

Global Best Practices for doubling Indian cotton farmers income

This report contains text reproduced from articles written by Dr Kranthi in the CAI Newsletter 'Cotton Statistics and News' published by the Cotton Association of India.

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INTRODUCTION

India has the largest share of 36-38% in the total global cotton acreage with 11 to 13 million hectares. Cotton is one of the main crops that, has been grown in the country for hundreds of years. Indian climate is ideal for the crop and so are the soils. India can race to the top comfortably by implementing simple changes that are derived from global experiences. This article is about a few simple things which can bring about a great change in the cotton production systems in India.

Can we double Indian cotton yields? Can we double farmers' income? Can we half the production cost? This article affirms the belief that these things are eminently possible, much sooner than later. But there is a need for a change.

Indian cotton production systems are radically different from rest of the world

Cotton production systems are very different in India compared to all other countries. We believe that long duration cotton is the best way to get higher yields. We believe that more bolls per plant is the best way to get more yields. We believe that big plants are better than small ones. We believe that hybrid cotton gives higher yields than pure-line varieties. The world thinks otherwise. Result -the yields of 'rest of the world' are double that of India!!

Everything is different in India. All the differences in crop production practices of India with rest of the world are related to one major policy factor –Hybrid cotton. India is now saturated with hybrid cotton. Rest of the world did not adopt the concept of hybrid cotton. However, it was only in India that there was a general belief that hybrid-cotton technology could lead India towards high yields. Efforts were made from 1970 to develop high yielding hybrids. In 30 years of intensive efforts, about 30 new intra-*hirsutum* hybrids were released for commercial cultivation and the area under cotton hybrids reached 38 to 40% by the year 2000. With the introduction of Bt-cotton only in hybrids, the area under hybrid cotton reached 95% by 2011.

In 2014-15, India's National average yield was 510 kg per hectare compared to the 'rest of the world's average yield of 931 kg per hectare. The yields in a few countries were 1500 to 2600 kg lint per hectare which is 3 to 5 times higher than India. A few years ago, yields in these countries were also at 500 kg lint per hectare. But, these countries used simple technologies to enhance yields progressively over the past two decades. Generally, every year, thirty four countries across the globe cultivate cotton in more than 50,000 hectares. Five of these have been able to achieve National average yields of more than 1500 kg lint per hectare, which is three times more than India's average. The five countries are Australia (2619 kg/ha), China (1508 kg/ha), Brazil (1601 kg/ha), Turkey (1574 kg/ha) and Mexico (1577 kg/ha). All these countries cultivate pure-line varieties. Turkey has only non-Bt varieties. Brazil has less relevance for Bt cotton because of negligible problems with bollworms.

Simple technological changes have swept the cotton world over the past 20 years. Biotech cotton, water management, new selective herbicides and insecticides, mechanization and new varieties brought in major changes in production technologies. Indeed, yield increases in Australia, China, Brazil and Turkey were technology driven.

In light of these observations, this paper attempts to explore the following aspects to find new ways of doubling the yields in India in a sustainable manner:

1. REASONS FOR LOW YIELDS IN INDIA

- Factor 1: Long duration:
- Factor 2: Low harvest index:
- Factor 3: Low ginning out-turn (GOT):

2. DIAGNOSIS OF THE INDIAN COTTON HYBRID PARADOX

3. BASIC DIFFERENCES IN PRODUCTION PRACTICES

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6. SUSTAINABILITY ROAD MAP BASED ON THE GLOBAL BEST PRACTICES

7. THE TEN COTTON COMMANDMENTS FOR DOUBLING OF FARM INCOME

- New short duration varieties: long-lint Desi (*Gossypium arboreum*) and Bt-varieties
- High density planting systems & short-dense-early pattern
- Sub-soiling to break hard-pans
- Precision planting, north-south oriented row direction & nursery raised plants
- Plastic mulching, drip irrigation under plastic mulch & water management
- Stale-weed-seed-bed system
- Conservation tillage, cover crops, crop residue recycling or mulching
- Square and boll retention with plant growth regulating chemicals
- Canopy management
- Precision chemical input management

8. IMPACT OF TMC PROGRAMME

9. NATIONAL COTTON MISSION TO DOUBLE FARMERS INCOME 2017-20

1. REASONS FOR LOW YIELDS IN INDIA

A critical analysis shows that cotton progress in India is being hampered by incorrect technological options that do not match the conditions. The yields in rain-fed cotton in the country are less than 350 kg lint per hectare mainly due to the mismatch of the monsoon window with the late season flowering and fruiting stages that starve of water and nutrients. The average yield in irrigated regions at about 700 kg/ha, is also far less than 904 kg/ha, which is the average of 'rest of the world. It is dismal that cotton production progress in India has hit a dead-end over the past 10 years. Undoubtedly, low yields in irrigated areas are also because of long duration varieties with low harvest index (seed-cotton / plant-bio-mass), which require intensive care to combat insect pests and diseases and season long technical-intensive management to cater to the crop needs of water and nutrients. The following factors played a critical role in hampering cotton yields in India:

Factor 1: Long duration: Cotton crop needs more than 80% of the total water and nitrogen requirements during the critical flowering and fruiting period. Crop thirst and hunger at this critical stage lowers yields significantly. Additionally, long duration of the flowering and boll-formation phase leads to prolonged vulnerability of the crop to insect pests and diseases, which leads to yield losses.

Hybrid technology can be good if the hybrids are of short-medium duration, if the seed cost is low, if the harvest index and yields are high and production cost is low to moderate. Hybrid cotton performs well under irrigated conditions and deep black cotton soils. However two factors make the production systems risky. One is the expectation of large number of bolls per plant and second is the long duration. Both the factors are interlinked, because more bolls per plant need longer duration. Longer duration renders the crop vulnerable to many insect pests all through the season, especially to the pink boll worm that occurs as a late season pest. As long as insecticides or Bt toxins were effective in controlling the pink bollworm, long duration hybrids delivered higher yields. However, with bollworm resistance to insecticides and Bt toxins, hybrids become highly vulnerable to bollworms.

In the quest of high yields with hybrids, long duration hybrid varieties (160-240 days) were developed so that the boll numbers were highest per plant. These hybrids have the longest reproductive window

(flowering + green boll-formation) that extends from 80-160 days or more as compared to 60-100 days in advanced countries. In majority of the hybrids boll formation starts after monsoon recedes. The greater terminal part of the broad window (60-120 days) of flowering and fruiting does not get adequate soil moisture and nutrients especially in rain-fed conditions that constitute 60% of India's cotton area. Thus the long duration hybrid technology which is unique to India creates a mismatch between the availability of soil moisture and nutrients during the critical reproductive phase thereby resulting in low yields especially in rain-fed conditions. Thus majority of the long duration hybrids are unsuitable for rainfed farming.

Out of the eleven cotton growing states in India, two states, Maharashtra and Telangana together have 5.6 million hectares of cotton almost completely under rain dependence. Monsoon in these two states starts by mid June and extends to first week of September. Natural soil moisture is available until end of September or at the most until mid-October depending on the soil type and conditions. Hybrid cotton is sown generally in the first week of July. Boll formation starts in September and extends up to boll bursting during November to January, sometimes into February. Flowering starts by mid-August and continues in a staggered manner until the end of October, sometimes even into November. Nutrient uptake is inconceivable with deficit soil moisture. Thus the crop suffers from thirst and hunger during the most critical stages of flowering and fruiting, thereby resulting in low yields in these two states which have half the country's cotton area.

The option of cultivating long duration hybrids resulted in a long flowering and fruiting window that is vulnerable to insect pests and diseases. Hybrid crops need more fertilizers which also make them more vulnerable to insect pests and diseases. The need for more nitrogen accentuates heavy infestation of sap-sucking pests all through the season. Further, the inordinately long 100-odd days of flowering and fruiting window also attract a continuous stream of bollworm infestation thereby necessitating repeated application of insecticides. Thus, chemical usage is high, yields are low, and production costs keep rising every year.

Factor 2: Low harvest index: Another factor that is responsible for low yields is the low harvest index of the long duration hybrids that were developed in India. The long duration, high vigor hybrid crop puts forth excessive vegetation and has low harvest indices of 0.2 to 0.5, compared to 0.5 to 1.0 in countries that harvest high yields. Low harvest index with excessive vegetations leads to a massive wastage of fertilizers thereby resulting in low yields.

Factor 3: Low ginning out-turn (GOT): Indian cotton is characterized by low ginning % (per cent of fiber weight in seed-cotton) of 32-34% as compared to 38-44% in the six countries. For example, from 1000 kg seed-cotton India gets 330 kg fiber, whereas other countries on an average get 390 kg fiber. Thus the fiber yields are low. The low GOT of Indian cotton could be due to focus on more bolls per plant, which leads to a compromise of traits such as GOT and fiber strength.

2. DIAGNOSIS OF THE INDIAN COTTON HYBRID PARADOX

The main differences in crop production practices of India with rest of the world are related to one major policy factor –Hybrid cotton. The following aspects related to hybrid cotton are unique to India and differ completely with many advanced countries as listed in table 1.

- **More bolls per plant:** Hybrid cotton varieties are selected for bigger bolls and large number of about 100 or more bolls per plant.
- **High boll numbers compromise ginning% and fiber strength:** In the process of selecting plants for larger number of bolls per plant, ginning% and fiber strength are generally compromised. Further late season bolls are smaller and of poorer quality.
- **Longer duration:** To produce a large number of bolls each plant takes a longer time of 6-8 months. These bolls are formed in a staggered manner in 3-5 batches over 160 to 240 days, thereby resulting in 3-5 multiple pickings.
- **Longer reproductive phase:** Flowering and fruiting stage extends over 80-160 days for the plants to produce more number of bolls.

- **Need for more water and fertilizer:** Since more than 80% of water and nutrients are required by the plants during flowering and fruiting phase, the extended reproductive window demands intensive irrigation and fertilizer management for high yields.
- **Energy intensive hybrid-vigour of traits:** Different hybrid varieties may show hybrid-vigor for different characteristics. Some hybrids may have hybrid-vigor for plant height, some for bushy nature, some for excessive vegetation, some for boll size, some for boll numbers, some for fiber length, some for duration etc. All these traits are energy intensive and are expressed better under intensive use of fertilizers and water.
- **Tall and bushy plants:** To produce more number of bolls per plant, the hybrid-variety plants are selected to be big and bushy. The hybrid plants respond well to irrigation and fertilizers to grow tall and bushy under ideal conditions.
- **Low harvest index:** Hybrid vigor leads to more vegetative unproductive excessive biomass comprising of leaves and stems, thereby resulting in low harvest index.
- **Low density of plants:** Because they are bushy, the hybrid plants need space and light. Thus, plant population for hybrid cotton was optimized at a low density of 6000 to 16000 plants per hectare depending on irrigation and soil type.
- **Wide spacing:** To accommodate the bushy plants with hybrid vigor, a wide spacing up to 150 x 120 cm was adopted in irrigated regions mainly in Gujarat and 90 x 60 cm in rain-fed Maharashtra.
- **Labor intensive seed production:** Hybrid seeds are produced by crossing two different varieties through a cumbersome method of emasculating the flowers of one variety and pollinating it with pollen of the second variety, thus making seed production expensive and labor intensive. In contrast, varietal seeds are directly harvested from a single pure-line variety.
- **Labor intensive production practices:** Sowing in a wider spacing of 90 x 60 cm or more cannot be easily adapted to machines. The existing technology of spindle-type machine-pickers, are not suited for cotton picking of the bushy wide-spaced Bt-cotton hybrid crop. Weed problems are more in widely spaced crop. All these operations are labor intensive and make cotton cultivation in India, the most labor intensive as compared to other countries.
- **Multiple pickings & inferior quality:** Multiple pickings resulted in variable quality, generally with inferior quality in late picked cotton due to poor availability of soil moisture and nutrients in the terminal stages of the crop.
- **Lack of seed sovereignty:** Seeds harvested from a hybrid crop cannot be used subsequently for sowing, whereas varietal seeds can be saved and sown recurrently for several seasons. Farmers are required to procure freshly produced hybrid seeds every year from the market.
- **High risk of bollworm resistance to Bt-cotton hybrids:** Two factors accelerate resistance risk are, long duration crop and seed segregation for Bt-toxins in Bt-hybrids. Long duration crop provides an extended window for the pink bollworm infestation which occurs mainly in winter when the crop is extended beyond 150 days. Seed companies found hybrid-seeds as a convenient vehicle of 'value-capture' for Bt-technology. The F-1 (filial-1 generation) hybrid seeds were developed by crossing one Bt-variety with another non-Bt-variety. This would result in F-1 hybrid seeds, containing one copy of the Bt-gene inherited from one of the parents. Bolls produced in a Bt-hybrid crop produce seeds that segregate for Bt toxins. A proportion of seeds do not contain Bt-toxins. Both these factors create an ideal condition for bollworms to develop resistance to Bt-cotton.

There was a general belief that hybrid-cotton technology could lead India towards high yields. Efforts were made from 1970 to develop high yielding hybrids. In 30 years of intensive efforts, about 30 new

intra-*hirsutum* hybrids were released for commercial cultivation and the area under cotton hybrids reached 38 to 40% by the year 2000. Until 2005, hybrid cotton was confined only to central and south India and was not accepted at all in north India. The long duration bushy hybrid cotton did not fit well with the cotton-wheat rotation, system. Hybrid cotton performed well in irrigated tracts of central and south India, but was not able to replace the pure-line varieties and Desi cotton varieties that were grown in more than 90% of the rain-fed region that constitutes about 60% of India's cotton area. Hybrid cotton gave better yields in irrigated regions and in assured rainfall areas. Before the advent of Bt-cotton, the late season pest 'pink bollworm' was effectively controlled by synthetic pyrethroid sprays, but the American bollworm, *Helicoverpa armigera* could not be controlled due to its high propensity for developing resistance to insecticides. In general, hybrids responded well to irrigation and fertilizers, but small mistakes in management of under-dose or over-dose of fertilizers and insecticides, lead to yield losses.

Bt-cotton was introduced in 2002 in central and south India and in 2005 in north India. Initially yields increased significantly all across the country during 2002-2005, with very less area under Bt-cotton in central and south and without any Bt-cotton in north India. In the first four years only 20 Bt-hybrids were approved for commercial cultivation. Subsequently, a large number of Bt-hybrids were released, thereby creating confusion. Interestingly, within five years from 2006 to 2011, more than 1000 Bt-hybrids were released and the hybrid-cotton area increased from 50% to 95%. Strangely, yields stagnated or even declined after 2005 until date (2017) despite several technological factors that should have otherwise resulted in high yields. These technological factors were, doubling of fertilizer usage, doubling of insecticide usage, introduction of Bollgard-II and other new Bt events, release of more than 1000 new Bt-hybrids and increase in Bt-cotton area from 11.7% in 2005 to >90% after 2010.

