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Vision 2030

Central Institute for Cotton Research
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सत्यमेव जयते
डा.एस.अय्यप्पन
सचिव एवं महानिदेशक

Dr. S. AYYAPPAN
SECRETARY & DIRECTOR GENERAL

भारत सरकार
कृषि अनुसंधान और शिक्षा विभाग एवं
भारतीय कृषि अनुसंधान परिषद
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FOREWORD

The diverse challenges and constraints as growing population, increasing food, feed and fodder needs, natural resource degradation, climate change, new parasites, slow growth in farm income and new global trade regulations demand a paradigm shift in formulating and implementing the agricultural research programmes. The emerging scenario necessitates the institutions of ICAR to have perspective vision which could be translated through proactive, novel and innovative research approach based on cutting edge science. In this endeavour, all of the institutions of ICAR, have revised and prepared respective Vision-2030 documents highlighting the issues and strategies relevant for the next twenty years.

Cotton is a commercial crop that plays an important role in strengthening economy of 82 countries across the world. In India, apart from providing 60% of the fibre used in textile industries, the crop is also a source for 11.5 lakh tonnes of oil, 90 lakh tonnes of animal feed and about 200 lakh tonnes of cotton stalk that is used for fuel and value addition as particle boards. Changing consumer preferences and spurt in non-textile uses of cotton are also leading to emergence of niche demand supply chain. The private sector is today investing strongly into research into next generation transgenics, hybrid seed production in the plant protection arena. The Central Institute for Cotton Research, Nagpur must keep pace with the fast changing scenario and bring about a paradigm shift in the R&D focus in public sector cotton research under the NARS. It is also time to connect research innovations to the needs of stakeholders in the entire cotton value chain.

It is expected that the analytical approach and forward looking concepts presented in the '*Vision 2030*' document will prove useful for the researchers, policymakers, and stakeholders to address the future challenges for growth and development of the agricultural sector and ensure food and income security with a human touch.

Dated the 17th June, 2011
New Delhi

(S. Ayyappan)

Preface

Cotton symbolizes civilization. Cotton clothes mankind. Cotton epitomizes a beautiful story and saga of how man converted a simple natural fiber into thread, fabric and apparel through technological innovations. And, to think that the story began in ancient India is humbling. The fibers still pass through the feeble hands in remote Indian villages to spin thread and weave into dreams that we wear. That the world's finest ever fabric found in Mohenjodaro excavations, was woven from the *Desi* species *Gossypium arboreum*, that we call today as 'coarse fiber' stands mute testimony to the brilliance of Indian ingenuity, art and skill that mankind can be proud of. The finest Dhaka muslins and the calicoes of India were made from *Desi* cotton.

Cotton made markets. Cotton shaped industries. Cotton built empires. Cotton caused revolutions. Cotton even today brings prosperity to richest nations and also buys food for the poorest countries. In a global market economy, cotton is one of the few commodities that every nations desires to possess. India was a global leader in cotton fabrics. Can we aspire to become global leaders again? Dr Abdul Kalam said 'you have to dream before your dreams can come true'. In the process of making our dreams come true, can we lead our cotton farmers into perpetual prosperity? How best can we move towards producing pollution free cotton? In this path towards global leadership, can we cultivate cotton that is close to nature and is in full consonance with ecology and environment?

Technologies have been driving cotton all through history. In recent times, global investment in cotton biotechnology has increased tremendously and has been making a lasting global impact. India needs to catch up, and we believe that we can. With smart thinking, strategic planning, appropriate investment and sincere scientific efforts, India can place the cotton farmer on the pedestal of global leadership. Now is the time to introspect back into time and envisage into the future of what our next generation can acknowledge with gratitude. Now is the time to plan. This vision document was made with a passion to lay the path towards inclusive growth. We earnestly hope that we find the way forward towards agrarian and value chain industrial prosperity through our vision and mission for Indian cotton.

Dr S. Ayyappan, Secretary DARE & DG, ICAR and Dr S. K. Datta DDG (CS), ICAR have been inspirational to plan and dream. I express my heartfelt gratitude to them. I thank Dr N Gopalakrishnan, ADG (CC), for the silent, sincere and strong support for all our endeavors. Dr M. V. Venugopalan, Principal Scientist and Dr M. S. Yadav deserve special mention for the superb support. All the scientists of CICR added hues to this canvas of dreams called 'Vision 2030'. I would like to thank each one of them. I am confident that this collective wisdom will lead us into a prosperous future for the Indian farmer and value chain industry that is built predominantly on indigenous Indian science and technology.

K. R. Kranthi
Director, CICR

Preamble

If vision is clear, it is choice and not chance that determines destiny. India has always been a land of thinkers, dreamers, visionaries and workers. A vision for the next twenty years could be a roadmap of dreams that can shape the destiny of India to become the global leader. We do have a choice to dream big. But, can we dare to dream? And, if we have the courage to dream big for cotton research and development in India, what will the vision be to make the dreams come true?

The demand for cloth will exist as long as civilizations exist. Though 60% of the global fabrics are made from man-made synthetic fibers, and the proportion might further increase, cotton, with a share of 35.8% in fabrics, continues to remain as the most skin friendly of all apparel available to mankind. During the last decade, the share of cotton came down from 39.0% to 35.8%. The global cotton production in 2010 was 25.1 M tons (1476 lakh bales of 170 kg/bale) from 34.0 M hectares. India has the largest acreage at 33.0% and 21.1% share of production. With population at 6.8 billion in 2010, the average per-capita utilization of fibers is estimated to be 10.4 kg. The global production of fibers increased from 52.0 M tons in 2000 to 72.5 M tons in 2010 at an average growth rate of 3.3% and is expected to reach 138 M tons by 2030. The world population is estimated to increase at an annual growth rate of 1.4% to reach 8.2 billion by 2030. It is being speculated that the declining supply of raw materials and oil reserves in the future will constrain man-made fiber production and the demand for cotton will increase. If the growing population has to be sustained, food production would have increased at least to 40% by 2030, by increasing land area under food crops, with concomitant decrease in area under cotton. Thus, man-made fibers would be in short supply and, there would be a crisis for cotton. The global demand for cotton would be about 48.0 M tons by 2030, at the existing share of 36.0% of the total fiber. The cotton demand would be higher, if the petroleum reserves become a limiting factor for the production of man-made fibers. Global cotton production reached a peak of 19.0 M tons in 1984 and fluctuated between a range of 16.0 to 21.0 M tons for 20 years until 2003. From 2004 onwards until 2010, cotton production continued to be relatively higher at 23 to 27 M tons. To produce 48.0 M tons in 34.0 M hectares (without reducing the current area) is a huge challenge. Since 33.0% of the global cotton area is in India, and the current yields (500 kg/ha in 11.1 M ha) are significantly lower compared to the four major cotton growing countries China (1300 kg/ha in 5.4 M ha), USA

(900 kg/ha in 4.0 M ha), Pakistan (700 kg/ha in 3.2 M ha) and Brazil (2027 kg/ha in 1.0 M ha), there is immense scope for yield enhancement in India, and this increase will have the greatest impact on global supply. The recent increase of production from an average of 3.0 M tons in 1992-2002 to 5.1 M tons after 2004 in India signals hope and provides evidence that, new technologies can drive the change. With the threat of climate change looming large, natural resources becoming more scarcer by the day, burgeoning population, shrinking land holdings, ever-rising cost of inputs, public sector research plans and vision for the future becomes immensely challenging. Though as harbingers of hope, the efforts and contribution of Indian farmers, traders, scientists and Government agencies, have been spectacular, much of the technological inputs in the form of transgenic Bt-cotton, chemical pesticides, fertilizers, were derived from multinational companies. If India has to emerge as the global leader in a sustainable manner with farmers garnering the benefits of such leadership, it is imperative that the growth is driven by indigenous innovations which can be used with sovereignty.

Contents

Cotton Scenario

Cotton is an immensely important crop for the sustainable economy of India and livelihood of the Indian farming community. It is cultivated in about 32.0 M hectares across the world and in about 10.0 M hectares in the country. India accounts for about 32% of the global cotton area and contributes to 21% of the global cotton produce, currently ranking second after China. India's contribution to global cotton production increased from 14% in 2002 to 20.5% in 2007. The production increased from a meager 2.3 M bales (170 kg lint/bale) in 1947-48 to a previous record production of 17.6 M bales in 1996-97 and an all time highest record of 31.5 M bales during 2007-08 and 2010-11. Cotton contributes about 65% of the total raw material needs of textile industry in India. Cotton and Textile exports account for nearly one-third of total foreign exchange earnings of India, each year at an estimate of Rs.750 billion in 2007. India has achieved significant breakthrough in cotton yarn exports besides increasing its global market share in cotton textiles and apparels. Cotton provides employment and sustenance to a population of nearly 42 M people, who are involved directly or indirectly in cotton production, processing, textiles and related activities. It is estimated that more than 6.0 M farmers cultivate cotton in India and about 36 M persons are employed directly by the textile

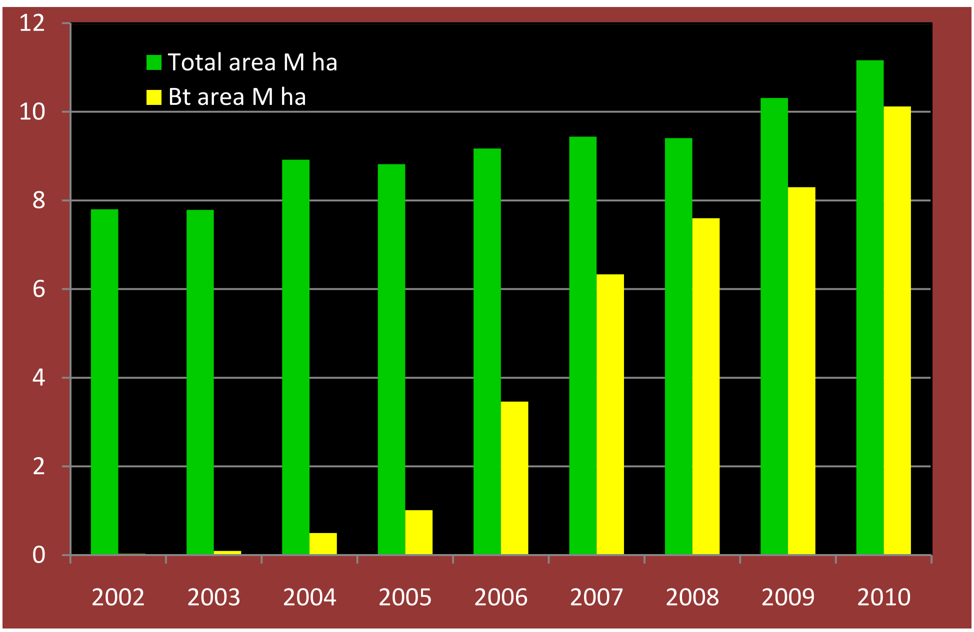
India accounts for about 32% of the global cotton area and contributes to 21% of the global cotton produce.

industry. There are more than 1.7 M registered looms, 1500 spinning units, and an estimated 280 composite mills. Therefore cotton production in India is considered to have a wide reaching impact not only on the livelihood of farmers and economy of the country, but also on international trade.

