assisted long term establishment of CWPS in the north-western states of India (Punjab, Haryana, parts of Rajasthan) and the Punjab and Sindh provinces of Pakistan, instead of wheat or cotton alone. In CWPS, two crops are grown in a span of 12 months (June-May). Cotton is grown during April-May to October-November, while wheat is grown during the winter season (November-May) on stored soil moisture with supportive irrigation. Rainy season in CWPS belt is from July-October, when nearly 600-900 mm rainfall is received. Some rain (5 to 10% of the total annual) is received during winter (November-March) in some areas. Most cotton in CWPS is planted during mid-April to mid-May using canal irrigation when temperature is above 39 °C, with bright sunshine and high wind velocity. Wheat sown in November matures by the end of April or first fortnight of May and the fields are mechanically prepared quickly for cotton sowings.

Area Under CWPS

The precise estimates of area under CWPS are not available but it is certainly the next dominant cropping system after rice-wheat in north-western India and cotton growing areas of Pakistan. Rice-wheat cropping system occupies around 12.3 mha in India and about 2.2 mha in Pakistan and is also practised in Nepal, Bangladesh and China (Prasad, 2005). Though variable, some estimates for rice-wheat cropping system are available. In case of CWPS, the estimates for India and Pakistan can be gauged from the area sown under cotton. It is observed that nearly 90% of the cotton area is in Punjab, Haryana and north Rajasthan, which commence sowing in mid-April to mid-May followed by wheat in winter. Similarly, 80% of the cotton area in Pakistan is under CWPS. North-Western plains of India and adjoining areas of the Punjab-Sindh provinces of Pakistan form the predominant contiguous area under CWPS (Fig. 1), although there are pockets under this system in Madhya Pradesh,

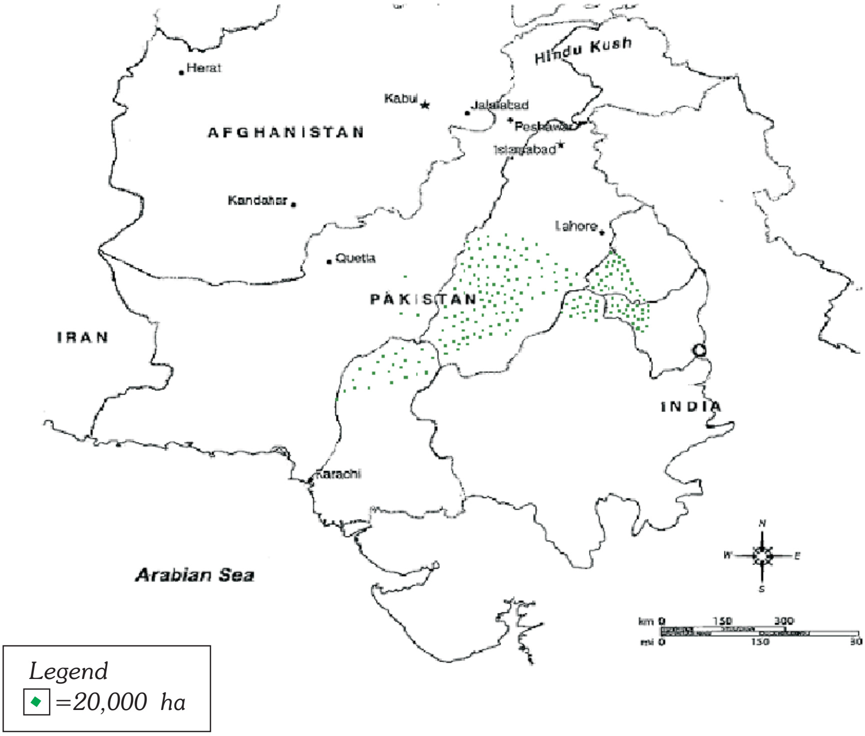


Figure 1. Cotton-wheat production area in the north-western plains of India and Pakistan

Maharashtra and Gujarat states of India. Based on the area under cotton, north-western states of India and the provinces of Pakistan, the estimated area under CWPS is given in Table 1. In India, CWPS is followed on 1.40 mha and on 2.62 mha in Pakistan. The total area under CWPS comes to about 4.0 mha in the north-western plains of India and Pakistan. CWPS covers about 82 to 93% of the total cotton area but encompasses only 22 to 25% of the total wheat area in this belt. In India, only 18 to 20% of wheat area is covered by cotton-wheat rotation against around 33% in the Punjab and Sindh provinces of Pakistan.

Varietal Improvement

An early maturing cotton variety is the main requirement of CWPS. With concerted efforts by the different research centers, a number of early-maturing varieties of cotton were developed to suit the cropping system. In 1988, 'RG-8' a high-yielding variety of *arboreum* cotton was released from Sriganganagar, Rajasthan, India. Since it matured in 170 days, the *desi* cotton-wheat cropping sequence also became most popular in northern Rajasthan and neighbouring states. Development of early-

Table 1. Estimated area under cotton-wheat (CW) cropping system in India and Pakistan

State/ Province	Area (mha) cotton		Area (mha) CW		CW rotation area as % of total cotton area	
	1995-96	2007-08	1995-96	2007-08	1995-96	2007-08
India						
Punjab	0.44	0.65	0.40	0.62	90.1	96.8
Haryana	0.49	0.48	0.45	0.47	91.8	96.7
Rajasthan	0.37	0.37	0.32	0.33	86.5	91.5
Total	1.30	1.50	1.17	1.39	90.0	92.7
Pakistan						
Punjab	2.40	2.6	2.00	2.20	83.03	84.6
Sindh	0.60	0.6	0.40	0.42	66.7	70.0
Total	3.00	3.2	2.40	2.62	80.0	81.9

Source: Agricultural Statistics at a Glance, Ministry of Agriculture (2007) and Country Report (2007) 66th Plenary Meeting of ICAC, Izmir, Turkey, October, 22-26, 2007 (Anonymous, 2007).

maturing cotton varieties made it possible to follow cotton-wheat cropping system. This doubling of cropping intensity from 100 to 200% gave a significant boost to economy of the farmers in irrigated tracts of northern India in all the three states. Similarly, wheat research got the real boost in entire Indo-Gangetic Plain with introduction of Mexican dwarf wheat varieties at Indian Agricultural Research Institute (IARI), New Delhi, G.B. Pant University of Agril. & Technology, Pantnagar, Punjab Agricultural University, Ludhiana and Haryana Agricultural University, Hisar. Simultaneously, in Pakistan, the concentrated research on wheat continued at Lyallpur. These efforts resulted in evolving series of important wheat varieties suitable for double-cropping in either cotton-wheat or rice-wheat production systems. Some of the important wheat and cotton varieties that became popular in cotton-wheat rotation in India and Pakistan have been listed in Table 2a & b, and their notable characteristics given in Table 3.

In India, Bt-cotton was approved for commercial cultivation in North Zone in 2005. A large number of hybrids with differing Bt-events (gene incorporation) have been in cultivation since then (Table 4). They have further strengthened the cotton-wheat production system (Figs. 2 and 3).

The above crop improvement efforts and its R&D initiatives in recent years have led to substantial growth in production and productivity of cotton and wheat in CWPS area of India and Pakistan (Table 5).