Interestingly, researchers are still undecided on the specific contribution of hybrid cotton technology to yield enhancement if any in India mainly because yields did not increase after 2006. But, did the massive adoption of hybrid cotton technology make any difference to India's yields? The question assumes significance in light of the fact that so far only the GM 'Bt technology' has been credited for higher yields with no credit whatsoever attributable for the hybrid cotton technology.

As mentioned earlier, in stark contrast to other countries, Indian hybrid cotton is characterized by an inordinately long duration of 210-240 days due to which pest management, nutrient management, soil moisture management and crop management get fairly complicated. This needs to be changed. The low stagnant National average yields over the past 10 years, despite the country being saturated with long duration Bollgard-II (BG-II) hybrids should prompt us to unlearn the dogmatic ideas that 'hybrids give high yields' and that 'long duration cotton tides over risks and gives higher yields'. Further, India needs to accept the fact that the country's cotton will not see a break-through as long as we do not realize that the existing scenario is actually bad when placed in a global perspective and is only likely to get worse if proper steps are not initiated in time. There is a constant propaganda that production has doubled due to the all-pervasive new Bt-hybrid-technology. It is also claimed that from being a net-importer, India became the world's second largest exporter of raw-cotton due to Bt-technology alone. Nothing would be said to highlight that the production could have increased because of the 50% increase in India's cotton acreage, increased irrigation and other technological advances. There wouldn't be any mention on the stagnant yields after 2006 despite doubling of Bt area, doubled fertilizer usage, doubled pesticide usage and tripled cost of production. Unfortunately the country's cotton scenario is saddled with the handicap of misinformation and ambiguity. There are several unanswered questions. If we do not ponder on these questions, if we do not accept ground-realities and bitter facts and if we convince ourselves blindly by the commercial propaganda, it is quite likely that we will never know what to unlearn and learn. A few issues that need to be examined critically are listed below in the form of questions.

1. Why is it, that India's 10-year average yields of 500 kg/ha are almost half compared to the average yield of 'rest of the world' comprising of 80 countries?
2. Despite being saturated with Bt-technology coupled with hybrid technology, why were India's yields less than the yields of 32 cotton growing countries? 25 of these countries neither grow hybrids nor have access to the GM Bt-technology.
3. What caused the significant increase in yield during 2002 to 2005 when the growth in Bt-area was very low from 1.2% in 2003 to 14.2% in 2005?
4. Why were the yields stagnant, despite the spectacular increase in 'Bt-hybrid area' from 37% to 95% in five years after 2006?

5. Why didn't the yields increase after 2006 despite Bollgard-II technology or the 734 Bollgard-II hybrids that were released in a short span of 4 years after 2006?
6. Why did the insecticide use in India double up after 2006?
7. Why did the fertilizer usage double up within five years after 2006?
8. Why did the pink bollworm develop resistance to Bollgard-II only in India just in 4-5 years and not in any other country even after 16 years of exposure to Bt cotton?
9. Bt-technology effectively controlled bollworms. But, were all yield gains due to Bt-technology alone? Is there any clear evidence of any significant infestation of American bollworm on cotton after 2002 which would have caused losses otherwise in the absence of Bt-technology? The American bollworm was known to be primarily induced by the indiscriminate use of synthetic prethroids. Pyrethroid usage declined significantly on cotton in India after 2004 and so did the infestation of the American bollworm.
10. What was the contribution of hybrid technology alone and prolonged crop duration of long duration hybrids to yield enhancement after 2006?

The above issues are related basically to the hybrid-technology that invariably leads to low plant density which results in bushy tall plants with excessive unproductive bio-mass and long duration that covers almost two cropping seasons. The long duration crop in India has a long critical window of 'flowering and fruiting' that has a long extended vulnerability to insect pests, diseases, water stress and nutrient stress thereby warranting a nightmarish crop management characterized by uncontrolled, faulty and indiscriminate applications of fertilizers and pesticides. Indian cotton scenario is thus characterized by indiscriminate fertilizer usage, imbalanced nutrition, nutrient wastage, excessive pests, indiscriminate repeated pesticide usage; pest resistance to pesticides, crop stress, low yields and high cost of cultivation.

3. BASIC DIFFERENCES IN PRODUCTION PRACTICES

The following aspects related to hybrid cotton are unique to India and differ completely with many advanced countries as listed in the table below.

	India	Australia, Brazil, Turkey, China, USA and Mexico
Cultivars	Hybrids	Pure-line varieties
Crop duration: days	160-240	140-160
Flowering-fruiting duration: days	80-160	60-100
Plant Population /ha	11,000	>110,000
Bolls/plant	20-100	7-9
Number of pickings	3-5	1
Sowing and picking	Manual	Mechanized
Laborers employed per hectare	100 to 120	1-10
Harvest index (seed-cotton v/s plant-bio-mass)	0.2-0.4	0.4-1.0
Lint % in seed cotton (Ginning%)	32-34	38-44
Plant architecture	Bushy	Erect-compact
Plants in meter row	1 to 2	10
Seed Rate Kg/ha	2	12
Seed production	cumbersome	Easy
Pink bollworm infestation in long duration crop	High	low
Non-Bt seeds in bolls	present	absent
Bollworm resistance risk	High	low
Area Lakh ha	119	224
Average lint yield Kg/ha	500	>1500

4. GLOBAL BEST PRACTICES

National average yields in Australia, China, Brazil and Turkey have been increasing steadily over the past two to three decades, specifically over the past 10-15 years despite having large cotton acreages. This could be possible either because these countries have the best climate for cotton

cultivation and/or because of the technological advances in production practices. But, the spectacular increasing trends in yields of these countries indicate that technological advances, mainly in plant breeding of improved varieties that were tailored to suit the local climatic conditions, actually contributed to higher yields. For example, historically, prior to 1994, Brazil's cotton yields never exceeded more than 440 kg lint per hectare. While the seasonal weather conditions almost remained the same, technological changes appear to have pushed up the yields within 5 years after 1994 to more than 1000 kg lint per hectare with a consistent incremental upward growth trend in productivity until date. Similarly, yields in China were never higher than 500 kg/ha prior to 1980, and were always less than 1000 kg/ha before 1997. China's progress can be considered as most spectacular because of its steady increase of National average lint yields from 1000 kg/ha to 1500 kg/ha during 2003 to 2012 in a large acreage of 5.2 to 6.2 M hectares. Yield increase in Brazil, Turkey and China are identical with an increase from 1000 kg/ha in the year 2000 to 1500 kg/ha in 2015. Impressively, the yield enhancement in Brazil happened in a large area of 0.8 to 1.4 m hectares during the past 12 years. However, chemical usage has increased enormously to an extent of 40-50 chemical applications in a single season, despite large scale adoption of GM cotton which includes herbicide tolerant and Bt-cotton. Insecticides in Brazil are used to control boll weevils, nematodes and sucking pests. Herbicides and plant growth regulators are used very frequently. It is quite likely that such rampant usage of insecticides would lead to collapse of the crop sooner than later. In stark contrast, insecticide usage has reduced very significantly in Australia due to Bt-cotton and in Turkey due to organic cotton. Both countries present very different perspectives. The most significant aspect of Australia is its application of science and discipline in implementation. Yields were above 1600 kg /ha after 1999 and reached as high as 2500 kg per ha in 2014. Impressively, insecticide usage declined to just about 2-3 sprays per season over the past 15 years at least. Similarly chemical insecticides in Turkey are restricted to small areas and are not used in organic cotton. The science of organic cotton in Turkey is very impressive. Though cotton area in Australia increased steadily until 1999 to reach 0.53 m hectares, acreage fluctuated wildly between 0.065 to 0.65 m hectares during the period 1999 to 2016 mainly influenced by drought.

The following passages focus on the case studies of China and Australia.

Best practices in China:

Based on cotton type, distribution and growth environment, the cotton growing area in China can be divided into three major agro-ecological zones, including the northwest inland cotton region, the Yellow River valley region and the Yangtze River valley region. It was reported that 99.7% of output and 99.5% of cotton growing area in China occur in the three main cotton regions (Yang and Cui, 2010). In 2014, China contributed to 25% of the world's cotton production from only 12.7% of the global cotton area. Over the past few years, the country had introduced a series of intensive farming technologies and cultural practices for yield enhancement. Technologies such as seedling transplanting, plastic mulching, double cropping, plant training and super-high plant density technique were reported (Jianlong and Hezhong 2014) to have played important roles in promoting unit yield and total output. These technologies are labor-intensive and are based on extensive use of fertilizers, pesticides and plastic films. Reports from China indicate that with intensive cultivation practices, farmers of Xinjiang were able to easily obtain yields of 2,250 kg lint per hectare, while record yields of 4,900 kg lint per hectare were also obtained.

Improved varieties coupled with a series of intensive farming technologies and cultural practices were developed and implemented on a large scale over the past 10-15 years for yield enhancement.

1. **Intensive cultivation:** Cotton is intensively cultivated currently in China through more than 40 procedures during the whole growth period (Mao, 2010).
2. **Compact varieties:** New varieties were developed with compact architecture
3. **Double-cropping:** Agronomic practices such as double cropping or multi-cropping of short-season cotton with wheat and watermelon were standardized
4. **Precision sowing:** precision seeding technologies are done either manually or by machinery with 15-19 kg seed per hectare

5. **Nursery planting:** New nursery bed technologies were developed to raise seedlings in “columned soil blocks” (4–6 cm in diameter and 8–12 cm high), containing soil plus organic manure at 9:1 ratio. Reports show that compared with direct-seeded cotton after wheat harvest, the yield of transplanted seedlings was significantly increased on average by 20–30%.
6. **New Machines:** New mechanized transplanting techniques were developed to transplant cotton seedlings 20-30 days before wheat harvest or after harvest.
7. **Drip irrigation:** Drip irrigation in mechanized plastic mulching and training plant architecture in high density planting played a major role in enhancing yields.
8. **Plastic mulch:** Use of machines to cover inter-row space with plastic film 30 days before sowing (early mulching) improved plant stand establishment by 38.7%, biomass by 26.5%, lint yield by 19.0% and earliness by 10-30% (Dong et al., 2009). About 3.0 to 4.0 million hectares of cotton area is covered with plastic mulch every year in China, especially in the arid and semi-arid regions of northern China and coastal saline-alkali areas (CRI, 2013).
9. **‘Short-Dense-Early’ pattern:** A novel pattern called “short-dense-early” is widely adopted in the north-west inland cotton region to obtain high yields. High density cotton is cultivated with early planting of early maturing varieties using drip irrigation under plastic mulches, which also leads to short plant height, promotes early maturity and results in high lint yields (Zhang et al., 1999). Super-high density planting technique is used with ‘short-dense-early’ varieties planted at 200,000 to 300,000 plants per hectare, mainly in the north-west inland area of China.
10. **Minimum tillage:** Inter-cultivation and tillage at full post-emergence and flowering
11. **Precision nutrient management:** Fertilizers are applied 3 to 4 times at planting, squaring or flowering stage and after topping with rapid release fertilizers. Controlled release of fertilizers are applied mainly through drip-fertigation.
12. **Canopy management:** Plant training practices such as removal of vegetative branches, old leaves, empty branches, early fruiting branches, apical points of vegetative and fruiting branches and removal of growth-tip (de-topping), are done for canopy management and also to facilitate nutrients to be redirected to fruiting parts.
 - a. **Restricting plant height:** Aeration and ventilation in the high density crop is ensured by controlling the plant height to 65-70 cm by using growth regulating chemicals coupled with management of water and nutrients.
 - b. **Topping:** Removal of growth tips on the main stem (topping) is carried out when the number of fruit branches is 10 to 20 per plant depending on the density of plants per hectare. Plant topping is conducted in 100% of cotton fields in China for regulating plant growth and increasing yield, (CRI, 2013).
 - c. **Removal of vegetative branches:** Vegetative branches are removed manually after appearance of the first fruiting branch. This reduced boll shedding by 9%, increased boll size by 7%, increased the number of fruiting nodes per leaf area by about 30%, enhanced the dry mass of fruiting parts per leaf area by 89% and increased seed cotton yield by 17.7% (Yuan, 1982; Dong et al., 2008). This practice is followed in 50-70% of the farms in China.
 - d. **Removal of unproductive plant parts:** Empty fruiting branches, old and yellow diseased leaves are removed after full flowering for remarkable improvement in ventilation, light penetration, reduction in soil humidity and boll rotting.
 - e. **Removal of apical points:** Apical points of vegetative branches are removed after peak flowering and those of fruiting branches are removed at peak boll-setting.

- f. **Removal of early fruiting branches:** Early fruiting branches, generally the lower most 2-3 fruiting branches of the main stem are removed at peak squaring stage.
13. **Bt-cotton in local varieties:** Bt-cotton technology is introduced into the locally adapted varieties for effective bollworm protection.

Best practices in Australia:

Cotton is cultivated in about 1500 farms with an average area of 500 hectares. Currently, Australia tops the world in lint yields. Australian scientists have been able to show that it was possible to get 5,034 kg lint per hectare. Cotton in Australia represents intensive high input system with high cost of production to obtain high National average lint yields that range between 2000 to 2500 kg lint per hectare. Average yields in irrigated farms range between 2500 to 3500 kg lint per hectare and 900 to 1200 Kg per hectare in rain-fed farms. Production systems from pre-sowing to post harvest are completely mechanized and are least dependent on manual labour.

The main production practices are:

- **GM cotton for insect and weed control:** GM varieties resistant to insects and herbicides are used all across the country.
- **Consultants:** Input application of water, nutrients and pesticides, is recommended by consultants based on scientific principles.
- **Improved input-use-efficient varieties:** The new cotton cultivars of Australia have reduced leaf sodium uptake, increased tolerance to water-logging, increased water use efficiency, increased nutrient efficiency and increased leaf photosynthesis. Short to medium duration cotton of up to 180 days duration are cultivated. The varieties have okra leaves which are ideal for high density planting to facilitate aeration and light penetration.
- **High density planting:** Cotton crop is grown generally on 1.0 m spaced ridges with nominal spacing of ten plants per metre row. A plant population of 110,000 is maintained.
- **Soil health:** Conservation tillage or minimum tillage are practices across the country
- **Crop rotation:** Cotton crop is alternated with wheat, pasture, canola, barley and oats
- **Fertilizer management:** Precision application of fertilizers as per crop requirement. Application of Nitrogen (220 kg/ha) and phosphorus (10 kg/ha), based on the soil nutrient data. Nitrogen fertilisers are applied prior to sowing cotton at 180 kg N/ha as anhydrous ammonia
- **Water management:** Precision irrigation scheduling based on the specific requirements of each crop stage, is followed. Cotton crops are furrow-irrigated regularly to avoid drought stress. About 5.2 million litres of water is used per hectare in 7-8 ml/ha furrow irrigation. Irrigation scheduling tagged with nutrient application: Studies showed that water stress and nitrogen at peak flowering had the greatest negative impact on yields. Therefore irrigation scheduling coupled with nutrient management received highest priority in Australia.
- **Weed management:** Stale-seed-bed technique, vigorous initial crop that competes with weeds and application of herbicides are used for weed control. Over the top applications of herbicides on HT (herbicide tolerant) GM cotton varieties are taken up depending on weed flora and intensity. Inter-culture operations are carried out by 1-2 inter-row cultivations during the first 60 days.
- **Insect pest management:** Principles of insecticide resistance management (IRM) and integrated pest management (IPM) are followed scrupulously to reduce chemical pesticide usage to the best possible extent. Insects are controlled when they exceed commercial thresholds. Insecticide application is carefully regulated with 1-2 application of insecticides for sucking pests and none for bollworms in Bt-cotton. Choice of insecticides is based on their

ecological selectivity for least toxicity to beneficial insects and high toxicity to target insect pests. IRM and IPM principles are applied to ensure that resistance development in target insects is delayed and that naturally occurring beneficial are least disturbed by human interventions, especially with chemical application in the fields. Soils are tilled to a depth of 10 cm after harvest to destroy pupae of the cotton bollworm. The practice is known as 'pupal busting'. prior to 1996 before the introduction on Bt-cotton, insecticide applications ranged from 12 to 16 per season. The five year averages for the periods 2008-2013 and 1998-2003, showed that insecticide usage was reduced by 89%, from 5.12 kg to 0.55 kg active ingredient per hectare (Roth et al., 2015)

- **Defoliation:** Two applications of defoliants are taken up at 60% boll bursting stage, prior to machine picking.