> India has the unique distinction of being the only country in the world to cultivate all four cultivable Gossypium species…

India has the unique distinction of being the only country in the world to cultivate all four cultivable *Gossypium* species, *Gossypium arboreum* and *G. herbaceum* (Asian cotton), *G. barbadense* (Egyptian cotton) and *G. hirsutum* (American upland cotton) besides hybrid cotton. There are a total of 50 *Gossypium* species in the world, comprising 45 diploid (2n=2x=26) and five allotetraploid (2n=4x=52) species distributed throughout the arid and semi-arid regions of the Africa, Australia, Central and South America, and the Indian sub-continent. Of the 50 *Gossypium* species, only four are cultivated commercially. *Gossypium hirsutum* represents 90% of the hybrid cotton in India and all the current Bt cotton hybrids are either *G. hirsutum* or inter-specific hybrids with *G. barbadense*. *G. hirsutum* L. (American cotton) and *G. barbadense* L. (Egyptian cotton) have superior fiber quality. *G. hirsutum* L. is most widely cultivated because of its wide range of adaptation and high yield potential, whereas *G. barbadense* L. has fine and unique fiber quality. *Desi* cottons have coarse and short fibre.

Area under Bt Cotton in India



Cotton in India is grown in varied soils, climates, and agricultural practices under irrigated and rainfed situations. Approximately 65% of India's cotton is produced under rainfed conditions and 35% on irrigated lands. It is cultivated in three distinct agro-ecological zones (north, central and south) of the country. The northern zone is almost totally irrigated, while the percentage of irrigated area is much lower in the central (23%) and southern zones (40%). Under the rainfed growing conditions rainfall ranges from <400 to > 900 mm coupled with aberrant precipitation patterns over the years leading to large-scale fluctuations in production. Cotton in North India is grown in about 1.5 M hectares in the three states, Punjab, Haryana and Rajasthan. Cotton area in Gujarat increased from 1.54 M hectares in 2000 to 2.6 M hectares in 2010. About 36% of the area (3.9 M hectares) under cotton is in Maharashtra, primarily under rainfed conditions, with the lowest area (3-4%) under irrigation. In 2010, Madhya Pradesh had 0.65 M hectares under cotton. Karnataka grew cotton in 0.52 M hectares, Tamilnadu in 0.13 M hectares and Andhra Pradesh in 1.74 M hectares.

Global Cotton Scenario The global cotton production increased significantly over the past 5 years. During 2010 a total of 25,185,000 metric tons (148 M bales, 170 kg/bale) were produced. Among the six major cotton growing countries, Brazil (2027 kg/ha) holds highest productivity level followed by China (1311 kg/ha), USA (945 kg/ha), Uzbekistan (859 kg/ha), Pakistan (684 kg/ha) and India (478 kg/ha).

Projected that consumption of cotton by the Textile Industry at 41.3 M bales by 2019-20, an increase of 68% over the estimated cotton consumption by the textile industry in the current year

India ranks first in terms of cultivated area occupying 32% of the world cotton area followed by China, USA and Pakistan. Before five years global cotton production had reached a plateau of 19 to 20 million metric tons (111.7 to 117.6 M bales) during 1990 to 2002. Brazil, China and India rank the best amongst countries which made significant progress during 1999 to 2009. China made spectacular progress with an impressive increase to 47.5 M bales in 2007 from 22.9 M bales in 1999. Brazil, which produced 3.0 M bales in 1998, increased its production to 9.4 M bales in 2007. Similarly, India doubled its production from a stagnating 15.8 M bales in 2001 to 31.5 M bales in 2007. The area under cotton in USA and Australia has been declining significantly over the past few years. The area in USA declined to 3.3 M hectares in 2008 from 5.7 M hectares in 2005. Similarly, the cotton area in Australia was 0.55 M hectares in 1999, but decreased to a mere 63,000 hectares in 2007. India's growing cotton is having a perceptible impact on the global import-export scenario. The country has been producing at least 6 to 9 M bales in excess of domestic consumption over the past few years. India became a leading global exporter of raw cotton with exports ranging from 0.6 to 1.5 M tons raw cotton each year from 2005 onwards, while concomitantly, imports declined from 0.43 M tons to 0.09 tons. Domestic consumption also increased from 15.8 M bales in 2002, to an estimated 25.8 M bales in 2010. The Draft National Fiber Policy 2010-20 has projected the consumption of cotton by the Textile Industry at 41.3 M bales by 2019-20, an increase of 68% over the estimated cotton consumption by the textile industry in the current year. Prior to 2002 long

staple cotton production was only 38% of the total cotton, but the proportion increased to 85% by 2010.

Global cotton production 2008-2010

	Area M ha			Production '000 Tons			Yield Kg/ha		
Country	2008	2009	2010	2008	2009	2010	2008	2009	2010
China	6.4	6.4	5.4	8025	6850	7079	1263	1070	1311
India	9.3	10.3	11.1	4930	5015	5304	533	487	478
USA	3.2	3.1	4.2	2790	2654	3970	880	856	945
Pakistan	2.9	3.1	3.2	1910	2019	2188	659	651	684
Brazil	1.0	0.9	1.0	1400	1261	2027	1443	1401	2027
Uzbekistan	1.4	1.3	1.2	1140	850	1031	800	654	859
others	7.5	5.1	6.9	3900	3317	4133	519	650	599
World	31.6	30.2	33.0	24660	21966	25185	781	727	763

Source: ICAC Cotton: World Statistics, September, 2010

India: The cradle of the world's finest cotton fabrics

Archaeological evidences from Harappa civilization (2300-1750 BC) clearly showed that Indian civilization had developed highly sophisticated textile craftsmanship. The world famous Indian Dhaka muslins were woven from the Indian *Desi* tree species *Gossypium arboreum* with mean fibre length of 18-24 mm, but the yarn was one of the finest ever heard of 345-356 counts. For over centuries, the Indian Dhaka handloom muslins ruled the world textile trade. The British East India Company which was established in 1615 in India started exporting 'Calicoes' and Dhaka muslins to Britain. The British Parliament passed the 1721 AD act prohibiting Calicoes and import of cotton textiles from India, so that the wool industry in Britain could be protected from a total collapse. Textile industrialization started in the 18th century, but the spinning frames invented for high speed spinning were suited for American cotton *Gossypium hirsutum* of medium staple length and good strength. Soon Britain established itself as the world's leading manufacturer and exporter of cotton fabrics and garments, using imported raw cotton from America. The American Revolutionary War during 1775-83 caused shortage of raw American cotton exports to England. Since India was the second largest cotton producer in the world after America, the British immediately considered India as an alternative option to cultivate American cotton to cater to their textile mills.

The world famous Indian Dhaka muslins were woven from the Indian *Desi* tree species *Gossypium arboretum* with mean fibre length of 18-24 mm, but the yarn was one of the finest ever heard of 345-356 counts.

The American cotton var Bourbon *G. hirsutum, punctatum* race was introduced from Malta and Mauritius into Bombay and Madras Provinces of India in 1790. Subsequently efforts were intensified to improve and promote the cultivation of American cotton in India. Since India had cheap labour, the British set up spinning mills in Calcutta (1814), Bharuch (1843) and Mumbai (1854) and starting putting efforts in improving American cotton in India to suit their mills. *G. hirsutum* (*latifolium* race) Var New Orleans was introduced in Gujarat, Deccan & Konkan in 1840. In the meantime, the British discovered that it was possible to grow G. hirsutum (Bourbon) in some parts of south India such as Dharwad and Hubli. By 1862, 72,313 ha *G. hirsutum* was grown in Hubli successfully. However, *G. hirsutum* was still not successful in Punjab. In 1905, *G. hirsutum* Var Cambodia was introduced successfully into Madras Presidency. By this time, seeds called 'Punjabi Narma' (Bourbon, *G. hirsutum*) were found to have established in parts of Punjab. Experiments in Uttar Pradesh from 1826, established Cawnpore-American variety in 1909. In 1912, Milne selected a variety '4F', resistant to jassids from Punjabi Narma, which was grown in 72,846 ha out of 1,11,697 ha under American cotton in Punjab. In a landmark development, Sardar Labh Singh developed a late maturing jassid resistant variety LSS (Labh Singh Selection) from F4 in 1933, which became very popular. But these varieties were of long duration and caused inordinate delays in sowing of wheat as the next crop. In 1920-29, Hilson and Ramanatha Iyer released Co.1 and Co.2 from Cambodia cotton for cultivation in south India. Egyptian cotton or Sea Island cotton, *Gossypium barbadense* was also introduced around 1790, but was able to get acclimatized only by 1940. It is interesting to note that it took about 60-70 years for *G. hirsutum* and 150 years for *G. barbadense* to adapt to the Indian climatic conditions.

Research and Development in Post Independent India

Prior to Independence, undivided Indian subcontinent produced 5.0-5.3 M bales from 8.5 to 9.0 M hectares. When the country gained independence, 2.3 M bales comprising of 67% medium staple and 33% short staple cotton was obtained from *desi* varieties cultivated in 97% of the area (65% *G. arboreum* and 32% *G. herbaceum*) were produced from 4.3 M hectares. During partition, the cotton mills remained in India and the regions that were suitable for long staple cotton went to Pakistan. Therefore efforts were intensified in India to produce long staple cotton that suited the mills. By 1965, 40% of the area was under *G. hirsutum*, 36% under *G. arboreum* and 24% under *G. herbaceum*. Despite intense

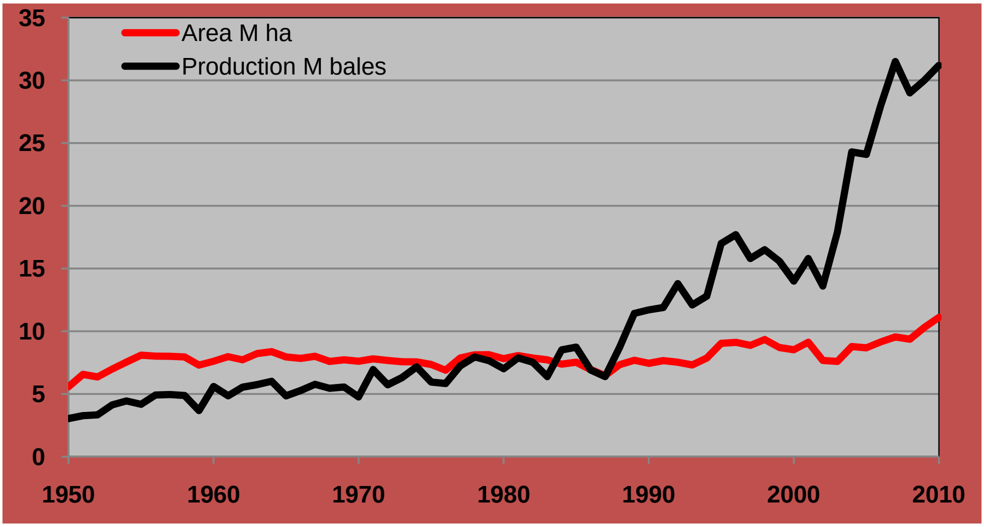
and concerted efforts to acclimatize and promote American cotton in India, the two *Desi* species continued to occupy at least 25% of the area (18% of *G. arboreum* and 7% of *G. herbaceum*) until 2000-2001, until recently before the introduction of Bt cotton in India. The American cotton varieties *G. hirsutum* and Sea Island cotton, *G. barbadense* are more susceptible to insect pests such as jassids, whiteflies, American bollworm (*Helicoverpa armigera*) and diseases such as bacterial blight, *Verticillium* wilt, parawilt and leaf curl virus. The American bollworm derived its name from the fact that it was first noticed only on American cotton *G. hirsutum*, and still continues to cause menacing damage to the species. By virtue of having been cultivated for ages, the two *desi* species *G. arboreum* and *G. herbaceum*, are known to tide over biotic and abiotic stresses with ease under the native conditions. Therefore these were preferred by farmers over the introduced cotton species. Currently (2011) about 93% of the area is under *G. hirsutum.*