Table 2(a). Important cotton varieties/hybrids grown in CWPS

India		Pakistan	
American cotton	***Desi* cotton**	**Punjab**	**Sindh**
J-34	LD-327	CIM-496	NIAB-78
F-414	Moti	CIM-506	CRIS-134
F-846	HD-107	MNH-786	CIM-473
Fateh	HD-324	CIM-534	FH-901
LHH-144	CISA-310	CIM-473	FH-1000
HS-6	AAH-1	BH-160	HARIDO ST
H-1098	RG-8	NIAB-111	SHAHBAZ-95
H-1226	RG-18	CIM-499	CRIS-121
CSHH-198	GRAJ-DH-9	FH-901	SOHNI
CSHH-243		NIBGE-II	CHANDNI
RS-89			
Bikaneri Narma			
G. Ageti			
RST-9			
Maru Vikas			

Source: Federal Seed Certification & Registration Department, Islamabad, Pakistan, Country Report: Pakistan; 66th Plenary Meeting of ICAC, Izmir, Turkey, October 22-26, 2007 (Anonymous, 2007); AICCIP Reports (1985-2000) and Visit http://www.pakissan.com.

Table 2(b). Important wheat varieties grown in CWPS

India	Pakistan	
	Punjab	**Sindh**
PBW-373	Bhakkar-2002	TD-01
PBW-509	Inquab-91	TJ-83
RAJ-3765	AS-2002	Kiran-95
RAJ-3777	Auquab-2000	Sarsabz
RAJ-2184	SH-2002	SKD-1
WH-291	Manthan-2003	Imdad-5
PBW-343	Shafaq-2006	Bhittal
WH-542	Sehar-2006	Khirman
PDW-274	Fareed-2006	Mehran-89
PDW-233	GA-2000	Marvi-2000
PBW-299	Chakwal W5	Sassai
PBU-502	Shaheen-2000	Abadgar-93
TL-2908		Moomal-2002
TL-1210		Anmol-91

Bt-Cotton: A Boon to Cotton-Wheat Production System

Cotton crop suffers severe economic damage from several insect pests, diseases and weeds, particularly bollworms, especially *Helicoverpa armigera*, has been responsible for heavy losses in yield. Annual losses caused by bollworms alone are estimated at about US$ 290-350 million despite repeated sprayings of insecticides.

Since no sources of resistance to bollworm are available in the existing germplasm lines of cotton or its near relatives, breeding efforts did not yield any useful results. Therefore, efforts were directed to harness genetic engineering (GE) technology for bollworm resistance and transgenics using the known *cry* genes from soil bacterium, *Bacillus thuringiensis* (Bt) subspecies *kurstaki.*

The Genetic Engineering Approval Committee (GEAC), an apex regulatory Government organization in India allowed commercialization of the first transgenic product, i.e. Bt-cotton in 2002 in central and south zones but not in CWPS of north-western plains. In 2005, the GEAC approved 16 cotton hybrids including six hybrids for north zone, which covers CWPS, thus making the technology available for the entire country. Realizing the potential of technology, several Indian seed companies have already incorporated the cry gene(s) into a number of hybrids suitable for CWPS including Bollgard II (Event 15985) having cry1Ac plus cry2Ab genes. To diversify the genetic background of the Bt gene, cry1Ac gene was developed indigenously and incorporated into cotton by JK Seeds Company as Event 1 and the Genetically Fully Modified or fused gene (GFM) event of cry1Ac (Chinese gene) used by Nath Seeds are also permitted in India. The public sector was also permitted commercialization of cry1Ac into the public bred varieties particularly Bikaneri Nerma in 2008. Acceptance and spread of Bt-cotton cultivation has been much faster than anticipated, particularly in the north-western plains of India where cotton production had been revived during the last three years. The adoption of the technology can be gauged by the area covered under Bt-cotton in the CWPS belt (Table 6) in spite of late commercialization of technology by three years in this area from the rest of the country (Mayee, 2007).

One of the major gains of Bt-cotton spread in north-western plains is the adoption of hybrid technology, which had the lowest penetration in this area in spite of availability of irrigation, mechanization and better input management practises. Prior to 2005, the CWPS hybrid technology was on less than 5% area which is now covering more than 47% area because Bt-technology is commercially available currently in hybrid background only. Short duration, quality hybrids have been developed in recent years which suit the double cropping of cotton-wheat rotation.

Before the introduction of Bt-cotton, the production and productivity was almost stagnant in the north-western plains of India mainly due to cyclic epiphytotics of

Table 3. Important varieties of wheat and cotton recommended for north zone of India

Sl. No.	Variety	Duration	Average yield (q/acre)	Remarks
Wheat				
1.	WH-157	Early medium	19.2	Resistant to yellow and brown rust, tolerant to Karnal bunt
2.	HD-2329	Early medium	20.8	-
3.	WH-542	Medium late	23.2	Resistant to rusts, tolerant to Karnal bunt
4.	PBW-343	Medium late	23.0	Resistant to yellow and brown rust
5.	UP-2338	Medium late	23.0	Tolerant to rusts
6.	WH-147	Medium late	20.0	Tolerant to brown rust and Karnal bunt
7.	WH-416	Early medium	22.0	Tolerant to brown rust
8.	Raj-3765	Early	18.4	Resistant to brown rust and tolerant to yellow rust
Cotton		**Days**	**q/ha**	
1.	H-117	Medium (165-170)	22.0	Resistant to CLCuV
2.	F-1861	Medium (165-170)	16.25	Resistant to CLCuV
3.	RS-2013	Medium (165-170)	20.0	Resistant to CLCuV
4.	RS-180	Medium (165-170)	18.0	Resistant to CLCuV
5.	LH-1556	Medium (165-170)	20.0	Tolerant to CLCuV
6.	H-1098	Medium (165-170)	22.0	-

Table 4. Bt-cotton hybrids approved for cultivation in north India

Year	Bt-cotton hybrids
2005	'RCH 134 BG I', 'RCH 317 BG I', 'MRCH 6301 BG I', 'MRCH 6304 BG I', 'Ankur 651 BG I', 'Ankur 2534 BG I'
2006	'RCH 314 BG I', 'RCH 308 BG I', 'MRCH 6025 BG I', 'MRCH 6029 BG I', 'NCS 138 BG I', 'NCS 913 BG I', 'NCES 6', 'JKCH 1947'
2007	'MRC 7017 BG II', 'MRC 7031 BG II', 'NCS 145 BG II', 'ACH 33-2 BG II', 'PCH 406', 'Sigma Bt', 'Ole Bt', 'JKCH 1050 Bt', 'SDS 1368 Bt', 'SDS 9 Bt', 'Ankur 2226', 'NCS-950', 'KDCHH 9810', 'IT905 BG I', 'NAMCOT 402', 'GK 206 Bt', '6317 Bt', '6488 Bt'

Source: GEAC Proceedings, Ministry of Environment and Forests, New Delhi (Compilation from 2005 to 2007 Reports)

Figure 2. General view of Bt-cotton hybrid MRCH 6301 cultivated in north-western plains of India.

Figure 3. Rust-resistant wheat variety PBW-343: Highly popular in the cotton-wheat rotation in north-western plains of India.