Conventional Practices in Mali and CoteD'Ivoire

Interestingly there are simple technologies that are followed in poor countries of Africa wherein yields of about 1500 kg seed-cotton per hectare were obtained consistently for several decades. Mali and Cote D'Ivoire are two such examples, where for 30 years after 1975, the average lint yields were 489 and 505 kg lint per hectare respectively, which was equivalent to double the Indian cotton yields, during the corresponding period. Mali harvested 425 to 606 kg lint per hectare at an average from about 1.5 to 5.0 lakh hectares with negligible inputs, under rain-fed conditions with hardly any technologies such as hybrids or Bt or drip-irrigation etc. Climate and rainfall in Mali are almost similar to Vidarbha. Cotton is completely rain dependent. Like in Vidarbha, sowing happens in June-July and harvest in November-December. The problems of bollworms, thrips and whiteflies in Mali are as acute as they are in India. India's average cotton yields during the corresponding 30 years from 1975 to 2004 were half that of Mali and Cote D'Ivoire (Figure 1). Compared to India's cotton travails, I would rate the cotton journey in these two countries as nothing short of a fairy-tale, given the logistic difficulties in Africa. It is interesting that Mali has been cultivating only two to three varieties called STAM 59A, NTA93-15 and NTA 90-5. Plant density is three to four times higher than India. Ginning % is more than 42%. The crop duration is about 150 to 160 days. Farmers know the risks, problems and prospects of the varieties under variable conditions, thus making management easier using simple, time tested strategies. Could these simple factors have been the main secrets of their success? Can these practices be adapted easily in India?

5. SUMMARY OF GLOBAL PLANT BREEDING AND PRODUCTION PRACTICES

Yield enhancing technologies in China, Australia, Brazil and Turkey are based on a combination of 'structured-varieties' in tandem with appropriate agronomy and efficient pest management. These systems deserve to be studied carefully so that lessons can be learnt for other countries. However, in some of these countries high yields were obtained due to intensive chemical usage, mechanization, irrigation and labor-intensive crop management. For example, China deploys labor for nursery transplanting, sowing and canopy management, while Brazil moved towards high level of mechanization, fertilizers and pesticides to obtain high yields. It is quite likely that these technologies will not sustain themselves in the long run only to lead production systems into perennial risks. Therefore there is a need to exercise proper discretion in choosing the most appropriate technologies that are suited for local needs and local conditions, with focus on sustainability. A few of the core technologies could then be adapted to India and other countries to establish sustainable production systems for high yields and low inputs costs.

A summary of plant breeding policies and best practices that are being followed in China, Australia, Turkey and Brazil are listed below:

1. **High 'harvest-index' short duration varieties:** Compact architecture; sympodial in nature with short-internodes; suited for high density planting and machine picking; short duration (150-160 days); high harvest index of 0.4 to 1.0 and robust seedling and root vigor.
2. **High density planting:** Optimizing plant populations at more than 110,000 plants per hectare with compact statured varieties. Spacing of plants is maintained for 10-12 plants per meter within rows and at 45 to 90 cm between rows.

3. **Canopy management:** Plant architecture is maintained through a combination of genetics and manual intervention (China & Turkey) or chemicals (Brazil and Australia) for better sunlight penetration into the crop canopy.
4. **Legume-cotton based cropping systems:** Cotton is either rotated or inter-cropped with legume crops for nitrogen-fixing.
5. **Soil health management:** Conservation tillage and crop residue management practices that enhance soil health with high residue cover, crop residue mulching, minimum tillage, etc.,
6. **Eco-conscious pesticide usage:** Least early season insecticide applications and careful choice of 'biological-control-friendly' insecticides in Australia and Turkey for highly efficient season-long pest management through conservation of naturally occurring biological control.
7. **Input-use-efficiency:** Enhancing water-use-efficiency (WUE), nutrient-use-efficiency (NUE) and pesticide-use-efficiency (PUE) by implementing INM (Integrated Nutrient Management), IWM (integrated water management), IRM (Insect Resistance Management) and IPM (Integrated Pest Management) strategies by optimizing application of water, manures, fertilizers, pesticides and biological resources.

Given below is a list of global practices that are being followed across the globe, especially in countries where the yields are above 1000 kg lint per hectare.

- **Land Preparation:** Practice zero-tillage, strip tillage and stale seed bed system that can facilitate timely planting rather than waiting for optimum soil conditions for conventional tillage. In zero-till or strip till systems, winter cover crops protect the emerging cotton seedlings. Avoid compaction due to tillage machinery to improve soil structure and internal drainage (hydraulic conductivity) a limiting factor in heavy clay soil. Wherever necessary, sub soiling can be done at a depth of 40 -46 cm to break hard pan / hard sub-soil layer to improve water and root penetration
- **Crop residues:** Post harvest shredding and incorporation of cotton stalks into soils plays an important role in pest management and nutrient management. Shredding of stalks prevents over wintering of pink bollworm. It also ensures a mandatory 90 days host free period for pink bollworm. Cotton stalks from one hectare when incorporated back into the soil, provide 20-25 kg nitrogen and 70-80 kg phosphorus per hectare.
- **Spacing:** Row spacing can be kept at 38 to 76 cm. Reduction in row spacing from 96-100cm imparts earliness and allows more efficient use of light. Ensure at least 7 plants are kept per meter row length. Fewer plants than this would produce more bolls on outer positions and delay maturity.
- **Varietal selection:** It is important to cultivate good quality seed of high yielding varieties with good fiber quality that perform best against the local conditions with tolerance to locally prevalent biotic (insects & pathogens) and abiotic (specific window of temperature, drought etc.). Plant new varieties in less than 10% of the farm area to evaluate new varieties and reduces risks.
- **Planting:** Seeds must be planted at uniform spacing with precision in drilled or hill drop pattern at a depth of 0.6 to 4 cm with precision planters. This will optimize emergence, save seed and ensure uniform germination. Planting on raised beds improves drainage, warms soil and provides less favourable conditions for seedling pathogens.
- **Seedling protection:** Apply pre plant, contact herbicides, three weeks prior to planting to prepare a stale-seed-bed and also to ensure that no green vegetation is left on the field. Use systemic pesticides for seed treatment to protect the seed and seedlings from insects, nematodes and pathogens. Scouting for early season pests / symptoms of pest damage Improves pest management decision making

- **Monitoring the crop:** Monitoring should be done by breaking the season to pre square (emergence to 1st square), squaring (first square to first bloom), flowering (first flower until cut out) and cut out (from cut out to harvest). COTMAN a computerized programme for cotton management is also useful. It helps to identify potential problems and provide time / opportunity to take corrective measures.
- **Pre square:** Data on plant population, plant height and number of nodes must be collected. Additional data on damages due to hail storms, poor drainage etc. provides an idea on reason for discrepancies in plant stands, stand uniformity and vigour if any.
- **Squaring:** Data on plant height, number of nodes, node of first fruiting branch and fruit retention at first position helps to detect fertilizer or moisture stress/excess. The need for application of plant growth regulators can be decided based on excessive vegetative growth if any.
- **Flowering:** Data on plant height, number of nodes, number of nodes above upper most position white flower (NAWF), retention of first position square (below white flower) helps to detect deficiencies or excess in fertilizer application or stress due to deficit or excess moisture. The need for application of plant growth regulators can be decided based on excessive vegetative growth if any. Data would also be useful to make end of season decision.
- **Cut out:** Track the progression of NAWF and take data on nodes above cracked boll and percentage of open bolls to decide the application time of harvest aid chemicals.
- **Pest and disease management:** The best pest management is through host plant resistance that can be supplemented by naturally occurring biological control. Varieties that are resistant to sap sucking pests provide robust foundation for integrated pest management. Coupled with appropriate seed treatment these varieties can tolerate sap-sucking pests and diseases so that there would not be any need for pesticide applications early in the season. In the absence of disruptive pesticides, naturally occurring biological control gets strengthened and plays a significant role in sustainable pest control. Early planting of short season varieties enables the crop to escape several species of insect pests. Avoidance of excessive nitrogen is crucial for crop health. Other technologies such as inter-crops, trap crops, botanical pesticides, augmented biological control, pheromones and cultural control practices can assist in effective control insect pests and pathogens in an eco-friendly and sustainable manner.
- **Soil Fertility:** Nutrient status of the soil can be determined by plant analysis and soil testing to diagnose nutrient deficiency and provide corrective measures. Synchronizing nutrient availability with plant nutrient demand, saves fertilizers, improves nutrient use efficiency and results in high yields. It is important to determine soil pH and amount of residual nutrients to make amendments for less mobile nutrients such as P, K, Ca and Mg. Cotton grows best at soil pH of 5.8 to 8.0. Use amendments like gypsum and lime to correct soil pH. Amendments act best six months after application.
- **Nitrogen:** Optimum nitrogen is crucial for high yields. Avoid excess nitrogen to ensure a healthy crop. Excessive application of nitrogen makes the crop susceptible to insects and diseases, induces rank vegetative growth, results in boll shedding, delays fruiting and crop maturity and reduces lint yield and profit. Nitrogen application must be based on past field production level, yield expectation, soil and plant analysis data. Field scouting for visible deficiency symptoms and petiole nitrate analysis will help in diagnosing N deficiency. Ensure right amount of N in all phases of growth and fruiting based on crop requirement to avoid deficiency and prevent excess vegetative growth, delay in maturity defoliation problem and reduce N losses.
- **Phosphorus:** Solubilization of soil bound phosphorus can be improved by making conditions favorable for mycorrhizal association with cotton roots

- **Potassium:** Use foliar potassium application only to supplement soil application and not as a substitute. Peak demand for potassium is during boll filling stage. Low potash in soils and less active root system limits soil K uptake and hence foliar supplementation of K is beneficial.
- **Secondary nutrients:** Ca and Mg needs as best assessed through soil tests. Normally amendments are used to regulate soil pH that takes care of Ca and Mg requirement
- **Micronutrients:** Micronutrient bio-availability is governed by soil pH. Therefore correction of soil pH is important. Boron is a key element for cotton and a separate soil test for Boron is helpful to decide on an efficient micronutrient supplementation program. Sandy soils with low organic matter are more prone to micronutrient deficiency.
- **Water management:** Micro-irrigation systems are used to irrigate cotton in arid regions and regulated surface flooding in humid and temperate regions. Arid regions have higher water requirement than humid regions and micro-irrigation systems can save water and improve water use efficiency. In humid regions only supplemental (to rainfall) irrigation is needed and this can be economically provided with surface flooding method. Drainage is as important as irrigation for cotton crop. Cotton is extremely sensitive to excess moisture and water stagnation could reduce yields in heavy textured soils. Avoid water stress from squaring to the end of flowering window. Adequate soil moisture during this critical phase helps plants establish the desired structure and helps in the retention of fruiting forms.
- **Irrigation:** Follow local guidelines on when and how much to irrigate. Feel of the soil and plant observations can be used by experienced growers. Plant monitoring, use of computer programmes, and book keeping method to track effective rainfall, crop evapo-transpiration (ET) demand and soil moisture loss, can also be helpful. Decision on initiation, continuation and termination of irrigation has physiological, ecological and economic implications and hence is crucial. Do not provide heavy irrigation after the first open boll. Moist soil at first open boll is sufficient to provide adequate moisture required to mature the crop. Excess moisture delays harvest and complicate pest management.
- **Plant Growth Regulators (PGRs):** Use of growth promoters or growth inhibitors based on height to node ratio, length of 3rd inter-node from top (> 7-10 cm) or length of top 5 internodes (> 18-23 cm) indicate excessive growth. PGRs are useful to maintain the balance between vegetative and reproductive growth. They modify the morphological and physiological processes and help in realizing high yield through efficient partitioning of photosynthates. Choice and application rate of PGRs is determined by the size of the plant, its age and environmental conditions. Low rate multiple applications are less risky. Growth inhibiting PGRs are not recommended for stressed cotton.
- **Harvest Management:** Harvest aid products (hormonal defoliant or boll openers) and herbicidal formulations (desiccants) are tank mixed and applied to defoliate the plants and prepare the crop for mechanical picking. The goal is to aid early harvest, maximize yield without compromising fibre quality. Plant status at maturity and environmental conditions vary widely from region to region. These factors greatly influence the choice of chemicals and dose. Apply defoliant when 60% of the bolls open or when the value of nodes above cracked boll (NACB) is less than four. Heat unit based computation is also helpful. Defoliant are applied in phased manner, 7-12 days prior to the proposed harvest date. Early application can decrease yield, expose lint to harsh weather and increase the likelihood of re-growth. Cool temperatures often retard the action of boll openers.

6. SUSTAINABILITY ROAD MAP BASED ON THE GLOBAL BEST PRACTICES

As mentioned earlier, National average yields of more than 1500 kg lint per hectare, which is three times more than India's average. Can we identify a few key technologies or strategies of these countries that could be adapted in India? Though a few common simple factors are striking across these countries, the growth curve is enigmatic since it is difficult to pin-point the exact factors that may have spearheaded the growth curve. One thing that is clearly acknowledged by these countries is that consistent scientific efforts resulted in technologies that sustained the growth curve. Plant breeders

worked hard to develop 'compact-statured', 'short duration' 'synchronous early-maturing' varieties that are suitable for machine picking and high density planting, which appear to have mainly triggered the yield enhancement. These varieties have premium quality fibre, high harvest index (yield v/s biomass), high ginning% (lint % of seed-cotton), high initial vigour and high nutrient-use-efficiency. High density planting with 7-12 cm between plants in a row is a common practice. Row to row spacing depends on whether the crop is irrigated or rain-dependent. Nitrogen fixing legume crops are commonly used in crop rotation generally in double cropping systems. Legume crops and broad leaf creepers are planted as inter-crops or cover-crops for pulses, oilseeds, green manure, nitrogen fixation and management of weeds and soil moisture. Cover crops and crop residue management are considered important for soil enrichment in all the six countries. Crop residue mulching or plastic mulching is done extensively for management of soil moisture and weeds. Canopy management is followed scrupulously by using chemicals or manual intervention to restrict plant height to less than 100 cm and width to 60-70 cm by removing unproductive branches and leaves. Management of plant architecture was reported to result in high yields by channelizing nutrients efficiently into developing bolls thereby preventing nutrient wastage. Drip irrigation, fertigation and plastic mulching are followed widely in China. Water and nutrient usage is optimized based on soil or plant analysis. Pesticide usage is mostly restricted to a bare minimum based on principles of integrated pest management (IPM).