Landmark achievements in cotton breeding

Though continuous efforts were underway to acclimatize American cotton to Indian conditions, systematic efforts on cotton breeding in India started with the establishment of the 'Department of Agriculture' in 1904 and Indian Central Cotton Committee in 1923. However research on improvement of *G. hirsutum* varieties and hybrids intensified after the establishment of the All India Coordinated Cotton Improvement Project in 1967. Until 2001, about 100 improved varieties and 50 hybrids of cotton in all the four species were released for commercial cultivation in all the cotton growing states of the country. Indian breeders have been credited for their achievements particularly in the development of highly adaptable varieties such as Bikaneri Narma, LRA 5166, Narasimha, SRT 1 and MCU 5; early maturing varieties, sucking pest tolerant varieties, disease resistant *Desi* cotton varieties, high yielding and superior fibre quality varieties of *G. arboreum and G. herbaceum,* development of inter-specific and intra-specific Hybrid cotton, development of high yielding *G. hirsutum* varieties and the development of finest quality *G. barbadense* variety Suvin. One of the most spectacular achievements that stands out as a technology that had the greatest influence on cotton in India is the hybrid cotton. In a landmark development, the world's first cotton hybrid 'H 4' (intra *hirsutum*) was developed by Dr C. T. Patel in India. The hybrid became popular and laid the foundation for research on 'hybrid cotton'. Until 2001, hybrids occupied 45% of the total cotton area and reached about 95% in 2011. There have been several landmark achievements made by cotton breeders in India after independence. Some of the significant ones which represent pioneering efforts are listed below:

1950:	*Gossypium herbaceum* variety 'Jayadhar' released (cultivated even today)
1968:	*Gossypium hirsutum* variey 'MCU-5' 60s counts released (finest quality *G. hirsutum* variety)
1970:	World's first Hybrid 'H-4' released (highest yield with superior fiber traits)
1972:	World's first Inter specific tetraploid hybrid 'Varalakshmi' 80s counts released
1974:	*Gossypium barbadense* variety 'Suvin' 120s counts released (finest Indian variety ever)
1976:	Bikaneri Narma and its selections 'F-414' and 'H-777' identified for adaptability and high yields in North India.
1978:	World's first GMS based hybrid 'Suguna' released from CICR
1980:	Hybrid 'H-6' with superior fiber quality of 60s counts released.
1981:	Inter specific tetraploid hybrid 'DCH-32' 80s counts released (cultivated even today)
1982:	Highly adaptable *Gossypium hirsutum* variety 'LRA-5166' released (high adaptability)
1983:	World's first Inter-specific diploid hybrid 'DH-7' released
1983:	Highly adaptable hybrid 'NHH-44' released for rain-fed conditions
1992:	Early maturing compact variety 'LRK-516' released
1989:	*Gossypium arboreum* variety 'AKA-8401' 40s counts released
2000:	40% areas under hybrid cotton
2002:	Bt-cotton approved for commercial cultivation. Subsequently, several superior Bt hybrids, Mallika, Bunny, MRC-6301, MRC-7351, Dr Brent, Bramha, RCH-2, RCH-134, Ankur-651, Jay Bt, MRC-6301, Ajeet-11, Tulasi-9, Vikram-5, Krishidhan-441, Bioseed-6488, Kaveri-707 etc., were released for commercial cultivation from the private seed sector.
2008:	Highly adaptable superior fibre variety 'Suraj' released
2010:	90% area under 809 Bt-hybrid cotton varieties.

Indian cotton improvement 1950 to 2010:



India has the unique distinction of being the only country in the world that has commercial hybrid cotton hybrids. The current hybrid area is estimated to have reached 90% of the total area under cotton, thereby creating a record of sorts, of being the only country with such a large acreage under hybrid cotton. During the period 1970-2010 about 50 hybrids from public research institutions and more than 800 hybrids from the private seed companies were released for commercial cultivation. Though north India was completely covered under varieties until 2005, the release of Bt hybrids for the region suddenly changed the profile and more than 90% of the area came under Bt hybrids by 2010. Currently about 20-30 Bt hybrids are very popular in the country and have contributed to the increase in the

long staple fibre from a meager 4.5 M bales of long staple cotton in 2001 to 20.0 M bales of long staple cotton in 2007.

Genetically Modified Cotton

Genetically Modified (GM) cotton, popularly known in India as 'Bt-cotton' was first developed and commercialized by the US multinational company, Monsanto, and later, by several other multinational companies such as Syngenta, Bayer, Dow, also by CAAS (Chinese Academy of Agricultural Sciences) and Indian companies such as JK seeds and Metahelix. A bacterial gene *cry1Ac* was isolated from a soil bacterium *Bacillus thuringiensis*, and introduced into the cotton genome through genetic engineering using a bacterium, *Agrobacterium tumifasciens* to develop commercial GM cotton called 'Bollgard'. Bollgard-Bt-cotton with *cry1Ac* was first cultivated in the US during 1996 and was released in China and Australia in 1997. Later it was released in Mexico, Colombia, Indonesia, Argentina, South Africa, and India. Currently an estimated 14.5 M hectares are under Bt cotton in 13 countries. This accounts for 42% of the total global cotton area. Recently, several other genes such as protease inhibitors, Vip3A, Cry1C, Cry2Ab and Cry1F have been used for the development of GM cotton and are being used for the control of cotton bollworms and other leaf feeding caterpillars. Extensive studies in accredited laboratories in India and across the globe showed that Bt genes are specifically toxic to insect pests and have high level of safety to non-target organisms such as beneficial insects, birds, fish, animals and human beings.

> The biggest gain from the Bt Cotton was in the form of reduced insecticide usage from 46% in 2001 to 21% during 2009 and 2010…

After intensive biosafety studies and extensive field trials under the regulatory system of RCGM (Review Committee on Genetic Manipulation) and GEAC (Genetic Engineering Approval Committee), Bt-cotton technology was first approved in 2002 by the GEAC for commercial cultivation in central and south Indian cotton–growing zones in India, and later in 2005 for cultivation in north India. 'Bikaneri Narma-Bt' was developed by UAS, Dharwad, and NRCPB, New Delhi and commercialized by CICR in 2009 after approval by the GEAC in 2008.

During the decade prior to 2002, cotton production and economy in India was in constant crisis due to insecticide resistant bollworms which were responsible for excessive use of insecticides at about 50% of the total insecticides used in the country coupled with constant low production and stagnant productivity of 15.0 to 17.7 M bales. Subsequent to 2002, after the introduction of Bt-cotton, the scenario has changed. It is beyond doubt that Bt cotton has been playing a major role in effectively protecting the crop from bollworms, especially the American Bollworm, *Helicoverpa armigera*, thus preventing yield losses. The biggest gain from the technology was in the form of reduced insecticide usage from 46% in 2001 to less than 26% after 2006 and 21% during the last two years 2009 and 2011. The reduction in insecticide usage in India from Rs 7180 M in 2004 for cotton lepidopteran caterpillars to Rs 1100 M, with only Rs 230 M for the control of American bollworm in 2010, can be seen as a spectacular achievement of Bt cotton technology. Over the past five years there has been a significant leap in the production. During 2004 and 2005 India produced about 24.0 M bales each year, 27 M bales in 2006 and 31.5 m bales during 2007-08. However, apart from the contribution of Bt cotton, the increase in yield may have also been due to other major changes in the past 8 years. Some perceptible changes include, implementation on IPM and IRM on a large scale by the Ministry of Agriculture and ICAR, the introduction of some excellent cotton hybrids, increase in cotton area in Gujarat from 1.5 M ha to 2.6 M ha, increase in check dams and drip irrigation systems, increase in hybrid cotton area from 40% to 90% and introduction of 6-7 new effective insecticide molecules for bollworm control and sucking pest management. Though bollworm damage declined, the changes in pest management systems with reduction in pesticides and introduction of several new Bt hybrids, most of which were highly susceptible to insect pests and diseases, has resulted in increased damage of sucking pests such as jassids, white flies, thrips mealy bugs and miridbugs. As a consequence of this, insecticide usage which had declined from Rs.10520 M in 2001 to Rs.5790 M in 2006, increased gradually to Rs.8804 M by 2010. It is interesting that the usage of fungicides and herbicides also increased significantly over the past 5 years. With the advent of herbicide resistant cotton such as RRFLex (Round-up ready Flex) that tolerates glyphosate and glufosinate resistant cotton, the use of post-emergence application herbicides is likely to increase further.

Pesticide usage (Rs Million) on cotton

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Insecticides on cotton	8390	10520	5970	9250	10320	6490	5790	7330	7906	8337	8804
Fungicides on cotton	96	64	34	78	60	85	111	248	315	522	669
Herbicides on cotton	15	10	5	34	39	78	118	215	261	455	869
Total Insecticides in Agrl.	20520	22680	16830	21460	24550	20860	22230	28800	32820	39090	42830
Total Pesticides in Agrl.	29725	32070	26223	31474	35814	24388	33960	46970	529330	69988	76836

Source: Pesticide Industry

Insecticide use on cotton was 46% of the total insecticides used in India in 2001 and before, but soon declined to 25% within 4 years of Bt cotton introduction. Insecticide usage on cotton further declined to only 21% of the total usage in India during 2009 and 2010.

Emerging challenges

Though, India ranks second in the world in cotton production after China, even its best productivity of 566 kg/ha, places it at 24th rank in the list of 80 cotton producing countries. Despite the good progress made by public and private sector research and development, it is a matter of concern that productivity started to decline from 566 kg/ha in 2007 to 522 kg/ha in 2008, 486 kg/ha in 2009 and 475 kg/ha in 2010. Several factors including erratic rainfall and emerging biotic and abiotic stress were found to have influenced the decline in yields. The quality profile of Indian cotton has also changed. Long staple cotton which constituted 38% prior to 2002, increased to an estimated 85% of the total cotton produced in 2010, primarily because of the Bt cotton hybrids, most of which are of the long staple category. However, the Confederation of Indian Textile Industries (CITI) estimates that in the 25.8 M bales utilization capacity, the current requirement of the Indian textile Industry is 37% long and extra-long staple cotton, 53% medium staple and 10% short staple. The area under public research bred varieties and hybrids reduced significantly to less than 8% of the total cultivable area. The area under hybrid cotton increased from 40% in 2002 to 92% in 2010. The area under *G. hirsutum* varieties was 33% in 2000 which reduced to less than 3% in 2009. The area under *G. barbadense, G. arboreum* and *G. herbaceum* which was 6.6%, 25% and 13% during 1995, declined to less than 7% in 2010 for the three species together. With intensive selection pressure of Bt toxins used in more than 90% area of Bt crops, and less adoption of refugia and declining area of inter crops in cotton cropping systems, development of bollworm resistance to the Bt toxins is an emerging concern. Resistance has the potential to diminish the benefits of Bt cotton.