Table 5. Production and productivity of cotton and wheat in CWPS

State/ Province	Production				Productivity			
	1995-96		2006-07		1995-96		2006-07	
	C[1]	W[1]	C[1]	W[1]	C[2]	W[2]	C[2]	W[2]
India								
Punjab	0.90	12.5	2.40	14.5	348	3884	630	4179
Haryana	0.87	7.2	1.60	10.1	302	3697	509	3847
Rajasthan	0.50	5.4	0.90	06.9	230	2501	416	2761
Total	2.27	25.9	4.90	31.5	293	3360	558	3596
Pakistan								
Punjab	8.40	12.2	11.0	17.5	595	2132	731	2876
Sindh	2.20	2.9	3.0	3.5	623	2086	797	2997
Total	10.60	15.1	14.0	21.0	609	2109	740	2839

C[1] : *Cotton in m bales,* C[2] : *Cotton lint kg/ha,* W[1] : *Wheat in m tonnes,* W[2] : *Wheat grain kg/ha*

Source: *Ministry of Agriculture, Govt. of India (2007), Agricultural Statistics of Pakistan (2006-07) and FAO Agricultural Database* (2006-07).

bollworms. Adoption and spread of Bt-cotton proportionately enhanced cotton yield not only in Punjab but all over the country. The average productivity improved from 300 to 558 kg lint/ha in the cotton-wheat production zone. The state-wise area, production and productivity of the last two years compared with the lowest productivity year (Table 7) indicates the beneficial effect of Bt-cotton. It is also found that the number of sprays have been reduced from 12 to 4 due to use of the genetically engineered cotton.

Bt-cotton technology is now made available in different genetic background and also diversified events to ensure its sustainability (Table 8) in CWPS of India. Recently, GEAC in its meeting in June 2008, also approved a new event of Cry1Ac gene developed as 'Dharwad Event' into the popular cotton variety 'Bikaneri Nerma' which is already grown in CWPS. Approval for the cultivation of indigenously developed GM cotton is still pending in Pakistan. The National Institute for Biotechnology and Genetic Engineering (NIBGE) at Faisalabad developed GM cotton for various traits; i.e. virus resistance, insect resistance, salinity tolerance in locally adopted cultivars. However, the regulatory mechanisms for assessment of biosafety and environment safety issues have not been put into place, which has delayed the

Table 6. Spread of Bt-cotton in cotton-wheat production zones of India

State	Area covered ('000 ha)		
	2005	2006	2007
Punjab	50	173	389
Haryana	10	40	275
Rajasthan	Trace	02	40
Total	60	215	704
% of total area of NZ	3.75	14.4	47.2
Rest of India	1240	3585	5543
% of total area	17.1	46.8	79.2

Source: James Clive, 2007, Global Status of Commercialized Biotech/GM Crops 2007, ISAAA Brief 37.

Table 7. Cotton area, production and yield in northern region (2002–2008) of India

State/Year	2007 – 08			2006 – 07			2002 – 03		
	Area (lakh* ha)	Production (lakh bales)	Yield (kg/ha)	Area (lakh ha)	Production (lakh bales)	Yield (kg/ha)	Area (lakh ha)	Production (lakh bales)	Yield (kg/ ha)
Punjab	6.48	24.00	630	6.07	26.00	728	4.49	7.50	284
Haryana	4.78	16.00	569	5.30	16.00	513	5.19	8.75	287
Rajasthan	3.68	9.00	416	3.50	8.00	389	3.86	5.00	220
North Zone	14.94	49.00	558	14.87	50.00	572	13.54	21.25	267
All India	95.30	310.00	553	91.42	280.00	521	76.67	136	302

*Lakhs = 100,000
Source: Cotton Advisory Board (CAB), Ministry of Textiles, Govt. of India, 2002 to 2008.

official approvals and release of GM crops. In case of Bt-cotton, around 0.15 m/ha unauthorized spread has taken place in Pakistan in 2005-06, which is expected to substantially increase in subsequent years (Zafar *et al.*, 2007). Government of Pakistan has recently made an agreement with the US Multinational Company, Monsanto for transfer of Bt genes (Cry1Ac and Cry2Ab) into the currently ruling cotton varieties of Pakistan (Personal communication, ISAAA, June 2008).

Table 8. Approvals of Bt-cotton in north zone in India

North Zone	2002	2003	2004	2005	2006	2007
Total No. of hybrids	-	-	-	6	14	32
Total No. of events	-	-	-	1	3	04
Total No. of companies	-	-	-	03	06	15
All India						
Total No. of hybrids	3	3	4	20	62	131
Total No. of events	1	1	1	1	4	4
Total No. of companies	1	1	1	3	15	24

Source: James Clive, 2007, Global Status of Commercialized Biotech/GM Crops 2007, ISAAA Brief 37.

CWPS : An Unique Cropping System

- Next only to rice-wheat cropping system, cotton-wheat production system occupies around 4.0 m/ha in the north-western states of India and adjoining areas of Punjab and Sindh provinces of Pakistan.
- Being a cash (cotton being industrial product) and grain cropping system, it ensures food security with financial security.

Cotton-Wheat Production Technologies: Successes Achieved

Improved Production Technologies

During the last sixty years, production technologies of both cotton and wheat have been improved in the system approach so as to suit to successful crop rotation requirements. Thus, formulation of packages of Cotton-Wheat (CW) production technologies has been the major goal to exploit maximum potential of the system. Research efforts have gone into the development of techniques related to suitable short duration, photo-insensitive high yielding cultivars, and these include diverse field operations- seeding, tillage, weed management, integrated nutrient as well as pest management, water management, and harvest technologies. Based on agro-ecological requirements, the package of agro-technology practices has been refined under specific environment. Some of the major interventions responsible for sustainability and profitability of CWPS are described here. Figures 4 to 9 provide views of field operations carried out.

Tillage and Seeding

Land preparation for cotton and wheat sowing is done with the help of machines, which reduce the operational timings between the harvest of first and second crop. Most of the cotton is direct seeded and therefore preparatory tillage is done by tractor-drawn cultivator with pulverizing roller. Cotton sowing is done from mid-April to mid-May exclusively under irrigated situation when temperatures are above 38 °C to 39 °C. *Arboreum* cottons are sown a little earlier. Low seed rate in traditional varieties was a problem but with constant education and motivation of farmers, there has been a marked improvement in seed rate and plant population. Depending on the compactness of varieties, now 32,000 to 40,000 plants/ha are maintained. Line sowing has also been established as a practice even in *arboreums* and now with the availability of cotton seeds of AxA or HxH non-Bt or Bt hybrids, precision planting is done whereas against varieties plant population has been reduced. Highly branched monopodial cotton varieties, hybrids require wider spacing than non-sympodial types. Closer spacing of 75 cm x 15 cm or 67.5 cm x 15 cm to wider spacing of 75 cm x 30 cm is adopted depending on the compactness of varieties. For Bt-cotton wider spacing of 90 cm x 90 cm is followed and as a result the seed rate is reduced from 4 to 6 kg/ha to 1.5 to 2.2 kg/ha. Since cotton sowing is done when soil temperature is high, hard crust formation has been a limitation for successful

Figure 4. Land preparation with tractor drawn disc plough useful in reducing time between harvesting and planting in CWPS.

Figure 5. Tractor drawn planking operation as a part of quick land preparation.

emergence. Studies carried out on depth of sowing revealed that seeds sown at the depth of 23 to 46 mm emerged better than deep sowing.

In cotton-wheat belt, seedbed preparation for wheat is relatively less complex. It is a routine practice that with any delay in second or third picking in cotton, farmers uproot the entire plants with green mature bolls and stock them on bunds so that the cotton left on the plants is collected from the boll after its bursting a few days later. This practice helps in early preparation of land for succeeding wheat sowing. Conventional tillage for wheat requires pre-sowing irrigation on well-drained soils or drying of soil in lowlands followed by one or two disking, harrowing and leveling. Occasionally, this requires time and delay in sowing, which results into lower yield.