Many of the global best practices have evolved over several years of hard work carried out by scientists of the respective countries. These practices were mostly tailor-made for the local adaptable conditions. Obviously, the best practices in a country would depend on the local climate, varietal adaptability, seasonal water availability, soil type and nutrient status, major insect pests and diseases and market demand. It is possible that many of the practices may or may not be suitable for other countries. However, the basic principles of 'best practices' are oriented towards ecology, environment and sustainability. These practices can be validated for local situations in India.

Technologies seldom deliver results independent of the environment in which they are expected to perform. One or two ideas picked up from the global best practices may or may not blend into the matrix of practices followed in other countries. Therefore to harness the full potential of the new practices, it would be extremely important to examine the interactive effects of the introduced practices with the extant technological environment prevalent in the country. For new practices to be harmonized with the existing system, it may be necessary to shed a few old practices that are incompatible with the new ones.

Cotton crop needs at least 80% of its total water and nitrogen requirement during flowering and fruiting phase. Water and nutrient availability during flowering and fruiting is crucial for good yields. While the critical reproductive phase has been compressed in many countries, India has a long critical window. Therefore one of the first considerations should be to compress the duration of the critical flowering-fruiting window in India. It would then become convenient to ensure the availability of water and nutrients during the critical phase. Pest management and weed management also would become easier. Thus the road-map for high yields and low production costs must essentially overcome the problem of long duration hybrid cotton by alternative systems that depend on short-duration cotton varieties.

Short duration varieties sown in time with onset of monsoon, under high density planting will be able to get proper soil moisture and nutrients. Such varieties will have a narrow flowering window of 20-30 days that would possibly enable the crop to escape the American bollworms. Soil moisture would also be available adequately during the short flowering and boll formation window for the 7-9 developing bolls per plant. With available soil moisture, the plants are able to absorb available nutrients. Under high density planting of 1.6 to 2.0 lakh plants per hectare, 7-9 bolls per plant result in high yields in a short time. Weather conditions of 27 to 32 °C with day temperatures higher than 20°C and night temperatures higher than 12°C are prevalent during the monsoon and the immediate period after cessation of monsoon, which coincides with the 20-30 day flowering and 60-90 day boll formation phase. Boll bursting is synchronous in high density planting. With the availability of adequate soil moisture and nutrients the fibre quality is uniform and good. Intercropping with short duration legumes provides adequate nitrogen exactly at the flowering and boll formation stage. Legume intercropping provides a wide range of beneficial natural enemies that assist in IPM, thereby reducing the need for insecticides. Cultivation of legume intercrops in between rows in high density systems or in crop rotation reduces the need for repeated weeding and can assist in conservation agriculture. Thus adjusting the narrow critical window to coincide with adequate natural resources, also enabling the

critical window to escape biotic and abiotic stress, coupled with providing water and nutrients to the crop at the critical phase, would result in doubling yields and ensure sustainable cotton cropping systems

7. THE TEN COTTON COMMANDMENTS FOR DOUBLING OF FARM INCOME

If there is one single message that Indian breeders, agronomists and plant protection specialists need to take seriously, it is “-**India needs to design its crop duration as per the monsoon and soils**” Hybrids may provide high yields in fertile soils with input-intensive management in irrigated farms. Pure-line varieties of the short-duration kind will be best suited for rain-fed farms. The one greatest fault-line in Indian cotton is the mish-mash usage of fertilizers and pesticides. As pointed out before, this happens only in India because of the inordinately long duration of the flowering and fruiting window of the crop, which is responsive to fertilizers and responsible for major pest attacks. Therefore the most important message is ‘**SHORT DURATION CROP**’ with a narrow flowering-fruiting window. Risk mitigation is possible with varieties that are endowed with the capacity to compensate and rejuvenate, just in case the first flush gets negative affected due to biotic or a-biotic stress.

The following strategies attempt to lay down the road-map to enhance the yields multi-fold through production strategies that are economically viable and ecologically sustainable. These are based on the established best global practices that helped countries to double their yields over the past 10 years which could be adapted to Indian conditions. While a few of the global best practices were validated through on-farm experiments in India, more needs to be done to validate the rest.

Following is the list of the 10 new ingredients based on ideas derived from ‘global best practices’ that when integrated with standard precision practices can potentially revolutionize cotton production in India.

1. **New short duration varieties:** long-lint Desi (*Gossypium arboreum*) and Bt-varieties
2. **High density planting systems & short-dense-early pattern**
3. **Sub-soiling to break hard-pans**
4. **Precision planting**, north-south oriented row direction & nursery raised plants
5. **Plastic mulching, drip irrigation** under plastic mulch & water management
6. **Stale-weed-seed-bed system**
7. **Conservation tillage, cover crops**, crop residue recycling or mulching
8. **Square and boll retention** with plant growth regulating chemicals
9. **Canopy management**
10. **Precision chemical input management**

The above 10 new ingredients are blended with the precision production practices to set out a new set of guidelines and principles listed below, that have great potential to enhance yields at low production costs in consonance with ecology and environment.

1. **New short duration varieties: long-lint Desi (*Gossypium arboreum*) and Bt-varieties:**
The most crucial factor for high yields in India, is a variety with five main attributes of -short duration (140-160 days), compact architecture, high harvest index, resistance to sap-sucking pests and high ginning% (>40%). Attempts were made over the past 10 years to develop such varieties suited for high density planting in India.

New Break-through Desi (*Gossypium arboreum*) varieties: The Desi cotton species are unique to India. The species is endowed with inherent robustness of high tolerance levels to insects, diseases, salinity and drought. However, Indian Desi varieties were known for their long duration, small boll size and short staple coarse fibre, because of which their cultivation was limited to challenging areas. The ICAR-CICR (Central Institute for Cotton Research) in collaboration with the State Agricultural Universities identified several short duration Desi cotton varieties of high ginning% (>40%), high harvest index, high tolerance to pests, diseases and drought in all categories of fibre (short, medium and long staple) that give high yields with negligible chemical inputs at phenomenally low cost of production. Phule Dhanwantary is an excellent high yielding short staple variety from MPKV Rahuri. PA-255, PA 402 from VNMKV Parbhani and Roja from ICAR-CICR are medium staple varieties. Two years ago, a break-through was achieved by the Cotton Research Station of Nanded (VNMKV, Parbhani). The breeders developed several long-lint (28-31 mm) *Gossypium*

arboreum (Desi species) short duration varieties. PA-08, PA-528, PA 740 and PA 812 are a few of the outstanding long staple varieties. The long staple Desi varieties were tested extensively by ICAR-CICR in multi-location trials across the country and were found to hold great promise because of their excellent premier fibre qualities, high yields in high density planting at very low production costs with least requirement of chemical inputs. Some of the varieties are likely to be released within the next two years.

Bt-cotton in local varieties: Bt-cotton technology performs best when introduced into locally adapted pure-line varieties. The ICAR-CICR in collaboration with the State Agricultural Universities has been working over the past few years to develop 21 new Bt-cotton varieties. These were tested at 17 locations across the country and 3-4 new Bt-varieties were short-listed separately for each state recently for their excellent performance under high density conditions. At least 8 Bt-varieties are likely to be available across India for commercial cultivation by the Kharif season of 2018. A few Bt-varieties are endowed with highly desirable traits such as short duration; sympodial architecture; early maturing with synchronous flowering and fruiting; high initial root and shoot vigor; high harvest index with least unproductive branches and leaves; resistance to sap sucking insects such as leaf hoppers, aphids, thrips and whiteflies; resistance to 'bacterial leaf blight' and tolerance to 'cotton leaf curl virus' and other diseases; desirable fibre qualities with high ginning% of 37-40% and amenable to machine picking. In a very exciting development, a new compact Bt culture 'Ugank' of 120 days duration was identified and is in the final stage of testing. The culture was originally contributed by Prof. Srikant S. Patil from UAS Dharwad and mentored as a Bt-variety by Dr Santosh at ICAR-CICR Nagpur. It is highly tolerant to sap-sucking pests, short statured at 65-70cm height with high harvest index and very good fiber quality. Its performance in field trials at CICR farm was excellent. In my 25 years of experience in cotton research, I would rate this development as one of the most promising for Indian cotton. It holds tremendous promise for its break-through potential especially in the rain-fed regions of Vidarbha and Telangana.

2. **High density planting systems (HDPS) & 'Short-dense-early' pattern:** High density is defined by a spacing of 10 cm between plants in a row, with variable row spacing at 38 to 100 cm. The ICAR-CICR spearheaded the HDPS programme in India to demonstrate high yields with low input costs with short duration varieties. All the countries that have yields higher than 1000 kg/ha are known to have been following the high density approach. Plant density is kept at more than 110,000 plants per hectare. Interception of light is an important factor for high yields. Therefore compact varieties are more suited for high density planting. In high density planting, at least 7 plants are kept per meter row length. Fewer plants than this would produce more bolls on outer positions and delay maturity. Generally row spacing is decided based on the soil type, weather and availability of water, with narrow spacing more suited for adverse conditions. Some parts of India did follow a spacing of 67.5 x 15 cm traditionally. However, the yields were low because of the long duration and unsuitability of varieties that were generally bushy. The new varieties (Bt & Desi non-Bt) were tested by ICAR-CICR under high density planting systems in all the major cotton growing locations under Indian conditions. Field experiments showed that the Bt-varieties and Desi varieties under high density planting consistently out-yielded the reference Bt-hybrids at recommended spacing at all locations. The varieties if cultivated with conservation tillage, plastic mulching, canopy management and precision input management are likely to give outstanding results.

A novel pattern called "short-dense-early" is widely adopted in the north-west inland cotton region of China to obtain high yields. High density cotton is cultivated with early planting of early maturing varieties using drip irrigation under plastic mulches, which also leads to short plant height, promotes early maturity and results in high lint yields. Super-high density planting technique is used with 'short-dense-early' varieties planted at 200,000 to 300,000 plants per hectare, mainly in the north-west inland area of China. Indian cotton breeders must new compact-short statured varieties for such systems to be tried in India for high yields.

3. **Sub-soiling to break hard-pans:** Though not taken seriously, hard-pan is a major problem in many regions in the country that results in poor root penetration and low yields. Land Preparation must be done by sub-soiling at a depth of 40-45 cm to break the hard-pan and sub-soil layer to improve water and root penetration. Avoid compaction due to tillage machinery

to retain porosity and soil structure for internal drainage which is a limiting factor in heavy clay soil.

- 4. Precision planting, north-south oriented row direction & nursery raised plants:** Under many conditions, early sowing helps the crop to establish vigorously and escape several insect pests. Seeds must be planted at uniform spacing of 10-12 cm between plants with precision in drilled or hill drop pattern at a depth of 4-6 cm with precision planters. Row spacing may be kept at 45cm or 60cm or 75cm or 90cm depending on type of variety, soil, water source and weather. This will optimize emergence, save seed and ensure uniform germination. Planting on ridges or raised beds using BBF (broad-bed furrow) planters improves drainage, warms soil and provides less favourable conditions for seedling pathogens.

North-south oriented row direction would ensure effective penetration of solar radiation to plants in a row especially during squaring, flowering and boll formation.

Seedlings can be raised in nurseries a month before the onset of monsoon using soil blocks (8x4 cm) containing 10% organic manure. Wherever nursery-raised plants are used, crow-bar method may be used for planting. Machines for nursery planting have been developed in China. These ensure precision planting at proper spacing of 10 cm between plants within a row. Cotton seedlings transplanted immediately after the onset of monsoon develop into vigorous and robust plants to give high yields. Use systemic pesticides for seed treatment to protect the seed and seedlings from insects, nematodes and pathogens. Scouting for early season pests / symptoms of pest damage improves pest management decision making

- 5. Plastic mulching, drip irrigation under plastic mulch & water management:** The use of plastic mulches is negligible in India. In China, plastic mulches are used extensively to cover almost all cotton fields across the country in 30 to 40 lakh hectares especially in the arid and semi-arid regions of northern China and coastal saline-alkali areas. Machines are used in China to cover inter-row space with plastic film 30 days before sowing (early mulching) to improve plant stand establishment, biomass, lint yield and earliness. Drip irrigation in mechanized plastic mulching and training plant architecture in high density planting played a major role in enhancing yields in majority of the areas in China and in some parts of India.

Water management: Cotton is extremely sensitive to excess moisture and water stagnation could reduce yields in heavy textured soils. Drainage of excessive water is crucial for a good crop. Ridges and furrows enable effective drainage and moisture conservation especially in rain-dependent regions. Wherever irrigation is available, drip irrigation or furrow irrigation may be followed. Ideally adequate amount of water and nutrients should be made available in a precise manner based on the crop requirements during flowering and fruiting period to obtain high yields. Avoid water stress from squaring, flowering and early boll window. Adequate soil moisture during this critical phase helps plants establish the desired structure and helps in the retention of fruiting forms. Do not provide heavy irrigation after the first open boll. Moist soil at first open boll is sufficient to provide adequate moisture required to mature the crop. Excess moisture delays harvest and complicates pest management.

- 6. Stale weed-seed bed system:** Weed management in the early stages of seedling growth is very crucial for high yields. Application of pre plant, contact herbicides, three weeks prior to planting enables the preparation of a stale-seed-bed while ensuring that no green vegetation is left on the field. Application of post-emergence herbicides on weed-seedlings and or application of pre-emergence herbicides such as pendimethalin 1.0 kg a.i./ha just before sowing helps cotton seedlings to retain their initial vigour in the absence of weed competition. Fields must be kept free of weeds through subsequent inter-culture and weeding at least for the first 2-3 months of the crop to prevent weed competition.
- 7. Conservation tillage, cover crops, crop residue recycling or mulching:** Wherever possible, zero-tillage and strip tillage should be practices to facilitate timely planting rather than waiting for optimum soil conditions for conventional tillage. In zero-till or strip till systems, winter cover crops protect the emerging cotton seedlings. Plant legume crops such as soy bean, cowpea, groundnut, sesbania and sunhemp or melon and pumpkin are sown in alternate rows of cotton as cover crops. The inter-crops, more especially the green manure

cover crops sesbania or sunhemp may be sown 15-20 days after sowing cotton crop to avoid competition. These crops may be mowed and tilled into the soil after they attain 30-40 days age to act as effective green manure and mulch. Sesbania and Sunhemp are also called "green manure" and "live mulches." because they fix atmospheric nitrogen, provide other nutrients to the soil apart from preventing soil erosion and evaporation of soil moisture. In addition, intercropping with legume crops such as red-gram, black-gram, green-gram, cow-pea etc., encourages establishment of predators and parasitoids of insect pests.