In the current scenario, with Indian exports gaining importance, there is a need to reorient research efforts to ensure that the advances made thus far in enhancing productivity levels should be sustained. Export potential for raw cotton as well as value added products will be enhanced thereby increasing our foreign exchange earnings. There will be modernization for ginning, pressing, spinning and textile industry. Breeding for improved fibre qualities as per emerging needs will receive due attention. There will be competitive pricing, grading and better marketing for cotton at national and International level. Appropriate initiatives must be taken up to face the new situation. However, with the cotton production challenged by vagaries of monsoon, onslaught of insect pests and increasing cost of production there is need for reorientation and reinvention of resources. The arena of pest management adds the dimensions of ecological and economic sustainability besides social stability. Cotton cultivation in India has changed immensely over the past five years. There has been a significant change in technologies related to production, crop protection, crop improvement, extension methods, approaches and socio-economic aspects. While, the introduction of genetically modified cotton, in the form of insect resistant Bt cotton, has been credited with the changes, it is prudent at this stage to critically examine factors other than Bt cotton that may

Cotton in North East India

have also contributed to the positive change and develop strategic plans for discovery and deployment of indigenous genes through genetic engineering technologies to enhance yields with low input costs.

Intensive plant breeding programs of many crop plants have capitalized on genetic resources and germplasm collections to develop improved genotypes with significant gains in yield. These intensive hybridization and selection plant breeding programs have also unintentionally narrowed the genetic base and increased genetic vulnerability of many of the world's most important crops. The fact that it took about 60-70 years for *G. hirsutum* and 150 years for *G. barbadense* to adapt to the Indian climatic conditions indicates that probably Indian researchers were making a mistake by trying to identify genotypes for wider adaptability. It is clear that each of the individual cotton genotypes has a specific photoperiod and thermal requirement for optimal performance. Therefore it would be most appropriate to identify individual highest yielding genotypes for extremely specific geographical zones that have a common photo and thermal profile across the season. In the process of attempts to identify common genotypes for the entire zone or the country, it is clear that every year a number of varieties that were submitted for varietal identification were discarded, since their performance would have been inferior in a few locations. Currently private seed companies have taken the lead in hybrid cotton sector. Hybrid seed production is expensive and highly labour intensive. It is praise worthy that the seed industry has been meeting the challenge effectively and profitably. At this juncture, it would be most appropriate for the public funded institutions to develop high yielding varieties for specific local geographical spots and convert them to Bt using the approved events that have been developed by the Government institutes. With the strength of the current germplasm pool and new molecular technologies, it would be possible to develop location specific genotypes that have the potential to yield 3-4 times more than the current productivity, almost comparable to the normal yields that are obtained by varieties elsewhere in the world.

National Agriculture Research System on Cotton

The Central Institute of Cotton Research, Nagpur under ICAR is a premier institute on cotton research that conducts and also coordinates basic strategic and applied research and development activities on cotton to enhance productivity and profitability of cotton farmers and the value chain associated with cotton. The institute through its regional stations at Sirsa and Coimbatore caters to the research needs of the country. The All India Coordination Cotton Improvement Project (AICCIP), located at the CICR regional station, Coimbatore operates through a network of 12 agricultural universities at 11 main centres and 10 sub centres. The Central Institute for research on cotton technologies, CIRCOT, Mumbai is one of the ICAR institutes that is closely associated with CICR in research and assists the institute with evaluation of fibre quality parameters of newly developed materials.

Mandate

- To conduct basic and strategic research on cotton to improve yield, fibre quality and by-products.
- To create new genetic variability for location-specific adoption in cotton-based cropping systems.
- To assist in the transfer of modern cotton production technology to various user agencies.
- To extend consultancy and link with international agencies to accomplish the above mandate.

Major Research Contributions of CICR

The institute has been recognized all over the world for its outstanding work on plant breeding, crop improvement, development of Bt-cotton, development of immunological diagnostic kits, basic research on insect resistance to insecticides

Cry toxins and xenobiotics, development and dissemination of IRM (Insecticide Resistance Management) and IPM (Integrated Pest Management) technologies for conventional and Bt-cotton. CICR has developed and released 26 improved genotypes including twelve varieties of *Gossypium hirsutum* (MCU 5 VT, LRA 5166, Supriya, Kanchana, Anjali, CNH 36, Arogya, Surabhi, Sumangala, CNH 120 MB, Suraj and CNHO 12), two varieties of *G. arboreum* (CISA 310, CISA 614), one variety of *G. barbadense* (Suvin), eight intra-*hirsutum* hybrids (Suguna, Savitha, Surya, Kirti, Om Shankar, CSHH 198, CSHH 238 and CSHH 243), two interspecific (*G. hirsutum* x *G. barbadense*) hybrids (HB 224, Shruti) and one intra-*arboreum* hybrid (CISAA 2). The institute has the world's largest germ-plasm collection and a large collection of wild species. Several other innovative aspects of useful research include the discovery of apomixes, cleistogamy, temperature sensitive male sterility and five-loculed genotypes. Under the Diversification and utilization of male sterility system, 82 genotypes were converted under CMS background, 66 genotypes were converted under GMS background. 12 GMS based hybrids were found to be promising in AICCIP trials. The institute has developed several other transgenic events including *Desi*-Bt-cotton incorporating *cry1Ac*, *cry1F* and *cry1Aa3* into *G. arboreum* and *G. hirsutum* cotton. The institute played a stellar role in supporting research for the introduction and popularization of Bt-cotton in India. Recently, three lectins have been identified by the institute as promising candidate genes for the control of sap-sucking insect pests (aphids, jassids, whiteflies). Two new bio-pesticide formulations, mealy-kill and mealy-quit were developed for the control of mealybugs and sucking pests. The institute scientists developed package of practices, poly-mulch techniques, multi-tier cropping systems, innovative inter-cropping systems and several other crop production strategies to optimize input use and maximize benefits from Bt-cotton. The institute has developed many implements and devices including a planter, battery operated sprayer, which have been commercialized. Several Indian patents and three international patents have been granted in South Africa, China and

Uzbekistan. Farmer usable Bt-detection kits were developed and commercialized. The kits became very popular all over the country and are being used by farmers seed testing labs and extension workers. Thus far kits worth Rs 42.2 M have been purchased by farmers, seed testing laboratories and extension workers. The Ministry of Agriculture declared CICR as 'National Bt-Referral laboratory' to provide expertise for regulatory purposes to maintain the seed purity and seed quality of Bt-cotton. The institute has won several awards for its outstanding work in development and dissemination of IRM strategies in about 200,000 hectares in 30 districts of nine cotton growing states in fields of about 90,000 farmers, resulting in net financial benefit of Rs 5000 lakhs per year due to 50-60% reduction in pesticide use and enhanced yields.

Cotton scientists have made significant contributions in the past 50 odd years and have changed the cotton production profile of our country with the active support of the farming community and state agencies and others. However, looking to the challenges ahead in the coming decades primarily as a resultant of emerging liberalized and globalised economic scenario, the efforts have to be intensified to bring about productivity improvement alongwith sustainability, and resource use efficiency with emphasis on eco-friendly approaches and technologies so as to reach the set targets and to make Indian cotton compete effectively both in terms of quality and price. Hence, additional financial support for expanding the research and extension base in the NARS is considered essential. Government of India has provided the additional support to the cotton R&D programme in the NATP, NAIP and other funded projects, and also through Technology Mission on Cotton. It is envisaged that the enhanced, concerted and wide ranging efforts in the field of cotton R&D under existing and proposed programmes will bring about the desired levels of improvement in-respect of production, productivity and quality.

CICR 2030

The Central Institute for Cotton Research has been striving to increase the production, productivity and profitability of cotton cultivation in different agro-ecological zone through novel, feasible, viable and eco-friendly production and protection technologies through basic, strategic and applied research.

Vision

Global leadership in cotton yields through native innovations in science and technology

Mission

To accelerate growth in national cotton productivity and minimizing agro-eco regional yield gaps through modern science and technologies by developing/providing technologies, products and services to different stakeholders (farmers, textile and processing industries, input agencies and other R&D organizations)

Focus

The Central Institute for Cotton Research has major challenges. Its main clientele includes farmers, farm input industry, ginning, spinning, textile and value addition industry. Recently, over the past decade biotechnology, information technology and industrial technologies have revolutionized cotton production and value chain processing. India has made good gains. Area under cotton increased, production doubled, insecticide usage reduced to half. There is a need to address several issues and enhance focus so as to ensure all round prosperity for all the cotton stakeholders.

The institute will focus on key areas and frontier technologies to achieve the following objectives:

1. Enhance the production from the current 300 lakh bales to 1000 lakh bales by 2030 in a sustainable manner through precision strategic planning and appropriate re-orientation of research and development approaches.
2. Develop methodologies and identify varieties for specific agri-eco zones for precise adaptability and sustainable production.
3. Orient developmental plans to develop varieties and cultivate specific quality varieties in specific agri-eco zones to ensure the production and

availability of adequate fiber that can cater to the precise demands of the domestic and International textile Industry and non-woven industrial segment.

4. Facilitate effective utilization of germplasm resources through selection, trait pyramiding, Marker Assisted Breeding and Transgenic approaches to achieve multi-adversity resistant varieties that can withstand current adverse environmental conditions and future climate change.
5. Explore, conserve and harness the full potential of the indigenous *Desi* cotton species *Gossypium arboreum* and *Gossypium herbaceum* by reorienting research towards developing cotton farming systems that can utilize and exploit the virtues of high adaptability, resistance to wide range of biotic and abiotic stresses and environmental sturdiness present in the *Desi* species.
6. Discover new genes for economic traits and use them through transgenic and RNAi approaches for gene-stacking and durable resistance.
7. Develop novel crop protection and innovative crop production technologies and disseminate through new information technologies to make cotton less labor intensive and more profitable for the cultivator.

Harnessing Science

The recent advances in cotton research have been based on novel technologies. There has been an all round development in all spheres of science that range from new methods of plant breeding, QTL analysis, isolation of markers, genome sequencing, new bio-pesticides, new genes for pest management, new methods of pest control such as transgenic crops and RNAi, new pest detection and scouting gadgets, new pest forecasting tools, new generation pesticides, yield modeling, water use efficiency enhancement technologies, nutrient use efficiency enhancement technologies, new cropping systems, new biofertilizers, new machinery and equipment to reduce farm drudgery, novel scientific tools of extension and revolutionary media that reaches out to masses instantly.

Yield and quality enhancement

CICR has a rich collection of more than 10,000 germplasm lines, that have been partly characterized but not exploited properly. A well focused approach can

ensure that appropriate germplasm lines can be identified and consolidated so as to enable the development of comprehensive resistant varieties that can help resource poor farmers. Such efforts can be enormously useful in reducing the input costs. Molecular markers shall be isolated for resistant traits and pooled together in a pyramid through marker assisted breeding programmes. Plant Breeders, all over the world, have so far subjected germplasm resources to intensive breeding, so as to enhance yield, fibre quality traits, high oil content or resistance to biotic or abiotic stresses. Such programmes also inadvertently result in narrowing of the genetic base. There is a need to take a re-look at the entire germplasm collections once again in light of the molecular markers and the genes that are currently available. The markers and genes identified recently for economically important traits, can provide an elegant tool to convert some high yielding germplasm lines into elite cultivars. Out of the 50 cotton species, 5 are considered as primary germplasm pool, 21 as secondary and 24 as tertiary germplam pool, based on the relative genetic accessibility. There are several high yielding germplasm lines that are deficient in just one or two economically important traits such as fibre strength or length or susceptibility to biotic or abiotic stresses. Useful genes can be transferred into cultivars through genetic engineering or desired traits, for which molecular markers are available can be back-crossed into the lines through accelerated marker assisted breeding. In addition to its lint, the oil and protein portion of the cottonseed also represents significant economic value. As far as possible, plant breeding programmes should also ensure that the newly developed cultivars should have reasonably high levels of oil and protein in seeds.