Performance of zero-tillage techniques

In recent years, zero-till technique is getting widely adopted by farmers, which has been recommended in rice-wheat system due to savings in cost, labour, fuel and energy consumption. Thus this technology is getting popular in CWPS system as well. Tractor-drawn zero till or strip-till drill for sowing of wheat in unprepared fields has proved highly beneficial over normal tillage (Bhandari *et al.,* 1998). Between 1998 to 2001, a large number of frontline demonstrations were carried out on farmer's fields under the All India Coordinated Wheat Improvement Project (AICWIP), where zero tillage gave 8.1% higher yields in the north-west plains (Table 9). Cotton is successfully grown in strip-till following wheat. To harvest maximum solar energy, wheat is sown bi-directional way using half the quantity of seed and fertilizer in one direction and remaining half in other direction. The bi-direction method of sowing gives 10 to 23% extra yield. The benefits of this method are more pronounced under late-sown conditions, which generally prevail in wheat sown after cotton. Another wheat seeding technology in CWPS in India is the furrow-irrigated raised bed (FIRB) system. Sowing of wheat on beds is possible because of new bed planters, which enable 2 to 3 wheat-rows 15 to 20 cm apart on 37.5 cm wide bed and 30 cm wide irrigation furrow in between. Wheat seed rate can be reduced from 100 to 75 kg/ha without compromising the yield. The FIRB system gives 5 to 10% higher yield over conventional sowing methods and brings considerable savings in irrigation water and facilitates manual weeding (Kumar *et al.*, 2001).

Table 9. Performance of zero-tillage in seeding wheat in north-western plains in FLD in India (average of 3 years)*

Wheat production (tonnes/ha)		
Zero-tillage	**Conventional tillage**	**Yield gain (%)**
4.95	4.58	8.1

Source: *Singh and Kharub (2001)

Figure 6. Mechanized planting of cotton widely adopted in CWPS.

Figure 7. Zero-till planting of wheat: a resource conservation technology extremely useful in CWPS.

Figure 8. Mechanical bed preparation for simultaneous operations of tillage and sowing useful in cotton and wheat cultivation.

Figure 9. A successful lush green wheat crop raised on beds.

In Pakistan, most of the farmers resort to broadcasting of seed for sowing of wheat following cotton taking advantage of removal of cotton debris, which makes the soil relatively friable and can be prepared quickly. The seed rate is as high as 150 kg/ha. However, in recent years resource management techniques like zero-tillage as a viable option has emerged as a successful technology.

Integrated Nutrient Management

Nutrient management is crucial for achieving high yields in CWPS. Successful production is achieved by application of 120 kg N + 60 kg P_2O_5 + 60 kg K_2O/ha for wheat and 80 kg N for cotton. The residual effect of P and K applied to wheat partly takes care of the requirements of the succeeding cotton crop. Application of 50% N dose as basal and remaining as top dressing with first irrigation is an established practice for getting optimum wheat yield. Although 80 kg N is applied routinely to cotton, better responses upto 120 kg N have been obtained for high yielding varieties and Bt-cotton hybrids.

With continuous rotation, micronutrient application has become an integral part of nutrient management strategy. One spray of 0.5% manganese sulphate 24 days before first irrigation and two to three sprays afterwards at weekly interval on sunny days is essential in Mn-deficient soils. Zinc at 17.5 kg and boron at 13.75 kg/ha are advocated on cotton in Pakistan in CWPS. Similarly, application of gypsum at 250 kg/ha is commonly practised in CW rotation commencing its use for wheat. An integrated package of nutrients involves addition of FYM (meeting 50% source of N) along with 50% recommended dose of NPK (Table 10), which gives highest monetary returns to farmers.

Table 10. Average yield and gross returns under different nutrient management practices in cotton-wheat cropping sequence

Treatment	Yield (q/ha)		Gross returns (INR/ha)	Increase over farmers' practice (%)
	Cotton	Wheat		
100% recommended NPK/ha	18.00	41.28	53.305	22.7
50% recommended NPK/ha through chemical fertilizer + 50% N through FYM	20.09	43.00	58,424	34.4
75% recommended NPK/ha through chemical fertilizer + 25% N through FYM	18.93	41.58	55,440	27.6
Farmers' practice	18.69	33.51	43,459	—

Source: Kairon *et al.* (1996)

Water Management

Depending on climate and total growing period, cotton needs 700 to 1200 mm water to meet its requirement. In vegetative phase upto first 60 to 70 days after sowing, water requirement is only 30% but during flowering and boll development it is about 60%. Several water saving devises such as; irrigation through furrow and alternate furrow irrigation are used without affecting the yield. In wheat, 4 to 6 irrigations are required. The first irrigation is relatively light and given three weeks after sowing in timely sown crop and after four weeks in late sown crop.

Wheat crop has been a subject of more attention from the point of view of irrigation than cotton. Several approaches such as depth of irrigation, climatological system based on Pan Evaporation (ID/CPE ratio), irrigation based on soil-plant-atmosphere water relationship have been advocated for optimum use of irrigation water in wheat (Prasad, 2005). However, irrigation at critical growth stages of wheat has been the easiest approach adopted by farmers. Five to six growth stages are recognized as critical for irrigation, namely crown root initiation (CRI), late tillering (LT), late jointing (LT), flowering (F), milk (M) and/or dough stage (D) (Agarwal and Khanna, 1983). The dwarf wheats introduced in CWPS and rice-wheat cropping system give increase in yield due to single irrigation over no irrigation. In soils, where the water level is 0.5 to 0.9 m deep and where some winter rain is received, single irrigation at CRI stage is adequate (Tripathi, 1992).

Water use efficiency: The economics and water use efficiency of different cotton-based cropping systems have been studied in Punjab, India. Though water use efficiency is highest in cotton-chickpea, highest net returns are obtained in cotton-wheat rotation, and it is the third best system for water use efficiency after cotton-chickpea and cotton-field pea systems (Table 11). Rotation of cotton with wheat using minimum tillage not only improves cotton yield but enhances water use efficiency.

Table 11. Economics and water use efficiency of different crop rotations in Faridkot, Punjab

Rotation	Mean net returns (INR/ha)	Water use efficiency (kg/ha/mm)
Cotton – fallow	15,928	3.82
Cotton – wheat	36,534	3.89
Cotton – chickpea	35,083	4.44
Cotton – barley	31,368	3.77
Cotton – mustard	20,011	3.20
Cotton – field pea	23,265	3.96

Source: Singh *et al.* (2003)

Weed Management

Liberal use of fertilizers and irrigation has tilted the ecological conditions in favour of growth of certain weeds in cotton–wheat cropping system in India. The predominant weeds in cotton are: *Eleusine aegyptiaca, Digitaria ciliaris, Eragrostis tenella, Leptochloa panicea, Trianthema portulacastrum, Digera arvensis, Celosia argentea, Cyprus rotundus* and *Cyprus compressus*. Similarly, in case of wheat after cotton, the following weeds are predominant: *Phalaris minor, Avena ludoviciana, Poa annua, Chenopodium album, Medicago denticulata, Melilotus indica, Anagallis arvensis* and *Cirsium arvense*.