Post harvest shredding and incorporation of crop residues and cotton stalks into soils plays an important role in pest management and nutrient management. Shredding of stalks prevents over wintering of pink bollworm. It also ensures a mandatory 90 days host free period for pink bollworm. Cotton stalks from one hectare when incorporated back into the soil, provide 20-25 kg nitrogen and 70-80 kg phosphorus per hectare. Currently, crop residues are burnt in India resulting in loss of biomass and environmental pollution.

8. **Square and boll retention with plant growth regulating chemicals:** Regular crop health monitoring should be done especially for canopy-shading and nutrient deficiencies that cause square-shedding, boll shedding etc. to ensure timely interventions of natural light, water, fertilizer and application of plant growth regulators such as 'alpha-naphthyl acetic acid' as and when necessary. The crop should be examined periodically for moisture stress, water-logging, diseases and insect pests to initiate timely interventions. At squaring stage, data on plant height, number of nodes, node of first fruiting branch and fruit retention at first position helps to detect fertilizer or moisture stress/excess. At flowering stage, data on plant height, number of nodes, number of nodes above upper most position white flower (NAWF), retention of first position square (below white flower) helps to detect deficiencies or excess in fertilizer application or stress due to deficit or excess moisture. The need for application of plant growth regulators can be decided based on excessive vegetative growth if any.
9. **Canopy management:** Plant training practices such as removal of vegetative branches, old leaves, empty branches, early fruiting branches, apical points of vegetative and fruiting branches and removal of growth-tip (topping), are done for canopy management mainly to facilitate nutrients to be redirected to fruiting parts. Plant growth regulators (PGRs) are used for canopy management to prevent excessive vegetative growth and allow adequate transfer of nutrients to bolls. Low rate multiple applications of PGRs are less risky. Under Indian conditions it may be appropriate to resort to topping at 90-100 days and use a PGR such as mepiquat chloride to prevent a bushy lateral growth of fruiting branches. It helps to maintain an open canopy, limits vegetative carbon sink and stimulates the development of bolls on lower branches, instead of inefficient boll set on the upper branches which gets most affected due to moisture stress in the late stages of the crop. However the effects of PGR application are dependent on soil moisture levels, nutrition and crop management.
 - **Restricting plant height:** Aeration and ventilation in the high density crop is ensured by controlling the plant height to 65-70 cm by using PGRs, water and nutrients.
 - **Topping:** Removal of growth tips on the main stem (topping) is carried out when the number of fruit branches is 10 to 20 per plant depending on the density of plants per hectare. Plant topping is conducted in 100% of cotton fields in China for regulating plant growth and increasing yield.
 - **Removal of vegetative branches:** Vegetative branches are removed manually after appearance of the first fruiting branch in 50-70% of the farms in China. This practice was found to increase seed cotton yield significantly.
 - **Removal of unproductive plant parts:** Empty fruiting branches, old and yellow diseased leaves are removed after full flowering for remarkable improvement in ventilation, light penetration, reduction in soil humidity and boll rotting.
 - **Removal of apical points:** Apical points of vegetative branches are removed after peak flowering and those of fruiting branches are removed at peak boll-setting.
 - **Removal of early fruiting branches:** Early fruiting branches, generally the lower most 2-3 fruiting branches of the main stem are removed at peak squaring stage.
10. **Precision chemical input management:**
 - Nutrient management based on soil fertility status:** Cotton crop needs 85% of nitrogen during the critical stage of flowering and early boll formation. Soil nutrient status is determined

by plant analysis and soil testing to diagnose nutrient deficiency and provide corrective measures. Synchronizing nutrient availability with plant nutrient demand at critical stages, saves fertilizers, improves nutrient use efficiency and results in high yields. Application of fertilizers in three splits at planting, squaring or flowering stage and after topping helps in providing nutrients when the plant needs them most. Band placement of fertilizers, especially neem-coated urea ensures controlled release with minimum nutrient loss. Drip-fertigation can be used for precision nutrient delivery. Application of Farm Yard Manure @ 5 to 10 t/ha or compost after the first rain. Seed treatment with *Azotobacter* and PSB (phosphate solubilizing bacteria) @ 25 g each / kg seed helps in nutrient uptake. Nitrogen should be applied in splits, with full dose of phosphorus and potash at planting or early vegetative phase. Nitrogenous fertilizers should be applied judiciously to the minimum to prevent the proliferation of sap-sucking pests. Excessive application of nitrogen makes the crop susceptible to insects and diseases, induces rank vegetative growth, results in boll shedding, delays fruiting and crop maturity and reduces lint yield and profit. Limited usage of nitrogenous fertilizers plus full application of P+K before flowering helps in reduction of sucking-pest infestation. Solubilization of soil bound phosphorus can be improved by making conditions favorable for mycorrhizal association with cotton roots. Use foliar potassium application only to supplement soil application and not as a substitute. Peak demand for potassium is during boll filling stage. Low potash in soils and less active root system limits soil K uptake and hence foliar supplementation of K is beneficial. Secondary nutrients such as Ca and Mg needs as best assessed through soil tests. Normally amendments are used to regulate soil pH that takes care of Ca and Mg requirement. Micronutrient bio-availability is also governed by soil pH. Therefore correction of soil pH is important. Sandy soils with low organic matter are more prone to micronutrient deficiencies. Appropriate application of micronutrients during the flowering and fruiting phase facilitates good crop health management. It is important to determine soil pH and amount of residual nutrients to make amendments for less mobile nutrients such as P, K, Ca and Mg. Cotton grows best at soil pH of 5.8 to 8.0. Use amendments like gypsum and lime to correct soil pH. Boron is a key element for cotton and a separate soil test for Boron is helpful to decide on an efficient micronutrient supplementation program.

Pest and disease management: The best pest management is through host plant resistance that can be supplemented by naturally occurring biological control. Varieties that are resistant to sap sucking pests provide robust foundation for integrated pest management. Coupled with appropriate seed treatment these varieties can tolerate sap-sucking pests and diseases so that there would not be any need for pesticide applications early in the season at least for 2-3 months after sowing. In the absence of early season application of eco-disruptive pesticides, naturally occurring biological control gets strengthened and plays a significant role in sustainable pest control. Early planting of short season varieties enables the crop to escape several species of insect pests. Avoidance of excessive nitrogen is crucial for crop health. Other technologies such as IPM compatible inter-crops, trap crops, botanical pesticides, augmented biological control, pheromones (monitoring and trapping) and cultural control practices can assist in effective control of insect pests and pathogens in an eco-friendly and sustainable manner without the need for chemical pesticides. Chemical pesticides must be considered only as a last resort. Pesticide and insecticide mixtures must be strictly avoided. Chemical pesticides belonging to WHO Class I (extremely or highly hazardous) must be strictly avoided. As far as possible prefer WHO Class III or safer insecticides. Choice of insecticides must be based on principles of IRM (insect resistance management) to minimize resistance risk and IOBC (International organization for biological control) rating for selectivity to beneficial and bio-control insects.

8. IMPACT OF TMC PROGRAMME

The TMC (Technology Mission on Cotton) project which made a tremendous impact on cotton production and processing was not acknowledged due to over-emphasis on the Bt-wave. The project that worked its way through farmers, researchers, traders and the value chain industry, was widely acknowledged initially for its great impact, but was soon subsumed into the Bt-wave especially after 2006. Cotton yields increased in India mainly during 2002 to 2005. And that this increase was due to many other factors that were supported with a bollworm-protection cover from Bt-technology.

Though not given its due credit, the TMC (Technology Mission on Cotton) did a spectacular job in developing and identifying the best technologies for integrated pest management, cropping systems for specific agro-eco zones, integrated nutrient management and integrating best practices in crop production. While new package of best practices were developed through research under the Mini-mission-1 (TMC-MM-I), MM-II focused on front-line demonstrations and area-wide technology dissemination across 9 cotton growing states. MM-III and MM-IV dealt with modernization of market yards and ginning mills.

The Ministry of Agriculture approved projects on the IRM strategies for dissemination all over the country (2002-2010 with a funding of about Rs 1.5 crores per year. IRM strategies were disseminated through the project "Dissemination of IRM strategies in 260 villages in India" Funded by the Ministry of agriculture under Technology Mission on Cotton, Mini-mission-II (TMC-MM-II). The IRM programme was implemented in major cotton growing states through Agricultural Universities, State Agricultural Departments and NGOs under the leadership of ICAR-CICR. Area wide farmer participatory 'Insecticide Resistance Management' strategies were disseminated in 322,858 ha area of 157,496 farmers in 2492 villages from 10 different states. In IRM fields, farmers sprayed average 2.56 sprays/ha as compared to 5.86 sprays/ha by non-IRM fields. Thus the research and technology innovation resulted in reducing the usage of insecticides by more than 60-80% without any reduction in yields. Proper use of insecticides also resulted in better pest control and up to 30% more yields as compared to fields of non-participating farmers. Subsequent to the introduction of Bt cotton hybrids in 2002, sap-sucking pests increased because of the introduction of hybrids susceptible to sap-sucking insects. The IRM/IPM strategies were followed by farmers in the initial phase of Bt-era from 2002 to 2005 using resistant varieties and seed treatment to ensure that sap-sucking pests were effectively controlled.

Cotton production from 1998 to 2001 was affected by a consistent drought. There was an outbreak of bollworm and whiteflies in 2001 due to severe drought in some regions of Maharashtra, Gujarat and AP. Insecticide usage on cotton was high at 12,722 Mt in 2001. Strong efforts made under the TMC MM-II project on insecticide resistance management resulted in effective pest management coupled with a significant 50% decline in insecticide usage to 6580 Mt in 2002. The TMC made significant impact from 2002 to 2004. The area under Bt-cotton, including the illegal hybrids was negligible at 0.4% in 2002, 1.2% in 2003 and 5.7% in 2004. However lint yields increased spectacularly due to the TMC project from 302 kg/ha in 2002 to 399 kg/ha in 2003 and 470 kg/ha in 2004 according to the Textile Ministry. Data of Agricultural Ministry showed that lint yields were 191 kg/ha in 2002, 306 kg/ha in 2003 and 319 kg/ha in 2004. Insecticide usage for bollworm control decreased consistently (except during 2001) from 7930 Mt in 1998 to 4470 Mt in 2002.

The Bt-technology was effective in controlling bollworms while farmers were able to manage sucking pests on Bt-hybrids and all pests including the bollworms on non-Bt cotton with the help of the TMC project. With the approval of more than 2000 new Bt-hybrids for commercial cultivation after 2006 management became unwieldy. After 2006, the TMC project found it difficult to handle the utter confusion created by the constant introduction of 200-300 new Bt-hybrids every year, most of which were susceptible to sap-sucking insects and were of long duration extending from 180 to 240 days duration. Pesticide usage increased, yields stagnated. The Bt-wave subsumed everything that came its way. TMC effects were marginalized and the project was not properly acknowledged.

NATIONAL COTTON MISSION TO DOUBLE FARMERS INCOME 2017-20

Doubling of income can happen either by increasing yields or by reducing production costs or both provided that the market demand remains sustainable. Appropriate technologies and strategies are needed either to increase yields or reduce production costs. Currently India has access to all the cotton technologies and agri-ingredients that are available to all other advanced countries, including Australia, Brazil, USA and China etc. More than 90% of the 10 to 13 million hectares in India are saturated with Bollgard-II Bt-hybrids. However, yields at an average of 500 kg lint per hectare were stagnant for more than a decade and are now on a declining trend despite the access to all the latest technological advances. Currently there is no prospective promising technology in sight from the private or corporate sector, either in the form of GM (genetically modified) or otherwise, that has the potential to trigger a change towards yield enhancement. Therefore, there is an imminent need to seriously introspect and explore ideas of all kinds including 'out-of-the-box' concepts, eventually to develop roadmaps to establish alternative cotton production systems to usher in a new sustainable

era of high yields from low production costs. The proposed alternatives must be robust enough to inspire confidence in farmers for a change.

Do we have the technologies available with us to double India's average yields to 3000 kg seed cotton per hectare, or do we have to explore new options? Indeed some farmers in India get yields of 3000 to 4000 kg seed-cotton per hectare with the existing technologies of early sown hybrids or varieties cultivated in deep black-cotton soils grown for about 210-240 days under drip irrigation, plastic mulching and high levels of fertigation. But these could be 'islands of prosperity in oceans of poverty'. Most of these high-yield farms are based on high input management and cannot be replicated in the fields of small farmers, especially those having marginal soils under rain-fed conditions. Therefore, there is a need to explore those technological options that can be most relevant to the vast majority of farmers who cultivate cotton on marginal soils with low inputs, especially in rain dependent conditions that constitute 60% of India's cotton acreage.

Indian cotton now has access to all technologies including IPM, IRM, INM, IWM, Bt-hybrids and Bt-varieties. With the new alternative system of high density planting with the new short duration Bt-varieties and Desi-varieties that have high harvest index, high ginning% and very good fiber qualities, there is tremendous hope that yields can be easily doubled and cost of production can be reduced significantly. It is now only a matter of time and concentrated efforts for the country to emerge as a global leader in cotton productivity in a sustainable manner.

India needs new remedies to set up sustainable cotton production systems. We need a clear plan. If farmers income has to be doubled, there is an imminent need for a robust set of crop production strategies to enhance yields and lower down production cost.

How will the yields increase?

Research across the globe and at ICAR-CICR proved that '**High Density Planting System (HDPS)**' of short duration varieties enhances yields significantly. Yields can be increased with HDPS of Bt-varieties to be taken up at 75x10 cm (133,000 plants/ha which is 10 times the current density) at 150 to 160 days. The current projects are designed to increase yields using **HIGH DENSITY PLANTING SYSTEM** of **NEW SHORT DURATION BT-VARIETIES & SHORT DURATION DESI LONG STAPLE VARIETIES**. The system would result in higher yields due to more number of plants producing fewer bolls in a short time.

How is the production cost reduced?

Management is long-drawn and cost of production is high with long duration crop. Management of water, pests and fertilizers are most critical for high yields during the flowering-fruiting window. Short duration crop greatly enhances management efficiency due to the narrow critical 'flowering-fruiting' window. Pest vulnerability is greatly reduced and fertilizer use-efficiency is greatly enhanced because of the narrow critical window thereby resulting in low production costs and high yields. The new short duration cotton varieties (Desi and Bt) are tolerant to sucking pests and escape the pink bollworm, which occurs mainly late in the season. Bt-varieties are effective in controlling American bollworm due to the homozygous of *cry1Ac* genes. One or two insecticide sprays may be required only on Desi cotton for the control of American bollworm at economic threshold levels. Thus insecticide usage and pest damage would be almost negligible.

What will the extent of impact be?