How can yields be increased in developing countries? Yields in developing countries mostly in Africa have been stagnating. Narrow and ultra narrow spacing is practiced in China, Uzbekistan and several countries of the world where plant population of 100,000 to 200,000 per hectare results in high yields with varieties. The plant population with hybrid cotton varieties as in countries like India, ranges from 6000 to 15000 per hectare. The cost of hybrid seed is much higher and plant growth is luxuriant and therefore does not permit high density planting. Plant population cannot be increased with hybrid cotton. Hybrids are highly input intensive and relatively more susceptible to pests and diseases and thus require more fertilizers and pesticides for optimum production. Progressive nutrient (Macro and Micro) depletion due to altered source sink relationship because of intensive hybrid cotton cultivation is causing long term soil nutrient deficiencies. Bt-cotton hybrids utilize more nutrients as compared to varieties to yield more. Therefore the soils are getting progressively depleted and need more nutrient refurbishment. Due to intensive farming, cotton crop has been showing nutrient deficiency symptoms in many developing countries, especially in rainfed zones where wilt and leaf reddening problems are getting severe over the years. It should be a priority area of research in countries of Asia and Africa to develop varieties through 'ideotype breeding' of compact genotypes suited for narrow and ultra narrow spacing, with specific fibre traits for specific locations. Additionally the compact genotypes with specific fibre traits can be converted to insect resistant biotech cotton. Such location specific high yielding varieties ensure sustainable production in major cotton growing countries of Asia and Africa in the future. it is also important to develop varieties suitable for dense planting that are more efficient in utilizing water and nutrients and can resist pests and diseases. Such measures can not only enhance yields but can also provide sustainable options for optimal and efficient use of inputs.

Hybrids occupied more than 90% area out of 11.1 M.ha in 2010. Hybrids have contributed to wider adaptation, higher quality cotton production, higher seed output and enhanced seed oil output. There is need for strong complementary research and development programmes for both hybrids and varieties so that the full potentials and practical advantages of both can be harmonized. Hybrids perform better under higher input technology conditions and superior management. Hybrid seed production is labour intensive and expensive. Research efforts should focus on the development of useful male sterile systems. Future efforts should also explore apomixis to fix heterosis so as to eliminate the cyclic need to produce hybrid seeds.

There is a continuous demand for improved cotton fiber quality. This demand has been met in the past to some extent by classical breeding. Currently we are trying to unravel the process of cotton fiber development step by step and identify the genes involved in determining the specific properties of the cotton fiber. This knowledge is then used by both cotton breeders and biotechnologists to explore possible modifications in key parts of the biochemical processes which could lead to improvements in cotton fiber quality. The first strategic plan to improve fiber quality traits is to characterize genes exclusively associated with fiber length and strength expressed during fiber initiation, elongation and the secondary wall formation by utilizing the high fiber length and strength germplasm available in the CICR. Genes available in public domain and specifically implicated in secondary wall formation of cotton fiber viz., *cesA-4, cesA*-7 and *cesA*-8 genes will be utilized. In collaboration with other partner institute few other candidate genes such as *Myb, aquaporin, Fiber protein, E6 protein, expansin, annexin* would be validated with fiber specific promoter (*expansin, annexin*) using low fiber length and strength genotypes to improve from 28-30mm with 25g/tex to 32-34mm length with 28-30g/text HVI mode. Beside, attempt would be made for improvement of fiber quality by transferring heterologous sources genes available in public domain such as SPS gene from spinach, acsA and acsB genes of *Acetobacter xylinum* and Fibroin gene from silkworm. Thus the novel ESTs identified from the high fiber strength cotton and the genes from heterologus sources are expected to be potential candidate for improving fiber strength. Attempt will also be made to identify and characterize Ramie fiber gene for length and strength using microarray analysis.

LRA 5166

Suvin

CISA 310

Surabhi

Sumangala

Sruthi

Suraj

MCU 5VT

Cotton fibre quality using recombinant DNA technology has been improved using the PHB genes from bacteria (John and Keller, 1996). Hormonal manipulations of developing cotton fibres through genetic engineering were successful as an experimental procedure but it did not result in significant improvement of fibre strength. Antisense RNA technology using antisense mRNA specific to E6, H6 and FbL2 A genes were linked to the 35S, E6 or FbL2A promoters and introduced into Deltapine cotton. Fibre traits such as strength, length and micronaire of various transformants were measured and the results suggested that these proteins are required at very low levels for normal fibre development to occur. Sucrose phosphate synthase gene, the enzyme that was reported to improve fibre quality especially under stress, was isolated from spinach and was introduced into cotton (Haigler et.al. 2000). The resultant cotton transgenics pushed the fibre quality to the premium range even when grown under stressful cool night conditions. Prokaryotic genes have also been used to improve fibre quality. Synthesis of synthetic genes governing the expression of fibroin (H- Fib, L- Fib, P25), sericin (Ser1 and Ser 2) and seroin in the silk worm *Bombyx mori.* would be initiated. Spider silk known as spindrons and their gene sequences are available too. Full-length gene sequences are available (NCBI accession numbers AB112020, AH 000965, AB112021, AB007831, AB193317, BMOSER I96 etc). Synthetic genes will be designed based on these sequences and synthesized from commercial sources. Development of an expression system of fibroin, sericin and seroin genes of Bombyx and spindroins of spiders. Designing constructs using these genes in consonance with fibre specific promoters. Fibre specific genes of cotton- E6, Fb-B6, Fb- B8, FbL2A and H6 have been manipulated to reduce or eliminate their expression through antisensce technology. Their promoters have been characterized and have been used for transgene expression (John, 1996). Based on the transcriptional ctivity of the FbL2A gene promoter fused to reporter genes in transgenic plants, gene expression of FbL 2A increases rapidly to peak levels around 35 days post anthesis coincident with maximum deposition of cellulose. Transformation of cotton using constructs carrying silk genes either through particle bombardment or through *Agrobacterium* mediated transformation. Selection of transformants using appropriate marker systems and evaluation of cotton fibre quality. Transgene integration and its confirmation using PCR, Southern blot and ELISA methods. These are standard protocols in any transgene production.

High yielding elite germplasm lines, which are inferior in only one or two of the desirable traits such as fibre quality or resistance to biotic or abiotic stresses, should be chosen as recurrent parents for marker assisted accelerated back-cross breeding method. Another set of high yielding germplasm lines should be identified, which possess the trait of interest, and can be used as donor parents. Recently (Xiao et al., 2009), 2,937 SSR primer pairs have been identified as highly informative which target unique genomic sequences and amplify about 4,000 unique marker loci in a tetraploid cotton genome. Chromosome-marker bins, each 20 cM in size, were constructed on the genetic linkage map containing the markers. Thus 207 marker bins were assigned for a total of about 4,140cM which is approximately the size of the tetraploid cotton genetic map. The markers can be used effectively to tag quantitative traits of interest in the already characterized germplasm pools and thereafter utilize in marker assisted breeding programmes for genetic enhancement of elite lines and genotypes to develop high yielding cultivars. Genes conferring strength and fineness can be identified from Ramie and utilized to enhance fibre traits in cotton through genetic transformation. Sucrose phosphate synthase and extensin genes have been shown to enhance fibre length and strength and can be further explored

Cotton fibre quality assessment through instrumentation is still a challenge. There are no rapid internationally acceptable uniform methods of testing of cotton for neps, stickiness and micronaire. The testing procedures are still time consuming in many countries of the world. There is an imminent need to invent simple and rapid testing equipment and procedures for fibre quality evaluation that can give a preliminary assessment before the fibre can be subjected to HVI and other tests to ensure better returns for the producers.

The demand for short staple cotton (less than 10 counts) and also coarse cotton for non-woven purposes such as surgical cotton, absorbent cotton, technical textiles etc., has been increasing of late. With demand for denim cotton on the rise, short staple cotton of 7-14s count is now in higher demand especially for denim export and local use. Production of fine and superfine counts (40s and above) has increased. 11 - 40s count group represents 71% and hence greater efforts are required in this category. The use of cotton and synthetic fibre blends will increase as it rose to 13% in recent years. MCU5, MCU 5 VT, Surabhi, Suvin, DCH 32 are useful for blending. But fibre maturity requires attention. Good fibre strength and extensibility are important for blending to get good yarn properties. Trash content in Indian cotton has declined significantly in recent times.

Textile industry has been demanding for quality cotton suitable for the recent spinning systems which were developed to achieve higher production rates, productivity and automation for cost reduction of yarn production. Open end (OE) spinning systems - Rotor spinning, Friction or DREF spinning and airjet spinning which ensure high rate of production and large size of yarn and package are coming into existence. Ring spinning for all counts with wide adaptability, rotor (upto 24s), DREF (upto 30-45s coarse counts) and airjet for finer counts (50s and above) and also for man-made fibres and blends including combed cotton, have increased. For the new systems, high fibre strength and fineness are now more important. Often raw material economy in mill is achieved by mixing few varieties to spin the required count. Sometimes mills also underspin. There is a need to improveme fibre strength to 25-30 g/tex for 3 mm gauge, 75-80% mature fibres, reduce stickiness and motes (neps and naps) in interspecific hybrids, low short fibre content/lowered trash content seed coat fragments etc. and improvement in ginning aspects etc., and optimum micronaire value without affecting maturity.

Sustainability of Cotton Ecosystems, Biological Control and IPM

Cotton ecosystems have been ravaged by pesticide onslaught over the past five decades. There are very few studies to document the biodiversity and genetic variability of predators, parasitoids, parasites, entomopathogens etc. that were available in the Indian ecosystems, and are remaining currently in our cropping systems. Such studies assist in exploiting the variability in biodiversity of the entomophagous fauna for advantage. Mitochondrial DNA sequencing has opened up new avenues for bioversity mapping for posterity and utility. In view of the changing biological diversity and evolution of biotypes there is need to map insect pests as well as natural enemies. Institute should possess a national repository of all metamorphic stages of predators and parasitoids along with their host insects of cotton.

Entomophagous insect populations operate as density dependent populations. New technologies such as transgenic crops and new selective insecticides do not favour the build-up of pest populations, which would otherwise serve as food source for predators and parasitoids. Food sprays have been effectively used in several countries and are covered by IPR (patents) and therefore not available for use. There is an immense need to augment the parsite and predator populations by the use of extraneous source of food sprays. Production of HaNPV, SNPV and several viruses can be done in cell lines so as to enhance the production capacities. It is possible to clone natural enemies for higher pest control potential (enhanced searching efficiency; thylatoky/ enhanced predation etc.).

Identification of nematodes is based on morphometeric characters and is time consuming. Development of computer aided expert system will aid in quick identification of nematodes by nematologists as well as by non nematologists and will aid in mapping of estimated about an estimated five thousand species of nematodes still in unchartered territory.

Research on pest/ predator/ parasite ecosystems will enable identification of critical factors that favour the beneficial fauna. Such factors must be suitably exploited for use in low input rainfed systems of crop protection. Several botanicals and indigenous pest control systems can be tested for their compatibility with the small scale cotton production systems. Biocontrol systems rely mostly on live production systems, which can be limiting in terms of production costs. There is an imminent need to develop simple and low cost production technologies. Formulation technology for biopesticides has not been separately developed and relies on the ingredients that are used with conventional pesticides. Such research can find effective solutions that can assist in enhancing the efficacy of bioagents. The conventional economic thresholds were developed earlier based on the damage potential and the relative cost of pest control. Over the past decade new technologies such as bollworm resistant transgenic cotton and several eco-friendly pesticides have radically changed the scenario of pest management. The relative efficacy and cost of conventional and new pest management systems are different and therefore the earlier methods have become irrelevant. It is necessary to devise simple methods of scouting to assist farmers intervene with appropriate methods of pest control. It is also important to develop intervention thresholds for bio-control agents.