Application of herbicides like alachlor, fluchoralin, diuron, fenuron and MSMA alone and in combination has been in use to control weeds in cotton. No single herbicide is effective under all situations. At Ludhiana, performance of pendimethalin @ 1.5 kg/ha along with one inter-culture at 35-45 days after sowing is better for controlling weeds and increasing cotton production. Effective control of annual weeds is also obtained with pre-emergence application of pendimethalin (1.5 kg/ha), followed by post-emergence directed spray of paraquat (0.2 kg/ha) in mid-August. Pre-plant application of trifluralin @ 1.5 kg/ha followed by one hoeing controls weeds in cotton efficiently. None of the herbicides show phytotoxic effect on cotton (Brar *et al.,* 1998). Sequential application of diuron @ 0.5 kg/ha (pre-emergence) and paraquat @ 0.5 kg/ha (post-emergence) also gives an acceptable control.

In wheat, broad-leaved weeds are effectively controlled with application of 2, 4-D. For realizing the best results in normal (November) and late-sown (mid-December) conditions, 2,4-D is applied at 35-45 and 45-55 days after sowing, respectively. There is no residual effect of 2,4-D applied to wheat on the succeeding crop of cotton. Wild oat in wheat is controlled with early post-emergence (20-25 days after sowing) application of isoproturon @ 0.5-0.75 kg/ha or metxuron @ 0.9 kg/ha. Use of diclofopmethyl @ 0.9 kg/ha or tralkoxydim @ 0.35 kg/ha is also recommended against wild oats at 30 to 35 days after sowing.

Isoproturon @ 0.9 kg/ha, metxuron @ 1.5 kg/ha or pendimethalin @ 0.75 kg/ha can control *Phalaris minor*, the most troublesome weed of wheat. These herbicides are applied at 30-35 days after sowing, except pendimethalin, which is applied within two days of sowing. Control of *Phalaris minor* and other weeds in durum wheat is done by metoxuron @ 1.5 kg/ha at 30-40 days after sowing or pendimethalin @ 0.75 kg/ha within 2 days of sowing. However, changing the cropping system is a better option in view of reports pertaining to development of biotypes of *P. minor* resistant to isoproturon as this weedicide is widely used in CWPS and rice-wheat system (Table 12).

Table 12. Effect of crop diversification on population of *Phalaris minor*

Crop rotation	Population of *P. minor* (Nos. sq. m)	Wheat yield (tonnes/ha)
Rice-Wheat* (continuous 10 years)	2350	3.0
Rice-Berseem, Rice-Wheat	255	4.2
Rice-Berseem, Sorghum-Wheat	190	4.5
Rice-Potato, Rice-Wheat	255	4.0
Cotton-Wheat* (for 4 years)	38	4.6
Rice-Berseem, Rice-Berseem, Rice-Wheat	28	5.0

Source: Banga *et al.* (1997)

*Isoproturon applied to wheat at 1 kg a.i./ha 30-35 days after sowing.

Growth Regulation in Cotton

Cotton often attains excessive vegetative growth due to high soil fertility, which coincides with rainy season and high relative humidity. Thick crop canopy prevents adequate penetration of light and utilization of energy, resulting in shedding of flower buds, flowers, immature bolls, and rotting and poor opening of bolls. To check excessive vegetative growth, spraying of mepiquat chloride 5% aqueous solution after 80 days of sowing is regularly adopted. It causes reduction in plant height, imparts dark green colour to leaves, increases boll size, boll number and gives 10-15% higher seed cotton yield.

In order to hasten the boll bursting in cotton and enable early sowing of succeeding wheat, defoliants like dropp and ethrel are used at various stages of boll bursting. Dropp @ 150-200 g/ha in 600 litre of water is applied at 60% boll bursting stage. Similarly, thidiazuron is safely used for leaf shedding and advancing the maturity by 2 to 3 weeks in cotton.

Insect Pest and Disease Management

A number of insects and diseases affect the cotton-wheat cropping system. Cotton is more vulnerable to insect pests and diseases as compared to wheat mainly because in CWPS rust resistant varieties only are planted. The severe incidence of American bollworm (*Helicoverpa armigera*) and cotton leaf curl virus disease on cotton has been a limiting factor in enhancing cotton productivity in CWPS. However, appropriate crop protection technologies have been worked out to optimize the production.

Cotton is attacked by a number of insect-pests, and if not managed properly, this results in 50-60% reduction in yield and quality of cotton. Under heavy infestation, American bollworm alone can cause 20-80% reduction in yield. Sucking pests such as Meady bugs, jassid and white fly are also important and cause considerable losses. Cotton also suffers from a number of diseases, among which, leaf curl of cotton caused by Gemini virus and transmitted by white fly (*Bemisia tabaci*) has become a threat to cotton cultivation in the entire CWPS.

The major diseases of wheat include leaf yellow and stem rusts, Karnal bunt, foliar blights, powdery mildew and loose smut. Development of resistant varieties and other plant protection technologies have contained these problems to a great extent.

Success of IPM strategies: In CWPS, success of the system is achieved through adoption of wheat varieties to minimal incidence of rusts, foliar blight and loose smut and in cotton through perfect popularization of integrated pest management (IPM) system, and in recent years the insecticide resistance management (IRM) programs (Figs. 10 and 11). The community based, holistic IPM modules with much reliance on naturally occurring bio-control agents and bio-pesticides as well as IRM-window approach system with reliance on effective chemicals at proper growth stage, have become backbone of pest and disease management in CWPS. The success of the production system is principally attributed to successful pest management in both the rotating crops. The IPM interventions include seed treatment with imidachloprid, scouting, placement of pheromone traps for monitoring, 2 to 3 releases of *Trichogramma*, 4 to 5 sprays of neem seed powder extract and need-based application of pesticides. IPM practices in CWPS has resulted in drastic reduction of pesticide use and stabilizing cotton yield (Table 13). After the introduction of Bt-cotton, the IPM program got further boost as the pesticide application could be drastically curtailed by farmers (Fig. 12). IRM program initiated in CWPS has further imparted through education to farmers on the proper use of pesticides. Window approach of IRM is based on use of safer insecticides till 120 days of planting and use of the toxic pesticides only once or twice at the advanced stage of boll opening for control of bollworm complex (Kranthi *et al.*, 2003).

Table 13. Significant benefits of IPM strategies in CWPS

Sl.No.	Particulars	IPM	FP	% Change
1.	Quantity of pesticides required (kg/ha)	437	10.55	-58.58
2.	Yield of seed cotton (kg/ha)	1,678	1,319	+27.22
3.	Net returns (INR)	24,135	15,004	+60.86

Source: Annual Report of NCIPM, New Delhi, 2007

Figure 10. Pest surveillance in cotton through pheromone traps: a common practice in CWPS.

Figure 11. Use of Tricho cards - an integral part of IPM followed in cotton pest management.

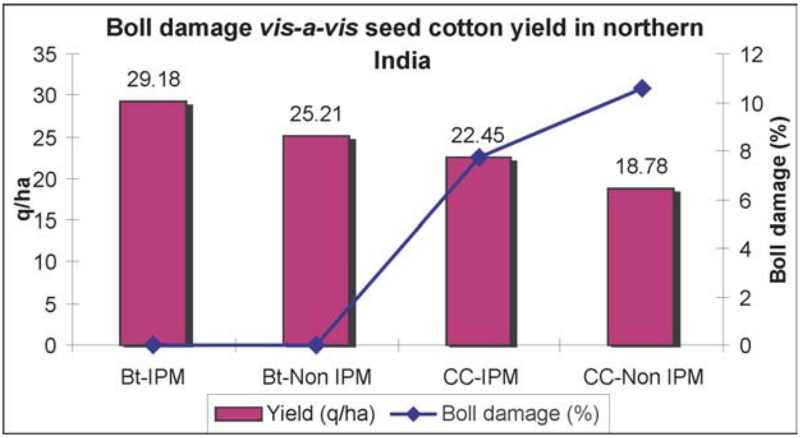


Figure 12. Bollworm damage and its effect on seed cotton yield in northern India.