For a change to happen, impact has to be on a large scale pan-India. Technologies can now be spread rapidly with the use of Information and communication technologies especially through voice-mails and mobile apps. **WEEKLY VOICE-MAIL & E-ADVISORY TECHNOLOGIES** will be used to relay messages periodically to at least 4 to 5 lakh farmers across India in the 50-60 major cotton growing districts of 10 cotton growing states, to ensure enhancement of nutrient use efficiency, water use efficiency & chemical-use-efficiency to reduce the cost of production significantly. The three projects will work in tandem with each other to establish sustainable production systems in India. The project also aims to create a new brand of '**INDIAN COTTON**' with the new long-staple *Desi* cotton varieties.

1. Sub-Project 1: Adapting global best practices to India
Sub-sub project 1a: Popularization of public sector Bt-cotton varieties & development of new ultra-short-duration (120 days) Bt-varieties
2. Sub-Project 2: New long staple *Desi* cotton (*Gossypium arboreum*) varieties
Sub-sub project 2a: Organic *Desi* cotton & creating a new brand of 'INDIAN COTTON'
3. Sub-Project 3: Technology reach-out with weekly 'voice-mails' mobile-Apps, SMS and Advisories

Sub-project 1: ADAPTING GLOBAL BEST PRACTICES TO INDIA

Many of the global best practices have evolved over several years of hard work carried out by scientists of the respective countries. These practices were mostly tailor-made for the local adaptable conditions. It is possible that many of the practices may not be suitable for other countries. However, the basic principles of 'best practices' that provide high yields are based on ecology, environment and sustainability. The choice of best practices in a country would depend on the local climate, varietal adaptability, seasonal water availability, soil type and nutrient status, major insect pests and diseases and market demand. Cotton crop needs 80-85% of its total water and nitrogen requirement during flowering and fruiting phase. Water and nutrient availability during flowering and fruiting is crucial for good yields. While the critical reproductive phase has been compressed in many countries, India has a long critical window. Therefore one of the first considerations should be to compress the duration of the critical flowering-fruiting window in India. It would then become convenient to ensure the availability of water and nutrients during the critical phase. Pest management and weed management also would become easier.

Based on the lessons learnt from the best practices followed across the globe, the following basic principles were considered in research programmes carried out at ICAR-CICR over the past 7-8 years to prepare a road-map for sustainable cotton production for India. Some aspects of the programme are listed below:

Guidelines for plant breeders to develop varieties for break-through production

1. Short duration (140-160 days)
2. Sympodial architecture
3. Early maturing with synchronous flowering and fruiting
4. High initial root and shoot vigor
5. High harvest index with least unproductive branches and leaves
6. Resistance to sap sucking insects such as leaf hoppers, aphids, thrips and whiteflies
7. Resistance to 'bacterial leaf blight', 'cotton leaf curl virus' and other diseases.
8. Desirable fibre qualities with high ginning%
9. Amenable to machine picking

Guidelines for agronomists for crop production practices

1. Plastic mulching or bio-mulching with crop residues
2. Crop rotation with legume crops or green manure crops
3. Intercropping with legume crops such as red-gram, black-gram, green-gram, cow-pea etc., encourages establishment of predators and parasitoids of sucking pests
4. Stale-seed-bed for efficient weed management
5. Adjusting sowing or planting dates to ensure vigorous plants
6. Early sowing is preferred under most situations
7. Direct precision seeding may be done at 1 to 4 cm depth on ridges at 10cm spacing between plants within a row
8. Wherever nursery-raised plants are used, crow-bar method may be used. Machines for nursery planting would ensure precision planting at proper spacing of 10 cm between plants within a row.
9. Orient rows in north-south direction in high density crop for light interception
10. Row spacing may be kept at 45cm or 60cm or 75cm or 90cm depending on type of variety, soil, water source and weather

Recommended production practices for sustainable farming

1. **Minimum tillage:** Inter-cultivation and tillage at full post-emergence and flowering
2. **Square and boll retention:** Regular crop health monitoring especially for nutrient deficiencies, for square-shedding, boll shedding etc. to ensure timely interventions of water, fertilizer and PGR application.
3. **Water management:** Drainage of excessive water is crucial for a good crop. Ridges and furrows enable effective drainage and moisture conservation. Wherever irrigation is available, drip irrigation or furrow irrigation may be followed. Ideally adequate amount of water and nutrients should be made available in a precise manner based on the crop requirements during flowering and fruiting period to obtain high yields.
4. **Precision nutrient management:** Optimizing of nutrient application should be based on soil health conditions. Application of fertilizers in three splits at planting, squaring or flowering stage and after topping. Band placement of fertilizers, especially neem-coated urea ensures controlled release with minimum nutrient loss. Drip-fertigation can be used for precision nutrient delivery. Application of Farm Yard Manure @ 5 to 10 t/ha or compost after the first rain. Seed treatment with *Azotobacter* and PSB (phosphate solubilizing bacteria) @ 25 g each / kg seed. Nitrogen should be applied in splits, with full dose of phosphorus and potash at planting or early vegetative phase. Nitrogenous fertilizers should be applied judiciously to the minimum to prevent the proliferation of sap-sucking pests. Limited usage of nitrogenous fertilizers plus full application of P+K before flowering helps in reduction of sucking-pest infestation. Appropriate application of micronutrients during the flowering and fruiting phase helps in good crop health management.
5. **Crop monitoring:** The crop should be examined periodically for moisture stress, water-logging, diseases and insect pests to initiate timely interventions.
6. **Weeding:** Fields must be kept free of weeds at least for the first 2-3 months of the crop. Stale-weed-bed with pre-emergence herbicides and subsequent inter-culture and weeding should be done to prevent weed competition.
7. **Pest management:**
 - a. Select varieties that are resistant to leaf hoppers
 - b. Seed treatment to protect seed and seedlings from insect pests, nematodes and pathogens
 - c. Short duration varieties under high density planting have less problems from bollworms because of the narrow flowering and boll-formation window
 - d. Early sowing helps to escape many insect pests
 - e. Avoid insecticides for the first 2-3 months after sowing
 - f. Avoid excessive nitrogen to avoid pests and diseases
 - g. Intercropping with legume crops strengthens biological control
 - h. Cultural practices for pest control must receive top priority
 - i. Use light traps, pheromone traps for monitoring
 - j. Use vegetable oils, botanical pesticides and augmented biological control in the initial phase
 - k. Chemical pesticides must be chosen as a last resort.
 - l. Pesticide and insecticide mixtures must be strictly avoided
 - m. Chemical pesticides belonging to WHO Class I (extremely or highly hazardous) must be strictly avoided. As far as possible prefer WHO Class III or safer insecticides.
 - n. Choice of insecticides must be based on IOBC (International organization for biological control) rating for selectivity to beneficial and bio-control insects.
 - o. Other technologies such as inter-crops, trap crops, botanical pesticides, augmented biological control, pheromones and cultural control practices can assist in effective control insect pests and pathogens in an eco-friendly and sustainable manner.
 - p. The use of bio-pesticides and biological control must be properly deployed in pest management to ensure least use of chemical pesticides for pest management
8. **Timely crop termination**

9. **Convergence of IPM, IWM and INM:** Integrated nutrient management (INM), Integrated water management (IWM) and Integrated pest management (IPM) should be worked out in consonance with each other to evolve harmonized crop health management.

Experiments that are required to be carried out

10. **Canopy management:**

- a. Restricting plant height to 80-90cm
- b. Topping when plants have 15 sympodial branches
- c. Removal of vegetative branches after square initiation
- d. Removal of empty branches and diseased leaves after flower initiation
- e. Removal of apical points of vegetative branches after peak flowering and those of fruiting branches are removed at peak boll-setting.
- f. Removal of 2-3 early fruiting branches of the main stem are removed at peak squaring stage.

11. **Bt-cotton in local varieties:** Bt-cotton technology performs best when introduced into locally adapted varieties. New varieties were developed by ICAR-CICR under the TMC programme. Twenty one varieties were tested during 2016-17 at 17 locations across India under the All India coordinated cotton improvement programme. Eleven varieties were found to give yields higher than the best Bt-hybrid under rain-fed and irrigated conditions at less production costs.

Sub-sub project 1a: DEVELOPMENT OF PUBLIC SECTOR BT-COTTON VARIETIES

Recently a few elite varieties were converted by ICAR-CICR and a few State Agricultural Universities under the CICR-TMC project into 'Bt-cotton varieties' using a cry1Ac gene Mon531 event (not covered under IPR).

Twenty four Bt-varieties containing the introgressed MON 531 event of Cry 1Ac gene were tested across different locations across North zone (Punjab, Haryana, Rajasthan), Central Zone (Gujarat, Maharashtra, Madhya Pradesh, Odisha) and South Zone (Telangana, Andhra Pradesh, Karnataka and Tamilnadu) under the aegis of AICRP on Cotton during 2016-17. The varieties were sponsored by ICAR-CICR Nagpur, ICAR-CICR-RS-Sirsa, PAU, Ludhiana, OUAT Bhanuapattana, MPKV Rahuri, South Indian Mills Association (Coimbatore), and a private company in Guntur (for South zone only).

Data on yield, yield attributes, fibre quality, plant height, ginning out turn and pest/disease incidence were collected at each location. Additional data on DUS characters, Bt toxin expression level, Bioassay against bollworms were recorded at representative centres in each zone. Event confirmation and homozygosity tests were conducted at ICAR-CICR Nagpur. Data from different centres were compiled at AICRP on Cotton, Headquarters (Coimbatore) and placed before the Council for approval.

- Fibre quality data has been obtained and was found to be on par with the Bt-hybrids.
- The Bt-varieties are of 140-170 days duration except code Number 220 which took 180-190 days for maturity.
- It is proposed to provide 120g pigeonpea seeds of early maturing varieties to be planted as refugia per acre of Bt-cotton variety.
- About 400 Kg seeds of each of the Bt-varieties are available with ICAR-CICR and the concerned breeders for multiplication during 2017-18

NORTH ZONE:

Based on the report submitted by the Project Coordinator (Cotton), vide letter F No PC/5/1/2016/17/1499/1505 dated Dec. 7, 2016, the Council has vide letter F No CS 4-4/2016-CC dated Jan. 3, 2017 approved 3 Bt cotton varieties viz **RS 2013**, **PAU 1** and **F 1861** for the preparation of release proposal and seed production during off-season.

CENTRAL ZONE:

Six locations viz., 1) NAU, Surat, 2) ICAR-CICR, Nagpur, 3) PDKV, Akola, 4) VNMKV, Nanded 5) MPKV, Rahuri (**irrigated**) and 6) OUAT, Bhawanipatna.

In Maharashtra, Bt-Variety CICR-SRI-1 gave high yields of 28.5 q/ha in rainfed and 31.89 q/ha in irrigated conditions compared to 23.5 q/ha of the best BG-II hybrid in the trials. Other entries such as MPKV-Rahuri-1, OUAT Bt-1 and CICR-CPT-1 gave yields of 30.15 to 31.76 q/ha in irrigated conditions. MPKV-Rahuri-1, CICR-GJHV-374 and CICR-CPT-1 gave yields of 25.25 to 26.99 q/ha.

SOUTH ZONE:

Seven locations viz., 1) UAS, Dharwad, 2) ANGRAU-Guntur, 3) ANGRAU-Nandyal, 4) PJTSAU-Warangal 5) PJTSAU-Adilabad, 6) PJTSAU- Mudhol and 7) ICAR-CICR, Coimbatore.

The entry Kantheru NSBT 306 gave 31.78 q/ha in AP compared to 30.6 q/ha of the BG-II check. The entry also topped in Tamilnadu.

Introduction of Bt-cotton in India in the year 2002 resulted in 50-60% reduction of insecticides and doubling of yield. Bt cotton was able to reduce insecticide use on bollworms by 90%. But because of continued damage by sap-sucking insect pests, especially on hybrid cotton, even now, 21% of the total insecticides are used on cotton in India. Currently more than 90% of the cotton area in India is covered by Bollgard-II Bt-cotton hybrids. Yields have been stagnating at 460 to 560 kg/ha over the past seven years.

Public funded institutions could not develop their own Bt cotton varieties earlier due to IPR issues and were behind the private sector in product development. The ICAR has developed excellent varieties and hybrids over the past 15 years, but these are not being preferred by farmers, because they do not have Bt genes in them. The current project aims to fill this gap by introducing elite Bt-varieties for cultivation in India. Apart from being able to use farm-saved seeds for sowing in the ensuing seasons, the Bt-varieties provide additional advantage of being amenable to high density because of low seed cost and low production cost due to short duration. The current project will conduct multi-location field trials to adapt and demonstrate global best practices using high density planting with the short duration Bt-cotton varieties.

In a recent development, ICAR-CICR also developed a series of ultra-short duration varieties of 110-130 days duration. The variety UGANK with 120 days duration has immense promise for rainfed regions of Maharashtra and Telangana. It was developed as Bt and non-Bt versions. With excellent fibre qualities, resistance to sucking pests, beautiful architecture that is amenable for high density planting, the series of these short duration varieties have the potential to be game-changers for cotton production in India, especially under rain-fed conditions. The project aims to validate their potential for rain-fed regions and also other parts of the country.

Sub-project 2: NEW LONG STAPLE DESI COTTON (*Gossypium arboreum*) VARIETIES

Objectives

1. Introduction and popularization of new 'elite Desi cotton varieties' at high density & low input costs.
2. Popularize current long staple (29-31 mm) varieties and develop new varieties with
 - a) Long staple (29-32 mm) and medium staple (26-28 mm).
 - b) Reduce the duration to 140-150 days.
 - c) Increase boll size (4.0 g).
 - d) Enhance locule retention.

The above varieties can be used in high density planting to double the yields. Since Desi cotton varieties are naturally robust, they need least chemical inputs and need less maintenance costs. Adoption of the new Desi varieties have great potential to easily double farmers income, with minor policy adjustments of assured seed availability and competitive minimum support price.

STATUS:

1. *Desi* cotton varieties with superior long staple fibre qualities of 27 to 32 mm suitable for high speed machines of the modern textile industry were tested in multi-location field trials across the country to assess their suitability to various ecological conditions. The performance was excellent.
 - a) Notified varieties with superior fibre staple length of more than 27 mm, such as G. Cot. Hy DH 9 (fibre length of 31 mm); PHa 46 (29 mm) Parbani Turab (28 mm); K-11 (28 mm); DLSa 17 (27.5 mm); PA 183 (27mm); ADB 332 (27mm); PA 402 (27mm); NA 48 (27MM) and Phule JLA 794 (27 mm).
 - b) Additionally new advanced cultures with fibre length of **30 to 32 mm** such as KWAM-3; PA 812; PA 785; PA 778 and PA 740 may be tested under multi-location trials. Notified Private sector *Desi* cotton varieties and hybrids such as MRDC 222, MRDC 233, MRDC 235 and NACH 6, which have a staple length of 26 to 27 mm were also included in the tests.