Research on conservation biocontrol of pests will be strengthened. Effective strains of antagonistic pathogens (fungal, viral, and bacterial) and entomophagous nematodes will be employed in the field for pest and disease control. The active principles will be identified from the antagonist and genes governing production of these inhibitory metabolites (like chitinases, phloroglucinol etc.) will be cloned and used for expression of inherent resistance by genetic engineering. Mass production protocols of biocontrol agents of pests and pathogens like *Trichogramma*, microbial agents viz, viruses (NPVs, GVs and CPVs), bacteria (Bacillus *thuringiensis, B cereus*), and fungal pathogens (*Beauveria bassiana, Metarrhizium anisopliae, verticillium lecanii, Nomuraea rileyii, Trichoderma rileyii, Gliocladium sp., Pseudomonas* spp.) will be standardized and commercialized. The optimum conditions for storage, efficiency and increasing shelf life of these biocontrol agents will be determined. Identification, characterization and evaluation of native PGPR strains of cotton and their response in inducing SAR in plant.

Changing climate and pest scenarios over localities need to be continually kept under observation vis-à-vis changing cropping pattern for a successful forewarning. Creation of national networks for online information on the insect pest situations and continuous data set generation for quality forecasts should the future line of work.

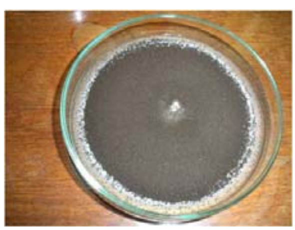
There is a need to develop mini-electronic gadgets & software to detect pest and natural enemy densities, integrate data and recommend appropriate remedial measures. With the current state of art technologies it is possible to initiate the development of electronic sensors to detect specific pests and intensity of infestation and electronic sensors to detect predator and parasite populations.

Insect behavior is guided by semiochemicals (pheromones) called allomones and kairomones. These chemicals have been identified for many species. Subsequently many such chemicals were synthesized in the laboratory for several economically important species and used under field conditions either to monitor their presence or to create mating confusion. Insects have receptors to recognize allomones, kairomones and many other chemicals present in nature. If such receptors can be developed artificially to detect the chemical signals, the detected signals can be converted digitally, amplified and thereafter alert for the presence of the concerned organism. Therefore it should be possible to prepare small electronic gadgets which can be used to detect specific pests and intensity of infestation, predator and parasite population densities, integrate the entire data and also make on the spot recommendations to initiate appropriate remedial measures. The pest scouting gadgets can be handy, accurate and will reduce the drudgery that farmers face in pest scouting and calculation of economic thresholds.

Plants emit chemical signals under stress. Signal transduction pathways in cotton are interspersed with many chemical signals including ethylene, jasmonic acid and several related volatiles. If such chemicals can be detected through sensors and if the intensity can be quantified through small electronic gadgets, it would become convenient to make an immediate damage assessment. Thus, based on the intensity of damage, appropriate remedial measures can be initiated. The crop damage assessment gadgets can help in alerting farmers on the overall health of the crop. The gadgets would prompt for an immediate need for crop inspection.

New GM technologies for Pest and Disease Management

The recent advances made in transgenic research over the past decade and the advent of insect resistant transgenic (genetically modified) crops, have opened up exiting possibilities, new areas of research and new avenues in eco-sustainable pest management. However, thus far all the genes deployed in GM research, without exception, have been discovered abroad and were products that were identified for their high suitability for the local relevance and application. The same products were then released for use in other countries. Over the past few years, open market economy and the associated IPR changes have facilitated a possibility for overseas inventors to apply patents in India. In such a changed scenario, indigenous discoveries assume enormous importance and significance for the country. Also, indigenously developed products would be more suited to meet national challenges and local needs. Thus in the context of GATT and WTO guidelines, product discovery assumes great significance for India. There is an imminent need to discover/invent/develop novel products for sustainable use in pest management, exploiting the rich biodiversity available in India. An exploratory search for insecticidal plant and microbial species should be carried out. A few recent examples deal with the use of allatotropins, allatostatins, proctolin etc that have a significant effect on several lepidopteran species when consumed. Peptide phage display technology will be used to identify inhibitors for key target sites in insects. The potential of such peptides and neuropeptides for bollworm control has not yet been explored anywhere. The search for the insecticidal proteins should include plant sources (leaves, seeds, roots etc.), microbial organisms (Bacillus, Xenorhabdus, Photorhabditis etc.) and neurohormones from insect species (*Helicoverpa, Pectinophora* and *Earias*).


Isolation of fungal Endophytes

The possibilities of discovering new genes for pest management have expanded into infinity, with introduction of new concepts such as gene silencing through RNA interference (RNAi). RNAi deploys double stranded RNA (dsRNA) to silence specific endogenous genes in the target organism, which can be specific to the class, genus or even the specific target species. Thus, crucial species specific genes of a species such as the pink bollworm, *Pectinophora gossypiella* can be identified and the dsRNA expressed in plants to control the pink bollworm by silencing the specific target gene. Gene silencing has been used recently to develop a new biotech cotton variety that specifically controls bollworms by silencing a gossypol degrading enzyme called *CYP6AE14* which otherwise enables bollworms survive on cotton (Mao et al., 2007). When bollworm eats the double stranded RNA (dsRNA) of the *CYP6AE14* gene, the enzyme is silenced and undigested gossypol remains in the stomach and kills larvae. The technology has immense potential in pest management that can be sophisticated to the extent of being extremely specific for the control of target pests alone. The RNAi technology is in the forefront of all the 'state of art' technologies for pest management. Ever since the publication in Nature, 1998 and the nobel prize awarded to Drs Andrew Fire and Craig Mellow in 2006, for their discovery of dsRNA based silencing of specific genes through RNAi (RNA interference), the technology has fired the imagination of researchers all over the world. Globally, attempts are being made to introduce alternative genes (new Cry genes, lectins, protease inhibitors, genes from nematodes etc.) and RNAi (RNA interference based gene silencing) based crop protection through GM cotton for more effective pest management. However, insect resistant GM crops that serve as alternate host plants of cotton bollworms (example, pigeonpea, chickpea, tomato and other vegetables, which are hosts of the cotton bollworm, *Helicoverpa armigera*) should be developed with genes that are not used in GM cotton. Use of the same Cry genes in all crops will enhance the chances of resistance development in insects to the genes used. There are several sources in nature that have been used to isolate insecticidal genes. Genes from endo-symbiotic bacteria of nematodes, *Xenorhabdus* and *Photorhabdus* are being actively considered for the development of transgenic crops. Amongst animal sources, anti-chymotrypsin, anti-elastase, chitinase, cholesterol oxidase and anti-trypsin were isolated from the tobacco hornworm, *Manduca Sexta* and used to develop biotech cotton resistant to sucking pests and lepidopteran insects. Trypsin inhibitors and spleen inhibitors isolated from cattle, protease inhibitors from plants (Soybean, Barley, Cowpea, squash, mustard, rice, potato, tomato), amylase inhibitor genes from beans and cereals and lectins from plant sources have been used to develop biotech crops resistant to insect pests. Other genes include *chitinases, glucanases, peroxidase* and *tryptophan decarboxylase* from various plant sources to develop insect and disease resistant cotton. Replicase genes and coat protein genes have been used to develop leaf curl virus resistant varieties through over-expression of the proteins or silencing of the genes through RNAi, especially for countries in Africa, India and Pakistan where the cotton leaf curl virus (CLCuV) problem can cause severe economic losses.

Mirid Bug

Mealy Bug

RNAi should be used to develop insect and disease resistant varieties. Important diseases such as the cotton leaf curl virus and bacterial blight can be effectively managed by GM technologies including RNAi by pyramiding native resistance available in India, especially in the *Desi* varieties. The insect and disease resistant products developed through RNAi will give India a competitive edge over other countries that have been developing GM-crops using the technology. Efforts should be made to identify 'pathogen species specific' genes present in the pathogen species and 'insect-species-specific' genes present in the insect gut which are functionally important for feeding, digestion and other biological activities. There is a need to identify effective siRNAs and/or miRNAs and their targets. Gene sequences and the novel structures must be explored for their utility for crop protection through conventional or transgenic approaches for the management of cotton insect pests such as the bollworms, jassids, whiteflies and new pests.

It is now been proven that new biotech crops that scare insects can be developed. Insects release chemicals called alarm pheromones when they are scared by their enemies. This warns their colonies to escape. New biotech crops express alarm pheromones that scare the specific insect pests. The alarm pheromone for many species of aphids, which causes dispersion in response to attack by predators or parasitoids, consists of the sesquiterpene (*E*)-farnesene (*E*f). High levels of expression in *Arabidopsis thaliana* plants of an *Efsynthase gene* cloned from *Mentha piperita were used* to cause emission of pure *E*f (Beale et al., 2006). These plants elicited potent effects on behavior of the aphid *Myzus persicae* (alarm and repellent responses) and its parasitoid *Diaeretiella rapae* (an arrestant response). Insect injury causes signal transduction. The signal transduction pathways leading to the release of plant volatiles have been found to alert other plants in the neighborhood. Jasmine scent reduced populations of jassids, aphids, *H. armigera* and enhances populations of predators and parasitoids in cotton fields. Some plants have been found to help cotton crop to fight pests. Insects make ultrasonic sounds or release pheromones or cause plants to emit ethylene that can be detected by simple gadgets for farmers to precisely detect insect infestations, even from home, without having to count any insects before taking pest management decisions.

Jassid

Whitefly

Over the past decade several simulation models have been proposed to predict the adaptability of pests to insecticides and transgenic crops. Some of the key factors influencing adaptability were identified as Bt-toxin expression in plants, sensitivity of the pest, and initial frequency of resistance allele and inheritance of resistance. The model output was solely considered for development of resistance management strategies. Such studies have been done so far only at CICR, Nagpur and will be strengthened.

Genes to enhance nutritional status of cotton seed

Low gossypol seed' can be possible through biotech cotton expressing cytochrome P450 *CYP6AE14* genes from pink bollworm and *Helicoverpa* to be expressed specifically in cotton seeds. The gene sequences are known and seed specific promoters are available. These can be used to develop low gossypol seed varieties. Sunil Kumar et al (2006) utilized RNA interference to inhibit the expression of the δ-cadinene synthase gene in a seed-specific manner, thereby disrupting a key step in the biosynthesis of gossypol in cotton. Compared to an average gossypol value of 10 μg/mg in wild-type seeds, seeds from RNAi lines showed values as low as 0.2 μg/mg. Importantly, the levels of gossypol and related terpenoids that are derived from the same pathway were not diminished in the foliage and floral parts of mature plants and thus remain available for plant defense against insects and diseases. Further, they reported that the germinating, RNAi seedlings are capable of launching terpenoid-based defense pathway when challenged with a pathogen. Thus, the silenced state of the δ-cadinene synthase gene that existed in the seed, does not leave a residual effect that can interfere with the normal functioning of the cotton seedling during germination. Apart from silencing of δ-cadinene synthase, there are several innovative strategies that can be used to reduce gossypol specifically in seeds and also to increase monounsaturated fatty acids to make cotton seed oil more acceptable nutritionally.