Popularization of Resistant Cultivars

Development and popularization of resistant varieties and hybrids of cotton and wheat is a major attribute towards the success of CWPS. A series of cotton leaf curl virus (CLCuV) resistant varieties has helped in containing the spread and damage due to disease both in India and Pakistan. CLCuV disease is predominant exclusively in the North-Western plains of India and Pakistan. Therefore, even while recommending the Bt-cotton hybrids, one of the major criteria is their resistance/tolerance to the virus disease in the north zone in India. Similarly, rust-resistant wheat cultivars are the backbone of wheat production success in CWPS since the period of green revolution. However, there are other disease problems such as loose smut, flag smut, Karnal bunt, powdery mildew etc. which have also been tackled through resistant breeding. The current disease resistant/tolerant varieties to different diseases of cotton and wheat in India are listed in Table 14. The approved cotton varieties resistant or tolerant to CLCuV disease in Pakistan are given in Table 15.

Key Production Technologies: Astonishing Benefits

- Early maturing high yielding, bollworm resistant Bt-cotton hybrids in India and CLCuV resistant varieties in Pakistan and uniform disease resistant varieties of dwarf wheat.
- Minimum operational timings between harvest of first and second crop due to mechanical sowings, zero-tillage, FIRB.
- Highest implementation of IPM with biological control and IRM with window approach sprayings.

Table 14. Resistant/tolerant varieties of cotton and wheat to major diseases in India

Disease	Resistant/tolerant varieties
Cotton	
Cotton leaf curl virus	'RS-2013', 'RS-810', RS-875', F-1861', 'H-1117', 'H-1226' (Varieties), 'HHH-223', 'HHH-287', 'Shresh', 'Kalyan' (Hybrids)
Cotton wilt	'LD-694'
Wheat	
Rusts	'PBW-502', 'PBW-343', 'WH-542', 'PDW-274', 'PDW-233', 'PBW-509', 'PBW-373', 'TL-1210', 'PBW-396', 'PBW-299', and 'PBW-175'
Loose smut of wheat	'PDW-274', 'PBW-233', 'TL-2908' and TL-1210'
Flag smut of wheat	'PDW-274', 'PBW-233', 'TL-2908' and TL-1210'
Karnal bunt	'PDW-274', 'PDW-233', 'TL-2908' and 'TL-1210' under irrigated conditions and 'PBW-396', 'PBW-299' and 'PBW-175' under rainfed conditions
Powdery mildew	'TL-2908' and 'TL-1210'
Head blight	'PBW-343' and 'WH-542'

Source: Package of Practices of Punjab, PAU Ludhiana, Haryana and Rajasthan.

Table 15. Virus resistant/tolerant cotton varieties cultivated in Pakistan

Early maturing		Medium late	
CLCuV resistant	**CLCuV tolerant**	**CLCuV resistant**	**CLCuV tolerant**
CIM-443	Karishma	FH-900	BH-36
CIM-482	NIAB-78	FVH-53	FVH-53
	NIAB-109	CIM-448	Ravi
BGG-552		MNH-554	FDH-170
FH-901		BH-118	ROHI
		CIM-1100	
		FH-634	

Source: Ayub Agriculture Research Institute (1996-2006) publication of Department of Agriculture, http://www.punjab.gov.pk.

Research Benefits and Impact

Economics of CWPS

Studies have been carried out in India and Pakistan on the economics of cotton-wheat rotation in comparison to other systems. In Punjab state of India, comparative analysis of cotton-wheat, cotton-barley and cotton-chickpea and of field pea has been made. Cotton-Wheat system proved to be highly economical under adequate irrigation and cotton-chickpea under deficit irrigation (Singh *et al.*, 2003). Similarly, highest cotton equivalent yield is obtained in cotton-wheat followed by chickpea, barley, pea and mustard. The farm trials in Haryana too indicated that cotton-wheat cropping system is superior in many respects and the gross monetary returns can be increased by adopting improved varieties with recommended fertilizer dosages (Table 16).

Table 16. Average yield and gross returns under different packages on cotton-wheat cropping sequence on farmers' fields

Treatment	Yield (q/ha)		Gross returns (Rs./ha)	Increase over farmers practice (%)
	Cotton	Wheat		
Farmers' practice + local variety	14.31	31.42	41,896	
Farmers' practice + improved variety	15.53	32.80	45,010	7.4
Farmers' practice + improved variety + recommended fertilizer dose	18.14	39.78	53,104	26.8
Farmers' practice + improved variety + recommended fertilizer dose	20.00	40.86	57,453	37.1

Source: Kairon *et al.* (1996)

Among the various crop rotations, *arboreum* and *hirsutum* cotton followed by wheat, mustard, lentil, *gobhi* sarson (transplanted) and sunflower, the highest mean yield was recorded in *desi* cotton-wheat and American cotton-wheat sequences in Rajasthan. In yet another study at Sriganganagar, the highest net return was obtained with *hirsutum* cotton-wheat cropping system (Table 17).

In a comprehensive economic analysis of four crop rotations *viz*., cotton-fallow, cotton-wheat, cotton-sunflower and cotton-maize at Multan (Pakistan), cotton-wheat

Table 17. Economics of different cropping systems at Sriganganagar, Rajasthan, India

Cropping system	Gross returns (INR/ha)	Net returns (INR/ha)	Sustainability index of net returns (%)	B:C ratio
Hirsutum cotton-mustard	47,341	30,111	93.3	1.75
Arboreum cotton-mustard	46,008	28,508	93.0	1.63
Hirsutum cotton-wheat	50,860	30,749	95.2	1.53
Arboreum cotton-wheat	49,330	28,651	96.3	1.40

Source: Nehra and Bhunia (2002)

cropping pattern has given highest total net returns over an average of nine years (Table 18). This clearly demonstrates the success of CWPS and hence has stabilized its adoption in north-western plains of India and Pakistan.