The new *Desi* cotton varieties developed recently by the public sector institutions in India would provide excellent alternative options to mitigate the existing uncertainty with the declining efficacy of the Bt-cotton hybrids on the pink bollworm and the American bollworm. Currently India's cotton area is saturated with the Bt cotton hybrids which need irrigation and intensive use of fertilizers and chemical pesticides to obtain higher yields. Majority of the Bt cotton hybrids are susceptible to drought, water logging, saline soils, sucking pests, cotton leaf curl virus disease and several other biotic stress factors. These factors make the current production systems unsustainable because of high production cost and intensive chemical interventions which cause serious harm to ecology and environment.

INTRODUCTION

The area under *Desi* cotton was 97% in 1947; 42% in 1990; 28% in 2000 and is estimated to be less than 3% in 2011. Until 2005 India had about 20 lakh hectares were under *desi* cotton in India which used to cater to the needs of this sector. Now, the area has been reduced to less than 1 lakh hectare. With decline in area under *Desi* cotton, currently short staple cotton is not available and is in severe 'short-supply' even for domestic use of surgical cotton. The industry in Maharashtra and MP, is sourcing *Desi* cotton at high prices from north east and pockets of Rajasthan. The demand is enormously high and *Desi* cotton can be grown with low cost in the nearby villages of surgical cotton industries with assured procurement at good prices. There is a need to popularize the newly developed medium staple and long staple *Desi* cotton varieties, develop new varieties with additional desirable features and also popularize short staple *Desi* cotton varieties for non-spinnable purposes.

Change in cotton species composition

Species	% of total cotton area						
	1947	1970	1980	1990	2000	2007	2013*
<i>G. arboreum</i>	65	30	20	30	17	4	0.6
<i>G. hirsutum</i>	3	53	54	48	69	90	98
<i>G. herbaceum</i>	32	17	14	12	11	5	1.4
<i>G. barbadense</i>	-	-	11	10	3	1	0.01
	100	100	100	100	100	100	100

Source: CICR (*recent estimates)

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. Thus the cost of production is very low. However the *Desi* varieties are now confined to marginal lands, under moisture stress and in drought prone areas.

ADVANTAGES OF *DESI* VARIETIES

1. The *Desi* cotton *Gossypium arboreum* is native to India. It is a very sturdy species.
2. Plants are deep rooted and have okra type of leaves for effective light penetration through the canopy.

3. Harvest index of cotton boll weight v/s plant biomass is high in Desi cotton
4. Highly suitable for rainfed conditions especially for light, marginal and saline soils.
5. The species has high level of adaptability to climate and is ideal to combat the effects of climate change
6. The species is endowed with high resistance levels to drought, salinity, water logging and abiotic stress.
7. The species is resistant to a wide range of insect pests and diseases. It is immune to the dreaded cotton leaf curl virus disease (CLCuD)
8. Requires less fertilizer and least chemical interventions due to high nutrient use efficiency in Desi cotton varieties
9. Highly suitable for organic cultivation systems.
10. Plant type in general is naturally compact and is amenable for high density planting.
11. Low cost of production for sustainable high yields
12. Desi seed-cotton has high lint recovery at 38-48% ginning%, compared to 32-34% in hybrid American cotton species that are cultivated in the market.
13. *Desi* varieties produce fibres of high maturity and least fibre neps.
14. Fabric made from *Desi* varieties gives higher values for dye uptake and air permeability.

Desi cotton for spinnable and non-spinnable fibres

Two categories of Desi cotton varieties can make a huge difference especially in the rain-fed tracts that comprise 60% of the cotton area of India. One type is the short and coarse fibre varieties that are suitable for absorbent cotton, surgical, denims, mattresses, technical textiles etc., whose demand is growing and the market price is very high.

Non-spinnable fibres

There are several varieties in this category. Desi cotton offers hygroscopic short fibre with high micronaire, which makes it an ideal choice for a wide range of applications. Yields are high with high density planting because of the compact nature of many varieties. For example, Phule Dhanwantary from MPKV Rahuri is one outstanding Desi variety which gives high yields of 25-30 q/ha or more under high density planting in rain-fed conditions with less than half of the production cost compared to any Bt-cotton hybrid. Ginning out-turn is very high.

Spinnable fibres

Other category pertains to Desi varieties that produce good quality spinnable fibres. There are some newly improved varieties have very good fibre traits that are equivalent to American cotton varieties. In a succinct study published in 2011 in the Indian Journal of Fibre and Textile Research, Chandra and Srinivasan (ex-Director CIRCOT, Mumbai) compared four improved new Desi cotton *Gossypium arboreum* varieties (PA-255, DLSA-17, MDL-2463 and Jawahar Tapti) with two American cotton *Gossypium hirsutum* varieties (Bikaneri Norma and LRA-5166) for their spinning potential at 16, 30 and 40 counts. They found that “..at medium count (30s), in general, all the improved *G. arboreum* strains perform better than the *G. hirsutum* strain LRA-5166 but the strain PA-255 shows most promising results. This may be attributed to the fact that almost all the improved *G. arboreum* strains evaluated, PA-255 possesses best fibre quality traits, especially fibre length and fineness. For 40s count the improved *G. arboreum* strain PA-255 shows significantly better results for U%, thick and thin places in comparison to the *G. hirsutum* strain LRA-5166.” The authors concluded that “The fabric produced from improved *G. arboreum* cotton shows comparatively higher toughness and appears to possess optimum rigidity. The improved *G. arboreum* cotton fabric records markedly higher values for dye uptake and air permeability as compared to *G. hirsutum* cotton fabric. These fabrics are suitable for the designated end use i.e. men’s winter wear with THV rating around ‘3’...The improved *G. arboreum* can be a viable and suitable alternative to the medium long staple *G. hirsutum* cotton particularly with regard to the yarn count range 8-25s and for specific end uses like denim and twills. Also, the *G. arboreum* genotypes are well known for their inherent resistance to biotic and abiotic stresses and widely considered as a potential source for organic cotton.”

In a recent article titled “Analysis of the performance of an improved *G. arboreum* L. Cotton under mill conditions” published in the *Journal of Cotton Research and Development* in July 2016, Matish

Chandra, Srinivasan and Akade showed that '*the improved G. arboreum cotton can be processed successfully on high speed modern textile processing machines. The qualitative analysis of the yarn, fabric and other relevant characters revealed that the improved arboreum cotton is a potent and viable alternative to the medium long G. hirsutum cotton.*'

Develop a new Brand 'INDIAN COTTON'

Studies conducted by Matish Chandra, Srinivasan and Akade clearly show that the medium staple *G. arboreum Desi* cotton fibres produced superior fabric compared to medium staple fibres of American cotton species *G. hirsutum*. The new long-staple *Desi* cotton fibres are also likely to produce superior special-quality fabric compared to the long-staple fibres of American cotton species *G. hirsutum*. Long staple fibres of PA 812, PA 740, PA 08 etc will be grown in large acreages to produce adequate cotton that can be processed for spinning and weaving in mills to be compared with the commercial Bt-cotton hybrids. If the properties of fabric of *Desi* long staple cotton fibres is found superior to the currently available fabric made from long staple *G. hirsutum*, it would be possible to establish a new brand 'INDIAN COTTON' which would be unique to India, given the advantages of the origins and diversity of the native India cotton species *G. hirsutum*.

Potential of *Desi* cotton

Thus, there is immense potential for *Desi* cotton varieties to make a huge positive difference to India's cotton sustainable future. Unfortunately some of the best research results with *Desi* cotton were achieved at a time when the country was under the Bt-cotton hybrid wave. All the new improved varieties were released mostly coinciding with the Bt-cotton wave. The improvements made in *Desi* cotton are important because they provide viable sustainable alternatives for high yields with low cost of production. This assumes significance in light of the significant increase in cost of cotton production over the past 10 years, when the yields also became stagnant. Also, over the past 2-3 years there is a growing demand for *Desi* cotton all across the country, especially in North India. But, seeds of many *Desi* varieties are not available in the local market. Public sector institutions such as State Agricultural Universities, state seed corporations and CICR have been producing limited quantities that are adequate for just a few thousand acres. In view of the increasing demand, it is possible that these institutions will upscale seed production programmes of the *Desi* varieties in the next few years. Even with moderate care, the yields of *Desi* cotton varieties can easily exceed the yields of Bt cotton in rain-fed and irrigated regions.

PROPOSED STRATEGIES

1. During the three years 2017-2020, the State Agricultural Universities of Maharashtra, MP and Telangana shall together conduct 1000 front-line demonstrations of the new *Desi* medium staple and long staple varieties, at the recommended agronomy of high density planting, moisture-nutrient management and canopy management.
2. Other cotton growing states shall conduct 40 adaptability trials each of the new *Desi* cotton varieties for high yields with low cost of production and least chemical intervention in their respective states.
3. *Desi* cotton varieties of short and medium staple fibre shall be promoted through subsidized seed production and seed availability.
4. Efforts shall be intensified to develop *Desi* cotton based organic cotton cultivation systems for different agro-ecological zones in the country.
5. Minimum support price shall be determined separately for *Desi* cotton fibres of short, medium and long staple properties to encourage their use. The support price may be fixed appropriately in excess of the MSP of corresponding staple length categories of the American cotton species and also additionally include a separate premium price for higher ginning percentage.
6. Promotional efforts shall be taken up by extension agencies in all cotton growing regions of the country to highlight the advantages of *Desi* cotton through field demonstrations and advertisements.
7. A special scheme on *Desi* cotton procurement may be launched by the Cotton Corporation of India.
8. The textile industry to launch a special drive on 'Make in India; specialty fabric made from *Desi* cotton fibres.

9. National campaigns shall be launched to promote products such as 'surgical cotton, absorbent cotton, denims and technical textiles made from short staple non-spinnable *Desi* cotton fibres.
10. Biodiversity of *Desi* cotton germplasm shall be legally protected through Geographical Indicators, PPV-FRA and other registration processes.
11. Creation of a new brand '**INDIAN COTTON**'

Sub-sub project 1a: ORGANIC DESI COTTON

Desi cotton varieties are highly amenable for organic farming. The Desi species *Gossypium arboreum* is not vulnerable for genetic contamination by the existing Bt cotton hybrids which belong to *Gossypium hirsutum* which is genetically incompatible with the Desi species. Therefore the new long staple Desi varieties provide an excellent opportunity for India to emerge as global leaders in organic cotton to produce high yields of long staple fibre at very low production cost based on organic farming systems. This can provide a sturdy roadmap for sustainability especially in small-scale farming systems.

India's contribution to global organic cotton production was only about 10-15% until 2002. Today, it is the world leader contributing 81% of the global production. The production rose from 2231 tonnes in 2003-04 to 19412 tonnes in 2009-10. About 117,000 farmers are currently engaged in organic cotton production. India is a classical case of coexistence of GM and organic cotton production systems, either by accident or by compulsion. Madhya Pradesh leads in the organic cotton production followed by Maharashtra and Orissa and together these states account for almost 98% of the organic cotton produced in India. There are 144 projects engaged in the production of organic cotton in 2008/09 (APEDA 2009), though according to Organic Exchange (2010), there are 204 such projects. The major projects include, Ecofarms, Mahima, Rajeco, Bio-Re, Vasudha, Chetana, Agroc cell, Zameen and Arvind Mills.

Only six countries produced organic cotton in 1992-93. Today, 23 countries cultivate organic cotton in 461,000 ha involving approximately 275300 farmers. The global organic cotton production skyrocketed from 6,500 tonnes in 2000-01 to 241,697 tonnes in 2009-10. The most important cotton producing countries in 2009-10 were India (195,412 tonnes), Syria (20000 tonnes), Turkey (11,599 tonnes), China (4,300 tonnes), USA (2,808 tonnes) and Tanzania (2,635 tonnes). The value of global organic cotton market jumped from under US \$300 million in 2002 to over \$4.3 billion in 2009. Organic textile industry is anticipating a global retail sale of US \$ 5.3 billion in 2011. Demand for organic cotton has been also increasing past years with 50 companies having significant organic cotton programmes and around 1500 brands and retailers taking a share in the international organic cotton market. The leading organic cotton consuming brands include C&A (Belgium), Nike (USA), Walmart (USA), Williams-Sonoma (USA), H&M (Sweden) and Anvil Knitwear (USA).

The most concerning issue for organic projects has become the supply of non-GM seeds for farmers, since both the private and the public sector has given up the production of non-GM cotton seeds and transgenic seeds are forbidden to be used in organic agriculture all over the world. While organic cotton projects are increasing in their numbers and output, the conventional, non-Bt hybrids are disappearing from the market. As an obvious consequence, organic cotton projects are facing a seed supply crisis. Of late, the central and state Governments have taken a pro-active stand in promoting organic cotton and infusing credibility in the production system. The Indian Council of Agricultural Research at the Centre and State Agricultural Universities have joined the movement to provide critical inputs, interventions and supports to producer groups and certifiers. The Agricultural and Processed Food Products Export Development Authority (APEDA), Government of India is now focusing on organic cotton as a sector of strength, prosperity and opportunity. The Government of India (GOI) has set up an Organic Cotton Advisory Board, under the Ministry of Textiles in 2009 for gathering correct statistics, making available package of practices and providing quality inputs, delineating potential areas and promoting research. Another initiative is the formulation of a sub-committee for organic cotton and Suvin. It is essential to raise the yield barriers of organic production system through the development and dissemination of novel knowledge and technology-based innovations to safeguard farmers interest in organic cotton and cement its place as a global leader in organic cotton production India.

The proposed program aims to increase yields 2-3 folds in shallow soils of rain-fed dry land farms with least inputs through large scale validation and demonstration of a new system of High Density Planting Systems (HDPS) of cotton production using compact varieties.

Sub-Project 3: Technology reach-out: 'voice-mails' 'Mobile Apps' SMS and advisories

VOICE MAILS

At least 4-5 lakh registered farmers will receive weekly 'package of practice' advisories based on the previous rainfall, weather and forecast of weather data as relevant to each district. CICR has an established programme called E-Kapas that delivered weekly free voice mail messages to 2.5 lakh farmers all through the cotton season in 9 languages during 2014, 2015 and 2016. This programme will be upscaled.

MOBILE APPS

Mobile apps for complete package of practices, varieties, seeds, IPM and IRM based pest and disease management, Water management, nutrient management, fertilizer management, soil management, pesticide management, mechanization, details of Government schemes, precautions in farming, price, markets and trade based on specific GPS location will be developed. Currently two mobile Apps have been developed by CICR at Beta versions. These will be finalized and released under the project.

WEEKLY ADVISORIES

Weekly advisories will be issued by ICAR-CICR based on the technologies, strategies, rainfall and weather. The institute releases the weekly advisory every Wednesday on the institute web page www.cicr.org.in

http://www.cicr.org.in/weekly_advisory.htm

The advisories will be issued in English and eight Indian languages. The nodal officer ICAR-CICR will coordinate the weekly messages in 9 languages and sends the advisories every week to the DOCD, State Department officials and all KVKs of cotton growing states all through the year. **These advisories are used by the respective State Agricultural Universities to relay voice mails and SMS advisories to registered farmers in their state in the native language. The ICAR-CICR weekly advisories will be sent to KVKs, SAUs, State Departments & ICAR (HQ).** Pest and disease alerts will be sent every week to the ADG (PP), ICAR every week by CICR scientists and PI Entomology and PI Plant Pathology of the AICCIP Programme. CICR has been releasing weekly advisories during 2014, 2015 and 2016. The advisories are widely appreciated. The web-based advisories will be strengthened to be presented in a complete pictorial format.