Resistance to Abiotic Stress and Climate Change

Though cotton is a drought tolerant crop by nature, undesirable stress either due to water logging at vegetative phase or moisture stress at reproductive phase or prolonged drought during sowing time or reproductive phase, or high saline/sodic conditions can severely debilitate the crop. Climate change can adversely affect adaptability levels of varieties that were carefully selected and developed by farmers and plant breeders over the past several years to suit specific agro-ecological conditions of specific cropping zones. Salinity problems in irrigated regions are increasing. Erratic distribution of rainfall that has become a more common phenomenon recently has also become more detrimental to the crop that is cultivated in more than 60% area of the country. It is necessary to

Poly Mulch in Cotton Production System

identify, classify and categorize germplasm lines that have unique traits to withstand cold, heat, high CO_2, and other stresses that are envisaged to occur with climate change.

Cotton is sensitive to photoperiod and thermal conditions and does not adjust easily to new environments. Cotton varieties from particular latitudes are known to take inordinately long time to adapt to unfamiliar latitudes across the globe. Genetic engineering can help to develop cotton varieties that can grow anywhere in the world. Genetic manipulation of Rubisco activase can alter photoperiod and thermal sensitivity to enhance the adaptability of cotton to a wide range of

Polytube Drip Irrigation

environments. Cotton susceptibility to abiotic stress especially drought, water logging and salinity adds to the adjustment complications. Drought responsive element binding proteins (DREB) *rd29A* genes for drought, high-salt & cold stress have been identified and used in several crops including cotton. Superoxide dismutase (SOD) confers chilling stress and is being explored for its utility in cotton**.** A few years ago attempts were made to develop biotech cotton for abiotic stress-tolerance, through the deployment of genes that are responsible for modification of a single metabolite that would confer increased tolerance to salt or drought stress. Stress-induced proteins with known functions such as water channel proteins, key enzymes for osmolyte biosynthesis of betaine, proline, trehalose, and polyamines were the initial targets of plant transformation. Now, several drought related genes have been cloned and characterized in recent times. Zhang et al (2009) reported on the nine ESTs including *photosystem I psaH protein*, and *H+-ATPase* related genes which were up-regulated at different levels in drought stress cotton seedlings. These genes are responsible for the absorption and utilization of water through adjusting the photosynthesis process. Under drought stress the two genes were found to be highly induced. cDNAs differentially expressed in response to drought stress also revealed the role of CaLEALI gene in response to various abiotic stresses. Transgenic approach provided proof of concept of the relevance of many genes such as *P5CS, Glyoxalase AHK1/ATHK1, DREBs, PDH45Helicase, NPK1, DREB2 like small protein such as CAP2, GmDREB2, AtHARDY, ARAG* etc., which mainly addressed cellular level tolerance in model plant species, need to be utilized in cotton. Maintenance of positive carbon balance during stress is of significant importance to avoid yield penalty. Cotton being C3 crop, genetic manipulation to maintain positive carbon balance either by increasing carboxylation reaction or by decreasing photo respiration will enhance the water use efficiency (WUE) and nutrient use efficiency (NUE), thereby enhancing yields. Single cell C4 mechanism suggests possibilities to express C4 genes in C3, recent progress in cloning and expression provides leads for the coordinated expression of relevant genes in target organelles. Recent successful demonstration of increasing CO_2 (CCM) and biomass in *Arabidopsis* by utilizing decarboxylation of glycolate (a pathway that exists in bacteria) acts as an option for improvement of C3 crops such as cotton. Along with the above improvement of primary constitutive traits such as root growth (*Alfin, AUX1, PIN-1, NAC-1*), Wax (SHINE / WIN1, WXP1/ WXP2) associated traits using transgenic approach. Finally combination of the above traits in coordinated manner will help us to obtain cotton genotypes with better adaption to climate change particularly abiotic stresses.

Micro-drip Irrigation System

GM cotton varieties for other traits such as drought and disease (leaf curl virus) management have not yet been released commercially and have immense potential in many countries. Herbicide resistant GM cotton in small scale production systems should find a useful place with careful planning and design of alternative placement of intercrops to avoid the direct effect of herbicide on them and also to ensure that cotton does not become the sole crop in the production systems because of the new weed management GM technology.

Ensuring seed quality of multi-gene based GM cotton

Genetically modified crops have emerged as important components of modern eco-friendly high yielding agriculture. Thus far a total number of 20 transgenic crop plants incorporating 42 genes with 97 transgenic events were developed by 28 commercial companies including public funded institutions and have been released for commercial cultivation in more than 25 countries. Since, the first introduction in 1996, the area under transgenic crops increased to 148 m hectares by 2010. In India, it is important to develop simple cost effective methods to assist farmers in the detection of transgenic purity of the product before they use the seed for sowing. Apart from assisting farmers, the GMO detection kits will help regulators and quarantine personnel to detect and track down the spread of approved, unapproved and unintentionally released GMOs in the environment. A database will be developed to enlist all genes, markers, promoters, traits and crops that have been released for commercial cultivation in India and elsewhere in the world. The database will also include genes, markers, promoters, traits and crops that are under active consideration in transgenic research and are likely to be released soon for commercial cultivation. Generic markers and the most commonly used trait conferring genes and promoters will be shortlisted to be used for detection methods. New methods will be attempted to design lateral flow strips that can detect DNA from plant samples 'on-the-spot' without having to isolate DNA or carry out PCR and electrophoresis. Transgene encoding proteins will be produced and purified either from over-expressing clones or will be obtained from commercial sources. The proteins will be used as antigens to produce specific antiserum, which will be used to develop ELISA, lateral flow strips (dip-sticks) and dot-blot methods. A common lateral flow strip will be designed to enable the detection of any of the most commonly cultivated GMOs, to be used at port of entry for quarantine purposes.

Organic cotton

Organic agriculture is an ecological production management system that promotes and enhances biodiversity, biological cycles and soil biological activity. Organic cotton production must be certified to be sold as 'organic' for which it is to be grown without the use of any synthetic chemicals like pesticides, inorganic fertilizers etc. Scientists in several countries have been conducting experiments over the past two to three decades to standardize sustainable organic cotton production systems through the use of pest and disease tolerant varieties grown under optimal practices for conserving soil moisture and also for improving organic matter content of marginal soils. Results indicated that the improvement in cotton yield with organic supplements was gradual and additive indicating their cumulative effect in improving productivity. Further, long term use of organic supplements, besides stabilizing rainfed cotton yields on marginal soils can also reduce the dependence on nitrogenous fertilizers. Sustained use of organic components in crop production and crop protection for about 8 years over large tracts of land have been found to result in a significant increase of organic carbon, macro and micronutrients in the surface as well as sub-surface layers under organic system (Venugopalan and Tarhalkar 2003). This system appeared to be one of the most sustainable management options to enhance the organic carbon status, which in turn improves many physical and chemical properties, besides arresting the natural degradation of these soils through the formation of pedogenic $CaCO_3$ and sodicity. The organic system reduced pest management cost and was also economically viable. However, it would be prudent for developing countries in Asia and Africa to consider the option of organic cotton cultivation only after their yields are stabilized over a few years and crop production systems are properly standardized for profitable and sustainable farming.

Currently GM cotton is not accepted by many organic cotton users, especially in Europe. The rapid adoption of Bt cotton cultivars into all the cotton growing agro-climatic zones has endangered organic cotton movement in their traditional niches as well as spread of organic cotton cultivation to new areas. Recently, over the past five years (2006-2011), India has emerged as a major producer of organic cotton. Currently it contributes more than 70% of the worlds organic cotton produce. In this context serious efforts have been initiated to identify pest and disease tolerant varieties that are most suitable for organic cultivation. Several individual components of nutrient management (FYM, Vermicompost, Bio fertilizers, Green manure, Industrial by products), pest management (predators, parasites, botanicals, etc,) crop management (inter crop, nipping, etc,) permissible under organic cultivation have been evaluated. Based on the local availability these ingredients have been integrated into economically and socially acceptable packages. To produce '*organic cotton textiles*', certified organic cotton should be manufactured according to organic fiber processing guidelines. Therefore development of local norms and standards of certification of organic cotton farming and development of tools and techniques (protocols) for standardization and accreditation are important. Moreover, there is a need for development of a holistic integrated index (like land quality index) based on physical and socio-economic parameters to objectively assess the long term consequences of organic cotton cultivation and use these indices to monitor organic farms.

Mechanization of Cotton Production

Cotton production is labour intensive in almost all the developing countries. Cotton production demands labour all through, starting from sowing to harvesting which include several operations including inter-culture, spraying and hand weeding. Cotton in several countries is cultivated in small scale production systems, which demand smaller machines that are affordable for small scale farmers. Several attempts are underway to develop machines for picking and other important operations in cotton cultivation in small scale production systems. Self-propelled check row planters, solar powered sprayers and pickers have been developed in developing countries recently. There is a need for computerized self propelled automated Planting Machines, especially to suit machine pickers, which are likely to become popular in view of the acute labor shortages. Recently, brush type pickers have been developed as alternatives to spindle type machines. Such innovations, especially suited for picking in narrow spacing conditions, can assist in enhancing the density of plant population, since dense planting does not suit picking operations with spindle type machines. Small scale two-spindle machine pickers are being developed and tested in developing countries of Asia and Africa. Investment needs to be done to ensure that new machines are developed so that crop production operations are not stalled in rainy days, which is normally the case with labour intensive operations.

There is a need to develop completely automated system of monitoring, forecasting and decision making: The system will monitor the entire farm by way of sensors installed at various locations, and the data on weather parameters, soil moisture, fertility status, pest build up etc will be collected, fed to the centralized knowledge base, along with satellite data on weather forecast, pest movement etc. for processing by an expert system centrally and decisions made in real time to be implemented either by humans or automatic machines.

Cotton based cropping systems and production technologies

Development of precision farming technologies is essential to raise efficiency of inputs for lowering cost of production. India is one of the few cotton growing countries where cotton is grown along side with many other crops. Cropping systems in various forms, like mixed cropping, inter-cropping, strip cropping, sequential cropping systems are adopted in traditional dry land agriculture which act mainly as risk cover against crop failures due to vagaries of monsoon or pest attack. Mixed cropping with sorghum, pigeonpea, maize or pulses in central India and with groundnut, *ragi* or millets in parts of south India is a common system followed. In Punjab and Haryana, mixture of moth and guar with cotton was in vogue before the advent of short duration cultivars. New strategies will have to be worked out to develop alternative plans to sustain cropping systems in the wake of herbicide resistant genetically modified crop introduction. Cotton based cropping system on new approaches could be considered depending upon the rainfall (amount, distribution and length of season) and type of soil. Profitable intercropping systems are possible with range of rainfall between 600-750 mm and on soils with moisture storage capacity of 100 upto 150 mm. With rainfall up to 900 mm and soils with moisture storage capacity upto 200 mm, relay and sequence cropping systems can be developed. Cropping systems for different zones (inter and sequence cropping) may be evolved, taking into account cost of cultivation, higher productivity and land equivalent ratios (LER).

Multi-tier Cropping System

Cotton farming has extended to a greater extent to marginal ecosystems in the rainfed tracts of central India. In these fragile ecosystems, soil nutrient status is very poor. To realize potential yields, large amounts of fertilizers will be needed to meet crop demands. There is a large difference in demand and supply and is expected in the future too. Therefore, fertilizer economy for higher yields as well as effecting N economy by introducing suitable legumes and biological nutrient sources is needed. Nitrogen fixing crops either grown as intercrops or in a sequential manner can help to supplement nutrient requirement. Additionally, there is a need to identify nutrient efficient varieties suitable for marginal soils. Site specific nutrient management has evolved as one of the useful options to optimize nutrient use in cotton farming.