Table 18. Economics of cotton-based cropping patterns in Pakistan (nine year average)

Cropping Pattern	Cotton		Other crops		Total net income (PKR./ha)
	Duration (Days)	Yield (kg/ha)	Duration (Days)	Yield (kg/ha)	
Cotton-fallow	212	3,302	..	..	9,072
Cotton-wheat	195	3,299	125	3,514	11,636
Cotton-sunflower	196	3,090	121	2,185	11,099
Cotton-maize	192	2,771	118	3,881	9,471

Source: Central Cotton Research Institute, Multan

Farmers' Experience of CWPS in India

Recently, an exhaustive survey was carried out by Regional Research Station (CICR), Sirsa, of a total of ninety farmers - thirty farmers each from Haryana, Punjab and Rajasthan, for three years i.e. 2005-06 to 2007-08 in order to gain farmers first hand experiences on CWPS in India. The information on all production aspects from field preparation to production transportation including rental value of land was collected to work out total cost of cultivation. The gross returns were then worked out by multiplying the market value of crop during the year with total production. The value of straw in case of wheat and stalks in case of cotton were taken into account separately to calculate gross returns. The net returns were worked by subtracting the costs from gross returns. The information collected from farmers of each state was then averaged and finally the average for the entire CWPS belt in India was worked out yearwise. The net profit from cotton-wheat system obtained by farmers is maximum in Punjab followed by Haryana and Rajasthan in all the years (Table 19). There is an increase in net profit from 2005-06 to 2007-08 in the three states. This shows the sustainability of the system and the reason why the farmers prefer to go for cotton-wheat system. Looking at the entire zone, the net profit increased from INR 29,361/ha in 2005-06 to INR 34,250/ha in 2006-07 and INR 42,606/ha in 2007-08 (Table 19). This has become possible due to increase in remuneration prices of both the commodities over the years and larger adoption of Bt-cotton hybrids by the farmers. The net profit due to cotton crop when the variety seed is used is low as compared to use of Bt hybrid seed (Table 20). Even though the cost of seed is higher in case of Bt-cotton hybrid, the overall profit has been more as the farmers have to go for less number of insecticidal sprays and the seed cotton yield are higher in Bt-cotton hybrids.

Table 19. Economic advantage of CWPS to farmers of north-western states in India (net returns in INR/ha)

Year	Haryana	Rajasthan	Punjab	North Zone (India)
2005-06	29,324	23,199	35,560	29,361
2006-07	34,584	27,237	40,930	34,250
2007-08	44,515	29,899	53,404	42,606
Mean	36,141	26,778	43,298	35,406

Source: Annual Report, Central Institute for Cotton Research, Regional Station, Sirsa (Haryana), 2007-08.

Table 20. Benefit of Bt-cotton hybrids over traditional varieties (in INR/ha)

Year	Cotton					
	Bt Hybrids			Varieties		
	Total Expenditure	Gross Return	Net Profit	Total Expenditure	Gross Return	Net Profit
2005-06	29,941	45,270	15,330	33,219	43,118	9,899
2006-07	32,525	49,660	17,135	34,538	46,735	12,197
2007-08	34,602	58,018	23,416	33,214	45,950	12,736

Source: Annual Report, Central Institute for Cotton Research, Regional Station, Sirsa (Haryana), 2007-08.

Secrets of Success and Lessons Learnt

The success of Cotton-Wheat Production System in north-western plains of Indian sub-continent is based on the following successes achieved through the overall R&D initiatives undertaken.

1. Development of high yielding, short duration, early maturing varieties of cotton and wheat.
2. In India, advent of short duration, Bt-cotton hybrids that suit in the rotation with wheat and sufficient availability of these hybrids by the well organized private seed industry.
3. Infrastructure built-up for assured irrigation facilities in this belt ensuring water availability for pre-monsoon sowing of cotton and post-monsoon sowing of wheat.
4. Improved production technologies for both the crops such as; seeding through tractor drawn cultivator, zero till and Furrow Irrigated Raised Bed (FIRB) technologies for wheat, machine harvesting of wheat, packages of integrated nutrient management including micro-nutrients, successful control of dominant weeds through pre- and post-emergence herbicide application in cotton and wheat and use of growth regulators for precision growth of cotton.
5. Adoption of integrated pest management (IPM) modules in cotton for successful control of sucking pests and bollworms with much reliance on bio-control agents, pheromone monitoring and need-based pesticide use. In cotton, there has been reduction in pesticide consumption by adopting 'Window Approach' of pesticide application for insecticide resistance management (IRM). Simultaneous use of cotton leaf curl virus (CLCuV)-resistant varieties and hybrids in cotton and use of resistant varieties to rusts, smuts, Karnal bunt and blight in wheat.
6. CWPS being a cash-grain crop system is viewed by farmers as an assured system of food security and financial security. Its success lies in the fact that cotton is immediately sold to ginners and spinners, while wheat is readily procured by government agencies. Furthermore, both crops are covered under the minimum support price (MSP) regimes of the government and thus have a continued incentive. Pre-announced prices by the state government agencies have been the major driving force in augmenting the production of CWPS in India and Pakistan.
7. Excellent support extended by the government at state or provincial levels and at

central level in both India and Pakistan for research, development and extension. Institutional support for research on technology generation, input availability, training in newer technologies, coordination and market support are key factors of success in establishment of CWPS.

8. Favourable government policies, timely policy interventions, particularly for promotion and export of textile goods and appropriate information network.
9. Liberal policies of farm credit in rural areas, schemes for farm income insurance, timely support of cheaper loans.
10. Better price realization and economic sustainability to the farmers practising CWPS.

Many lessons could be learnt from the current system in India and Pakistan and collaborative programs among interested countries will help in accelerating the agriculture growth in Asia-Pacific regions. These could be in the area of exchange of germplasm, sharing of experience in the areas of INM, IPM, etc. in cotton and wheat, which would further give a boost to R&D efforts.

The Social Sciences Institute (SSI) located at National Agriculture Research Center, Pakistan conducted field research on adoption and impact of various agriculture technologies under the Social Sciences Division of Pakistan Agricultural Research Council and studied the adoption and impact amongst several technologies of resource conservation and cotton-wheat rotation system in Pakistan (Director's Report, SSI, 2003-2004). The study explained the present status of no-till drill use and its spill over effects on farms and at household levels. The preliminary results show that almost every farmer has awareness about the new wheat planting method. The performance of zero-tillage is certainly better while pace of adoption is not so encouraging due to operational and field related problems. The impact study was specifically carried out on cotton-wheat system in Pakistan which is extremely popular in the provinces of Punjab and Sindh, particularly in the context of WTO and globalization. The impact of globalization on cotton-wheat system in Pakistan was examined through effective incentives and resource use efficiency. Two indicators *viz.*, effective rate of protection (ERP) and domestic resource cost (DRC) were used to measure the incentives and resource use efficiency, respectively. The results brought forward the fact that cotton and wheat based on cost of production can be paid more by 25-29% and 42-47%, respectively under free trade and still both the commodities shall remain competitive in international trade. The economic efficiency of both crops is good in the use of resources. Cotton and wheat growers in Pakistan have comparative advantage over others and hence the policy implications are clear that greater emphasis be laid on production strategy of cotton-wheat system through better incentives to reap the benefit from globalization of agriculture under WTO regime.

Emerging Concerns and the Way Forward

Cotton-Wheat Production System over a decade has emerged as a major cropping system which is gaining ground in the Indian sub-continent in South Asia, and in Central Asia. The system has not only proved most remunerative cropping system but also is the most sustainable too. The widespread adoptability of this system is playing an important role in changing the economy of the region. Cotton-wheat cropping system has provided a favourable option to the agrarian community to achieve both nutritional and economic sustainability. Furthermore, there has been a progressive push in the form of government support in order to meet the growing needs of cotton and wheat, both for domestic consumption as well as for export.

Over the years, the consistent and focussed research efforts have led to improvement in the system by adopting to different changes and modifications as required which have gradually resulted towards making this system sustainable. The system has evolved a holistic approach taking collectively all the components like crop rotation, no-tillage or zero till technology, integrated biological control of pests and weeds, and location-specific technologies to tackle different problems. As a result, its adoption has led to several ecological, environmental benefits - there has been reduction in soil erosion, increase in soil organic matter content, conservation of soil water, eco-friendly treatment to soil flora and fauna, minimal environmental hazards, etc.