PROJECT PERSPECTIVES AND BACKGROUND WORK CARRIED OUT BY ICAR-CICR

Currently 11.0 to 12.9 million hectares of land is saturated with Bt-hybrids in India. Yields are declining over the immediate past. There is an imminent need to establish alternative cotton production systems using compact-statured varieties under high density planting in India. India never had short duration (150 days) compact varieties suitable for plant to plant at 10cm spacing.

From the list of 'best global practices' a few that are new to India are as follows:

1. High density planting
2. Bt-varieties
3. Conservation tillage
4. Plastic mulching
5. Canopy management
6. Square and boll retention and
7. Precision input management

The Central Institute for Cotton Research has pioneered a new concept of 'High density Planting Systems' (HDPS) that has potential to obtain record yields in rain-fed farming systems, especially in Maharashtra and Madhya Pradesh. The concept takes its inspiration from several countries such as China, Brazil, Uzbekistan and Argentina wherein plant population of 100,000 to 200,000 per hectare results in high yields of 40-80 Q/ha seed cotton, with dwarf compact varieties. The plant population with hybrid cotton varieties as in countries like India, ranges from 6000 to 15000 per hectare. High yields have been obtained with narrow spacing (less than 75 cm between rows) and ultra narrow (less than 45 cm between rows) with less

nutrient inputs in many countries for several years. The HDPS system requires dwarf varieties with compact stature bearing 6-8 bolls per plant, so that they do not compete with one another for light and other inputs such as nutrients and water. The institute has embarked on the new programme from 2008 to identify such varieties that can suit high plant population of more than 150,000 per hectare. Trials initiated by CICR, Nagpur over the last 2-3 years indicated that varieties such as PKV081, ADB 39, NH630 and Suraj, though not developed for high density planting, were also amenable to be planted 1.11 Lakh plant / ha at 1.66 lakh plant/ha at spacing of 60 X 15 cm or 45X15 cm. Similarly Desi varieties such as CINA404, JK5 and AKA7 produced high yield at 2.22 lakh plant/ha. (45x10cm). The variety Suraj was released by CICR 2008 and is known for excellent fiber qualities. PKV081 was released in 1987 by Dr PDKV Akola, ADB 39 a compact variety was released by ANGRAU, Hyderabad and NH 630 is a compact variety released by MAU Parbhani. These were suitable for high population densities of 100,000 to 150,000 plants per hectare and gave yields of 15 to 20 Q per hectare with minimum production costs in shallow soils without any irrigation. Interestingly these non-Bt varieties yielded 20-40% more than the most popular Bt-hybrids under similar cultivation conditions. Encouraged by the results, CICR is proposing to conduct pilot demonstrations of about 1000 plots per district to be conducted in rain-fed dry farming regions through the KVKs, State Agricultural Department and State Agricultural Universities, with funds being sought from the Ministry of Agriculture. The institute scientists have also developed simple package of practices for the varieties to significantly minimize the cost of production on sowing, fertilizers, weed management and pest management. The institute has initiated a new programme to develop new dwarf compact varieties with 6-8 bolls per plant with superior fiber qualities suitable for HDPS, to be taken up on multi-location basis under the All India coordinated cotton improvement project coordinated by CICR.

Studies conducted at CICR and other locations in Maharashtra indicated that the average yield improvement over the recommended (55000 plants/ha) in 5 genotypes tested last year was around 30%. Similarly Desi varieties such as CINA404, JK5 and AKA7 produced high yield at 2.22 lakh plant/ha. (45x10cm). The plants matured a week to 10 days earlier under high density planting. The nutrient uptake efficiency was higher under high density planting. This system has the ability to compensate yield loss due to delayed planting of cotton. High Density Planting Systems have been found to be highly suitable for machine picking due to short stature and synchronized boll bursting. Thus, if varieties suitable for high density planting are developed in India, apart from the advantages of enhancing yields in rainfed shallow soil conditions, it would be possible to move towards mechanization. The new system has immense potential for rainfed cotton farmers of Vidarbha, particularly those cultivating cotton on marginal soils.

The ICAR-CICR (Central Institute for Cotton Research) has been working over the past few years on several concepts related to the above listed 'best practices' that can lead towards 'sustainable cotton production systems'. Over the past 10 years ICAR-CICR coordinated a project under the Technology Mission on Cotton to develop 21 short-duration compact Bt-varieties with high harvest index. A new Bt variety of 120 days duration is in the final stage of testing and hold tremendous promise for its breakthrough potential. The new culture 'CICR-Ugank-Bt' is a compact Bt-variety of 120 days duration. It is highly tolerant to sap-sucking pests, short statured at 65-70 cm height with high harvest index and very good fiber quality. Its performance in field trials at CICR farm was excellent. High density planting systems were experimented under Indian conditions. Conservation tillage, plastic mulching, canopy management and precision input management were successfully tested at different centres.

The 21 varieties and Desi varieties were tested at 17 locations across the country and 3-4 new varieties were identified separately for each state recently for their excellent performance under high density conditions. Brief results are presented below:

Results obtained with the recent varieties developed/coordinated by ICAR-CICR and tested for sustainable productivity

	Commercial Bt Hybrids	Public sector Bt Hybrids	Bt Varieties	Desi varieties
Duration (days)	160-240	160-180	140-160	140-150
Cost of cultivation Rs.	75,000	60,000	50,000	30,000
Plant population /ha	11,000	28,000	168,000	225,000
Yield/ha	22 Q	*25 Q	*30 Q	*35 Q
Gross returns Rs/ha	88,000	100,000	120,000	120,000
Net Returns Rs/ha	13,000	30,000	70,000	90,000

*Yields obtained under high density planting of public sector Bt hybrids (H-6 & H-8), Bt varieties and Desi varieties.

The short duration compact Bt-varieties and short duration Desi cotton varieties of high GOT (>40%) have excellent fibre qualities in all categories of short, medium and long staple for all purposes of non-spinnable (surgical, absorbent, denims, mattresses etc.) and spinning potential varieties with 60-80 counts.

The Desi cotton species are inherently robust with high levels of tolerance to a-biotic and biotic stresses. At least eight Desi varieties with excellent long staple (26-31 mm) fibre, were developed recently by scientists of the Cotton Research Station of Nanded (MAU, Parbhani). These varieties were tested by ICAR-CICR in multi-location trials across the country over the past 2-3 years and were found to hold great promise because of their high yields in high density planting at very low production costs with least requirement of chemical inputs.

Field experiments showed that the Bt-varieties and Desi varieties under high density planting consistently out-yielded the reference Bt-hybrids at recommended spacing at all locations. With input use, low cost of production and high yields under high density, the future holds great promise for Indian cotton with the new INM, IWM, IRM and IPM technologies to be implemented in the short duration high density planting systems.

Objectives

1. Doubling farmers income
2. Doubling National yields
3. Reducing cost of cultivation to less than half the current cost
4. Reducing the chemical load in cotton farming
5. Establish linkage with 500,000 farmers through weekly voice-mail message, SMS and weekly advisories in 9 languages for each of the 10 cotton growing states.
6. Special focus on rain-fed agro-eco regions of Maharashtra, MP, AP, Karnataka and Orissa to establish low cost systems for sustainable yields of 25 to 30 Q/ha seed-cotton with integrated technologies of genetics, crop protection and crop production
7. Validate and demonstrate suitable varieties with: *Superior fiber quality X high-harvest-index X architecture X crop geometry X agronomy X biotic-abiotic-resistance X agro-eco-specificity*; for shallow soils and sub-optimal conditions to obtain high yields
8. Consolidate all GM-cotton developed by Indian institutions for gene-stacking-pyramiding through accelerated breeding; facilitate bio-safety testing; and commercialize multi-gene GM varieties resistant to insect pests
9. Strengthen and promote 'specialty-cotton' initiatives to promote *Desi*, organic and heritage cotton varieties for high profits through contract-farming with user-industry linkages

Technical Programme (2017-20)

1. Develop 'Mission-Team' through collaborative net-work of public funded institutions
2. Identify strategic villages and conduct one-acre Pilot demonstrations of the new long-staple Desi varieties (6) and medium staple Desi-cotton varieties (6) with new high density planting systems at low production costs in 8 districts in Maharashtra; 2 districts in Madhya Pradesh; 3 districts in Telangana, 1 district in Andhra Pradesh; 1 district in Karnataka and 1 district in Orissa for three years in different villages each year.
3. Identify strategic villages and conduct Acre Pilot demonstrations of *Desi* varieties for surgical cotton purposes with surgical-industry linkages in rainfed regions of 8 districts in Maharashtra; 2 districts in Madhya Pradesh and 3 districts in Telangana, 1 district in Andhra Pradesh for three years in different villages each year.
4. Identify strategic villages to validate cultivation of the new public-sector Bt-cotton and non-Bt varieties and conduct one-acre Pilot trials by adopting global best practices in each of one district in Maharashtra, Madhya Pradesh, Telangana, Andhra Pradesh, Karnataka, Gujarat, Orissa, Punjab, Haryana, Rajasthan and Tamilnadu for three years in 90 different villages each year.
5. Conduct training programs on implementation of the novel-agronomy based package of practices from global best practices for HDPS, Desi and organic cotton in a 'Time Table Window' format to be provided to all implementing centres and farmers
6. Registration of 500,000 farmers for weekly voice-mail message, SMS and weekly advisories in 9 languages for each of the 11 cotton growing states.
7. Establishing a common supervising and relay system for the voice-mail message, SMS and weekly advisories in 9 languages for each of the 11 cotton growing states

8. Finalize MoU and MTA agreements with all collaborating partners to consolidate strategic plans and genetic material
9. Strengthen/create specialized facilities for breeding of novel varieties. Identify new short duration Bt-variety homozygous lines event specific primers and evaluate them in multi-location trials to be released for cultivation.
10. Strengthen/create specialized facilities for bioassays, trait testing and accelerated breeding under confined/contained conditions at participating institutions.
11. Seed Production of elite compact varieties (Desi, Bt and non-Bt) for large scale cultivation

ANTICIPATED OUTPUTS

1. Doubling of farmers income by establishing sustainable production systems for cultivation of *Gossypium arboreum*, Desi-cotton (short staple, medium staple and long staple) through conventional and organic conditions to obtain doubled yields (1000 to 2000 kg lint cotton per hectare) with low cost of cultivation under high Density Planting.
2. Doubling of farmers income by adapting global best practices to establish 'novel-agronomy' for sustainable production systems of the newly developed public sector Bt-cotton and non-Bt cotton varieties of *Gossypium hirsutum* to obtain doubled yields (1000-2000 kg lint cotton per hectare) under high Density Planting.
3. Development of new Desi cotton varieties of long staple, big boll size, short duration and high loculi retention.
4. Development of new Bt-cotton and non-Bt varieties of short duration (140-160 days); sympodial architecture; early maturing with synchronous flowering and fruiting; high initial root and shoot vigor; high harvest index with least unproductive branches and leaves; resistance to sap sucking insects such as leaf hoppers, aphids, thrips and whiteflies; resistance to 'bacterial leaf blight', 'cotton leaf curl virus' and other diseases, desirable fibre qualities with high ginning% and amenable to machine picking.
5. Strengthening Desi-cotton *G. arboreum* species based organic cotton systems to sustain the current global leadership role of India in cultivating organic cotton and exporting apparel and organic surgical cotton using organic Desi cotton.
6. High yields with short staple fiber Desi Cotton varieties to be cultivated in villages adjacent to surgical cotton industries in Maharashtra, MP, AP and Orissa with linkages tied up to the surgical cotton industries.
7. Doubling yields to at least 1000 kg lint per hectare at all the field trial locations.
8. Dissemination and demonstration of the new technologies.
9. Significant reduction in cost of production
10. Significant reduction in chemical usage of fertilizers and pesticides
11. Higher yields in a short time

Technology components:

Seed (cultivar/Bt hybrid); Row direction (north- south); High density planting; Conservation tillage; Land configuration BBF, ridge/furrow; Cover crop and mulch sunnhemp; Weed control; Nutrient Management; IPM/IRM Pest management; Crop termination at 160 days & Irrigated systems: Drip irrigation with poly-mulch

Lead Institution: Central Institute for Cotton Research, Nagpur

Sub-Projects	Project Leaders:
Adapting global best practices to India	ICAR-CICR, Nagpur
Desi cotton for sustainability & organic Cotton	MAU Parbhani
Breeding of new Desi cotton and non-Bt varieties	ICAR-CICR, Nagpur
Weekly voice mails, SMS and advisories	ICAR-CICR, Nagpur

Implementing partners

Partners	State	District
BCI	Punjab	Bhatinda
	Gujarat	Surendranagar and Rajkot
	Telangana	Adilabad and Warangal
	Andhra Pradesh	Guntur
	Karnataka	Raichur
CITI-CDRA	Rajasthan	Banswara and Jodhpur
CICR	Haryana	Sirsa
BCI, COTTAP, CICR, CITI-CDRA	Maharashtra	Wardha, Amravati, Nagpur, Yavatmal, Jalgaon
SIMA	Tamil Nadu	Salem

	Role
ICAR-CICR, Nagpur	Overall cooordination, Seed, Package of Practices, Inputs-Yellow sticky traps, Pheromone traps Training On-line monitoring and documentation
KVK's	Soil test and soil health cards Monitoring of the demonstration Reporting to the State co-ordinator
Implementing agencies (BCI, CITI-CDRA, SIMA, COTTAP, CCI)	Conduct of the demos Procurement and marketing (CCI)
Co-operating agencies	Weekly advisories in local language Co-ordinating training of the entire staff involved in the state

Programme Implementing Institutions (Budget Rs Lakhs for 3 years 2017-2020)

	Adapting global best practices to India for sustainability	Long linted desi cotton for climate resilience and organic cotton production	Breeding for early, compact desi and upland cotton varieties	Weekly voice mails, SMS & advisories	Total Rs Lakhs
ICAR-CICR, Nag	48	30	30	18	126
ICAR-CICR, Coim	36		24	15	75
ICAR-CICR, Sirsa	36		24	15	75
Dr PDKV Akola	24	18	24	15	81
MAU Parbhani	24	30	24	15	93
MPKV Rahuri		18	24	15	57
NAU Surat	24			15	39
JAU Junagarh	24			15	39
RSKVV Gwalior	24	18		15	57
PJTSAU, Hyd	24	18	24	15	81
ANGRAU, AP	24			15	39
UAS Dharwad	24			15	39
PAU Punjab	24			15	39
HAU Haryana	24			15	39
RAU, Rajasthan	24			15	39
OUAT Orissa	24	18		15	57
TMC cell					25
Total	408	150	174	243	1000

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