There is growing concern of environmental pollution because of farming (increased C emissions through burning and oxidation of organic matter, fertilizers and pesticides contaminating the ground and surface waters, excess irrigation causing land degradation through salinization etc.). To protect and improve the resource base, developing sustainable conservation technologies are necessary. Loamy to sandy loam soil with effective drainage system in north zone is highly suitable. Soil temperature is high at sowing, while soils are low in nutrient status. In central and south zone, deep vertisols (black loamy soils) are good for hybrids and *hirsutums, Desi* cottons have now been confined to marginal and shallow soils. Red loamy soils are also good in south zone pockets. Cotton on 65% of the rainfed area suffers from water stress at the crucial phase of boll development, and from inefficient water management on rest of the irrigated areas, facing problems of drainage and rising salinity. Drip irrigation system attains relevance here for saving in water consumption to the tune of 40% over conventional irrigation system, and with higher productivity of cotton, the water use efficiency is high. Other advantages, like fertilizer saving upto 30% through fertigation, uniform maturity with optimum fibre quality. Large tracts under cotton are under saline soils, or under saline water use. Since root zone is constantly wet under drip system, soluble salts are pushed away from the zone, enabling a reasonably good harvest of cotton in these areas.

The development of simulation models in association with GIS (Geographical Information System) and remote sensed data to estimate cotton area, soil characterization and its suitability for cotton cultivation, identification of plant types for a particular agroclimatic zone, crop monitoring and forecasting of pest and yield. This is going to help the planners and policy makers to take appropriate marketing strategies. Delineation of agro ecologically harmonious (in terms of soils climatic and management) production sub-regions can help in prioritizing constraints and opportunities for yield enhancement. It would also help in developing customized nutrient delivery systems. Herbicide based weed management technologies to overcome labour shortages-including discovery of new molecules, new tank mix formulations based on weed diversity and residual toxicity are other options for yield enhancement.

Plants respond to different environmental cues through signal perception and transducing the signals to combat stress. The phenomenon can be elucidated through functional genomics. Physiological efficiency of cotton crop can be improved by changing C_3 pathway to more towards C_4 pathway. Other options include use of nanotechnology in the development of stress monitoring devices and development of biosensors to indicate stress and nutrient deficiency.

Desi Cotton

The *Desi* cotton *G. arboreum and G. herbaceum* species have advantages of resistance and tolerance to sucking pests including whiteflies, jassids, aphids, thrips; immunity to new leaf curl virus and tolerance to moisture stress. However the *Desi* varieties are now confined to marginal lands, under moisture stress and in drought prone areas. In Tamil Nadu, staple improvement was achieved to obtain superior medium long staple Karungannies *(G. arboreum),* but not matched by high yield. In Maharashtra State, PKV developed long staple *arboreum* A 8401 with high yield potential but has not become as popular expected. At Parbhani, MAU has developed long staple varieties PA 255 and PA 402.

There is need for improvement of *desi* cottons for plant type, reducing duration, increasing the boll weight, non shedding locules, fibre density and fibre length besides micronaire to required level besides yield. Genes from *G. arboreum and G. herbaceum* species can be identified and utilized to confer stress resistance into *G. hirsutum.*

Economics, extension and sociology

With increased access to global market following GATT, effect of quality parameters on market prices of cotton has to be monitored as in international market, quality will be stressed upon. Horizontal market integration is needed to avoid wide fluctuations in prices within markets and crop seasons. Vertical integration of processing with production will facilitate enhanced the sharing for the producer in value added proceeds. The impact of changing technological of trade regime on-farm production and marketing needs to be monitored.

To keep pace with the global changes there is a need to move from commodity centered approach of extension to a farming systems approach including audit of local resources, market segmentation, production planning, standardization and quality control, and post harvest technology. In the near immediate future, it would be useful to utilize the power of online networks, computer communication and digital interactive multimedia to facilitate dissemination of cotton production technology and marketing information. It would be useful to effectively utilize information and communication technology, TV, radio, national and international networks, internet, expert systems and computer based training systems to improve information access to the farmers, extension workers, research scientists and extension managers. Other envisaged changes include, introduction of innovative and decentralized institutional arrangements to make extension system farmer driven and farmer accountable, inclusion of private sector, NGOs and other entrepreneurs in the arena of transfer of technology in cotton production, skill enhancement of extension professionals engaged in transfer of technology, strengthening of locally relevant innovation processes and knowledge systems and better linking of cotton growers to input and output markets.

Strategy and Framework

The strategic framework outlined here addresses concerns, some of which are immediate and some extend into the future. There can be several programs in the future based on the developments in basic sciences. The framework with performance measures is listed in a separate annexure.

Programme 1: Modification of plant architecture and crop geometry for high yields through geo-spatial precision breeding for the specific 15 AESR (agro-eco-sub-regions), high harvest index, high Ginning out-turn, high efficiency for nutrient and water use and low input cost. Genetic enhancement for high yield, superior fiber quality, resistance to biotic and abiotic stresses.
Breeding for 1. Improved harvest index 2. High lint yield through appropriate genotype, architecture and geometry in specific agro eco sub regions

3. Dwarf compact plant varieties for high density planting in Maharashtra and MP
4. *Desi* varieties for high yield.
5. Organic cotton varieties
6. Genetic enhancement and population improvement
7. Superior fiber traits with desired length, strength and fineness
8. Heterotic pools of *G. hirsutum*
9. Varieties better than Suvin
10. Resistance to waterlogging and salinity/sodicity
11. Resistance to drought
12. Resistance to jassids

Programme 2: Development of transgenic cotton with novel genes for sustainable resistance to insect pests, leaf-curl virus, water logging and drought

1. Discovery of new genes, promoters and constructs for RNAi transgenic and other transgene expressing GM cotton resistant to insect pests, water logging and drought
2. Development of Bt cotton varieties
3. Development of CLCuD resistant transgenic and conventional varieties

Programme 3: Strengthening genetic diversity of cotton germplasm, DNA bar-coding and utilization of molecular markers in breeding

1. Collection of *Desi* land races and perennials
2. Characterize germplasm, re-classify working and core collections, DNA bar-coding and publish complete catalogue
3. Development of RILs and NILs and Marker Assisted Breeding

Programme 4: Development of sustainable precision farming systems through integrated nutrient, water, weeds, pests and disease approaches decision support systems, yield forecasting, nanotechnologies, mechanization and climate resilience

1. Consolidate integrated nutrient, water and weed management package systems for low cost production and sustainable profits
2. Yield modeling
3. Novel crops for cotton cropping systems that can enhance pollination and profits
4. Development of Machine picker for small scale farming conditions
5. Nanotechnologies for enhancing input use efficiency
6. Assess preparedness for climate change - adaptation and mitigation strategies
7. Leaf reddening remedies

Programme 5: Consolidating ecologically compatible and profitable sustainable crop health management for conventional, transgenic and organic cotton
1. Insect resistance: monitoring, mechanisms, genetics, modeling, and management 2. Mapping genetic diversity of insect haplotypes 3. Development and commercialization of new bio-pesticides 4. Organic cotton support systems including biological control 5. Pest and disease forewarning systems 6. Development of new pest monitoring gadgets 7. Farmer usable diagnostic kits for GM crops and disease detection

Programme 6: Priority setting and market intelligence to prioritize 'demand driven research, forecasting and appropriate 'technology placement'
1. Identification of demand of textile industry and non-woven segments in India 2. Identification of farmer needs to formulate 'demand driven research' 3. Market intelligence surveys for technology commercialization

Epilogue

India has all the potential to emerge as a world leader of cotton. India has the largest cotton area in the world with 111 lakh hectares in 2010, accounting for more than one-third of the global cotton area. It has the best dedicated scientific talent of the world for cotton research. With carefully planned policy on cotton research we can ensure that the emerging challenges facing cotton farming are addressed from time to time, while harnessing the full potential of our natural resources, manpower and technologies so that cotton farming becomes a sign of prosperity and India emerges as a global leader of cotton.

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Annexure: Strategic Framework

Goal	Approach	Performance Measure
Modification of plant architecture & crop geometry for high yields	Breeding for high yield through, architecture and geometry in specific Agro-eco-sub-region Breeding for dwarf compact plant varieties with high harvest index and their evaluation for high density planting in Maharashtra and MP	High yields and enhanced production under sub-optimal conditions Low input use, high yields and high profits in rainfed systems
Superior fibre quality and resistance to biotic and abiotic stress	Development of superior fiber traits in *G. hirsutum* and varieties better than Suvin Genetic enhancement and population improvement Development of cotton varieties suitable for organic farming Breeding for resistance to water-logging, drought and jassids Development of heterotic pools of *G. hirsutum* Strengthening and harnessing the superior traits values of native *Desi* cotton species	Global leadership in quality and exports Diversity and novel trait combinations Environmental sustainability and enhanced global market High yields under adverse conditions Sustainable heterosis and hybrid vigour *Desi* varieties for high yield
Transgenic cotton with novel genes for resistance to insect pests, leaf-curl virus, water logging and drought	Discovery of new genes, promoters and constructs for RNAi based GM cotton Discovery of new genes to develop GM cotton resistant to insect pests, water logging and drought Development of gene pyramided Bt cotton varieties	Indigenous IPR and global leadership in technology development Durable resistance Long term resistance to CLCuD Enhancing food security through use of cotton seed protein for human consumption

	Development of CLCuD resistant transgenic and conventional varieties Development of GM varieties with low-gossypol in seeds	
Strengthening genetic diversity of cotton germplasm, DNA bar-coding and utilization of molecular markers in breeding	Collection of Desi land races and perennials Characterize germplasm, re-classify working and core collections, DNA bar-coding and publish complete catalogue Association Mapping and develop linkage-disequilibrium groups for breeding Development of RILs, NILs, markers and Marker Assisted Breeding	Strengthening & consolidating National resources Streamlining and effective utilization of genetic resources Accelerated plant breeding through marker assisted selection
Sustainable precision farming systems through integrated approaches (INM, IWM, IPM), decision support systems, nanotechnologies, mechanization and climate resilience	Refinement of production technologies and their evaluation using input use efficiency yardsticks Decision support systems for management interventions Novel crops for cotton cropping systems to enhance pollination & profits Development of machinery and implements for small scale farming Nanotechnologies for enhancing input delivery Preparedness for climate change	Sustainable profitability and cropping systems Simplified precision farming Sustainable cropping Reduction in drudgery High precision application and reduction in input losses, improved use efficiency Environmental sturdiness Remediation of physiological and crop nutritional problems

	Elucidation of leaf reddening and remedies	
Consolidating ecologically compatible and profitable sustainable crop health management for conventional, transgenic & organic cotton	Insect resistance Management to Bt and insecticides: monitoring, mechanisms, genetics, modeling, management and IPM Mapping genetic diversity of insect haplo-types & DNA bar-coding Development and commercialization of new bio-pesticides Organic cotton support systems including biological control Development of new pest monitoring gadgets Farmer usable diagnostic kits for GM crops and disease detection Explore endophytes for crop protection	Long term sustainability, profitability and benefits to environments Precision pest management Strengthened bio-control Strengthening ecological benefits Simplified pest scouting and prediction Precision diagnosis Strengthening inbuilt resistance
Priority setting and market intelligence to prioritize 'demand driven research, forecasting and appropriate 'technology placement'	Identification of demand of textile industry and non-woven segments in India Identification of farmer needs to formulate 'demand driven research' Market intelligence surveys for technology commercialization	Strategic research planning Demand driven research Technology popularization and enhanced benefits

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हर कदम, हर डगर

किसानों का हमसफर

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