Therefore, the new technologies, which are environmentally compatible, socially acceptable and economically viable, may be generated and disseminated among the farming communities in this region to further strengthen the CWPS technology. It is imperative to identify the gaps between the potential and actual production of cotton and devise suitable measures to fill these gaps. Further, high cost of production was one of the reasons of decline in productivity as well as the area under this crop. Various aspects of cotton production like socio-economic analysis and characterization of cotton-based system, control of leaf curl viral disease in cotton and development of protocols for mass multiplication of predators, evaluation and identification of suitable pest tolerant compact cotton varieties amenable to mechanical harvesting, evaluation of genotypes for cultivation as a spring season crop, efficacy of bio-inoculants based production systems, evaluation of tillage, residue and nutrient management practices, etc. have helped in stabilizing the CWPS.

Region specific varietal trials for particular objectives such as, evolving extra-early maturity cotton varieties/Bt variety to fit into cotton-wheat rotation in the region, testing for biotic stresses (pests and diseases) etc. and abiotic tolerance such as drought, salinity and also for fibre quality should receive the focus. Besides, effort should be made to meet the specific regional needs and for exploiting the resources available for managing the nutrients and plant protection modules. This shift would definitely lead to reduction in the cost of cultivation and enhance the eco-friendliness of the technology. With the increase in area under Bt-cotton varieties, there has been a substantial decline in pesticide application, which is a positive sign. In the regions where high yielding superior varieties are grown, the shift should be on IPM and ITK research to minimize the pressure of cotton pests and minimal use of plant protection chemicals.

The key areas requiring both international and regional cooperation in promoting/ strengthening CWPS are as follows:

- Strengthening the multi-disciplinary approaches in CWPS.
- Increased public private-partnership to receive full *benefits* of new techniques.
- Promoting inter-regional collaboration through INCANA, as far as applicable.
- Involving inter-institutional collaboration in exchange of germplasm, technologies related to seed production, cultivation technologies, efficient irrigation management, INM, IPM, IDM, IRM etc. on sharing of information and knowledge.
- HRD/capacity building and exchanges of researchers and clientele groups on different technological advancements.
- More focussed training for farmers at grassroots level to impart new techniques, use of new varieties *vis-a-vis* their package of practices and implications there of; more collaboration of research scientists and extension workers.
- Involving farmers and cooperatives in feed back and fine-tuning regional specific research efforts.
- Developing sound market system-linking farmers to markets; an emerging necessity for farmers' benefits.
- Overall more income generation to farmers, *vis-a-vis* rural development through R&D initiatives, and above all, contribution of the system to food security, poverty reduction and thus meeting the millennium development goals (MDGs).

Epilogue

Cotton-Wheat Production System (CWPS) occupies an important place in the agricultural economy of north-western plains of India and Pakistan and also several Central Asian countries. These crops contribute significantly towards economic well being of large number of people engaged in farming, trade, textile industry and processing. At present, cotton is the major foreign exchange earner through export of raw cotton, readymade garments, clothes, cotton seed by-products in the form of edible oil, oil cakes and linters. Wheat provides the necessary food security and therefore the cash-grain CWPS has classical elements of both the financial and food support and has thus become more popular. Cotton being a cash crop, has direct influence on the economy of both the countries. In recent years there has been a substantial growth in production and productivity of both cotton and wheat in CWPS area of India and Pakistan, and certainly it is the next prominent cropping system after rice-wheat in north-western India, and cotton growing area of Pakistan and Central Asian countries.

Considerable research and development efforts have gone into establishing the crops. Concerted crop improvement efforts to evolve short duration cotton varieties and use of superior agronomic technologies like zero tillage have further made the system more sustainable with increased production and productivity. Further, consistent high returns in the CWPS makes the system successful for livelihood of farmers and also changing the economy of the region.

The conventional pest management strategies rely heavily on the use of chemical insecticides in cotton-wheat belts of India. With only 5% cultivated area under cotton, nearly 50% of the total pesticides are applied. Therefore, efforts were directed to harness genetic engineering (GE) technology for bollworm resistance using *cry* gene(s) in cotton. With introduction of Bt-cotton in the cotton-wheat areas of India, a major economic transformation has occurred, which is evident from the adoption rate of Bt-cotton hybrids. Short duration, quality cotton hybrids have also been developed, which suit the double cropping of cotton-wheat rotation. Other improvements in agronomic aspects have been the adoption of zero tillage, integrated nutrient management, efficient irrigation management systems, integrated pest and disease management modules, weed management strategies etc.

The success of the system serves as an *eye* opener to several other cotton growing countries of the Asia-Pacific region that have similar prospects of double cropping and thus are shifting to Cotton-Wheat Production System. The comprehensive economic analysis of the different crop rotations followed in the region *viz*., cotton-fallow, cotton-wheat, cotton-sunflower and cotton-maize have confirmed that cotton-wheat cropping system gives the highest net returns. The success of CWPS system in India and Pakistan can be fully exploited in a collaborative manner through better networking and coordination, as there are several areas of mutual exchange which would further give a boost to R&D efforts.

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Asia-Pacific Consortium on Agricultural Biotechnology

The Asia-Pacific Consortium on Agricultural Biotechnology (APCoAB), was established in 2003 under the umbrella of the Asia-Pacific Association of Agricultural Research Institutions (APAARI)— an initiative of Food and Agriculture Organization that has been promoting appropriate use of emerging agri-technologies and tools in the region.

APCoAB's mission is "To harness the benefits of agricultural biotechnology for human and animal welfare through the application of latest scientific technologies while safeguarding the environment for the advancement of society in the Asia-Pacific Region".

APCoAB's main thrust is:

- To serve as a neutral forum for the key partners engaged in research, development, commercialization and education/learning of agricultural biotechnology as well as environmental safety in the Asia-Pacific region.
- To facilitate and promote the process of greater public awareness and understanding relating to important issues of IPR's *sui generis* systems, biosafety, risk assessment, harmonization of regulatory procedures, and benefit sharing in order to address various concerns relating to adoption of agricultural biotechnology.
- To facilitate human resource development for meaningful application of agricultural biotechnologies to enhance sustainable agricultural productivity as well as product quality, for the welfare of both farmers and consumers.

ASIA-PACIFIC ASSOCIATION OF AGRICULTURAL RESEARCH INSTITUTIONS

The Asia-Pacific Association of Agricultural Research Institutions (APAARI), established in 1990 at the initiative of FAO, is an apolitical, neutral, non-profit forum of Agricultural Research Institutions, National Agricultural Research Systems (NARS) in the Asia-Pacific region, in the pursuit of common objectives.

The 'Mission' of APAARI is to promote the development of national agricultural research systems in the Asia-Pacific region through facilitation of intra-regional and inter-institutional, and international co-operation/ partnership.

The overall objectives of APAARI are to foster agricultural research for development in the Asia-Pacific region so as to help address the concerns of hunger, poverty, environmental degradation and sustainability of agricultural production. More specifically, the objectives are as follows:

a. Promote the exchange of scientific and technical know-how and information in agriculture;

b. Encourage the establishment of appropriate co-operative research and training programs in accordance with identified regional, bilateral or national needs and priorities;

c. Assist in prioritizing NARS/Regional needs, strengthening of research organizational and management capabilities of member institutions including information and communication technology;

d. Strengthen cross-linkages among national, regional and international research centers and organizations, including universities, through involvement in jointly planned research and training programs; and

e. Promote collaborative research among member institutions including need based support to regional research networks.